DEPARTMENT OF
MECHANICAL AND INDUSTRIAL ENGINEERING

EXPLORING THE ENGAGEMENT, KNOWLEDGE, AND EFFECTIVE TRAINING OF SEAFARERS IN ENERGY-EFFICIENT SHIP OPERATIONS

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Master in Marine Technology

DOCTORATE IN INDUSTRIAL ENGINEERING
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Exploring Engagement, Knowledge, and Effective Training of Seafarers in Energy-Efficient Ship Operations

I dedicate this work to my parents and my family.

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"In the name of Allah, the Most Gracious, the Most Merciful."

I extend my deepest gratitude to the Almighty for guiding me throughout this research endeavor and granting me the fortitude to bring it to fruition.

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Thank you.

"You cannot teach a man anything; you can only help him.
discover it in himself." (Galileo).

Abstract

The maritime industry is responsible for 2.89% of worldwide carbon emissions, requiring immediate action to reduce its environmental impact. This study examines the crucial role of seafarers in reducing carbon emissions. It introduces a strategic training framework to enhance their knowledge, awareness, and skills for implementation of the Ship Energy Efficiency Management Plan (SEEMP) onboard ships. Active seafarers from 41 shipping companies in 24 countries were surveyed using mixed methods to assess their knowledge, awareness, and commitment to energy-efficient shipping practices after ten years of regulation enforcement by the International Maritime Organization (IMO). Structural Equation Modeling (SEM) is utilized to evaluate the effectiveness of training programs on energy-efficient ship operations (EEOS) provided to seafarers. The study identifies several critical challenges faced by seafarers in implementing energy-efficient practices, such as increased paperwork, heavier workloads, and technical difficulties. Notably, a significant gap exists between male and female seafarers regarding awareness levels. Additionally, social media platforms are emerging as increasingly popular sources of knowledge for seafarers. Moreover, experience plays a pivotal role, showing a strong connection with knowledge acquisition. The study advocates a strategic training framework, integrating in-house, onboard, simulator-and computer-based training to enhance seafarers' competence in EEOS for improving energy efficiency and reducing carbon intensity. Recommendations include leveraging IMO E-Learning courses and simulator-based training by specialized providers, complemented by onboard training initiatives. This study offers insights for policymakers and stakeholders to steer the maritime industry towards a future with net-zero emissions while enhancing the human element for sustainable shipping practices.

Keywords: Maritime Energy Management, GHG Emissions, Seafarers' Training, SEEMP, Energy-efficient Ship Operations, EEXI, CII, Net-Zero Emissions.

Resumo

A indústria marítima é responsável por 2,89% das emissões de carbono em todo o mundo, o que obriga a uma ação imediata de modo que se reduza o impacto ambiental causado por parte dos atores desta indústria. O trabalho efetuado nesta tese examina o papel crucial das tripulações na redução das emissões de carbono. Este estudo apresenta um quadro de formação estratégica para aprofundar os conhecimentos, consciencialização e habilidades da tripulação para a implementação do Plano de Gestão da Eficiência Energética em Navios (SEEMP). São alvo de inquérito a tripulação ativa de 41 empresas de transporte marítimo, representando 24 países. Sendo assim, ao fim de dez anos de aplicação dos regulamentos pela Organização Marítima Internacional (IMO), pretende-se avaliar os conhecimentos, a consciencialização e o compromisso com as práticas de eficiência energética no transporte marítimo por parte destas empresas e das suas tripulações. De modo a avaliar a eficácia da formação dada à tripulação acerca das práticas dos sistemas de obrigação de eficiência energética (EEOS), é utilizada a Modelação de Equações Estruturais. Os resultados do estudo revelam que continuam a persistir vários desafios significativos encontrados pela tripulação na execução de operações de eficiência energética em navios, incluindo questões relacionadas com o excesso de procedimentos administrativos, carga de trabalho muito elevada, complexidades técnicas, entre outras. Observa-se uma disparidade notável entre a tripulação do sexo masculino e a tripulação do sexo feminino em relação aos níveis de consciencialização. Ainda, as plataformas de redes sociais estão a ganhar cada vez mais popularidade, como fontes de conhecimento, entre os membros da tripulação. Os resultados também indicam que a experiência é um elemento fundamental e que tem uma ligação muito forte com o conhecimento. Sendo assim, é proposta uma nova abordagem de formação da tripulação ao integrar a formação interna e a formação com uso de simuladores e computadores para capacitar a tripulação na aplicação das medidas de eficiência energética. As recomendações incluem alavancar os cursos de E-Learning da IMO e a formação através do uso de simuladores por especialistas, sendo estes complementados por iniciativas de formação a bordo. Este estudo oferece novas perspetivas aos decisores políticos e às partes interessadas de modo a conduzir a indústria marítima para um futuro com zero emissões, e ao desenvolver, ao mesmo tempo, a componente humana nas práticas sustentáveis no transporte marítimo.

Palavas chave: SEEMP, Operações de Eficiência Energética em Navios, EEDI, EEXI, CII, Emissões de GEE, Gestão da Energia, Formação da Tripulação.

CONTENTS

LIST OF FIGURES

LIST OF TABLES

GLOSSARY

Auxiliary Engine	A diesel engine on a vessel used to power non-propulsion functions, excluding emergencies, including all diesel-electric engines
Bridge Simulator	A computer-based system that replicates vessels, ports, weather, and traffic conditions for training, assessment, and research purposes.
Dual Fuel Engine	An engine that can run on gaseous and liquid fuels simultaneously
Eco-Voyage	A program to plan and optimize ship voyages for the lowest fuel consumption
GreenVoyage2050	It is a global program supporting developing countries to reduce emissions from ships, in line with the 2023 IMO GHG Strategy
Internet of Things (IoT)	It refers to the network of linked devices and the technology that allows them to communicate with each other and the cloud
Main Engine	The main propulsion engine of a ship
VPOA	Utilizing advanced machine learning algorithms, Voyage Performance Analyzer aids in prioritizing voyages, crafting routes for enhanced profitability, reducing claims, and minimizing vessel emissions by optimizing for weather, speed, and route efficiency.

ACRONYMS

AER	Annual Efficiency Ratio
BIMCO	Baltic and International Maritime Council
CBT	Computer-Based Training
CII	Carbon Intensity Indicator
CVI	Content Validity Index
DCS	Data Collection System
DNV	Det Norske Veritas
DWT	Deadweight Tonnage
EEDI	Energy Efficiency Design Index
EEOI	Energy Efficiency Operational Indicator
EEXI	Energy Efficiency Existing Ship Index
EU	European Union
GHG	Greenhouse Gas
GIA	IMO-Industry Alliance
GloMEEP	Global Maritime Energy Efficiency Partnerships
GMN	Global MTCC Network
GT	Gross Tonnage
HRM	Human Resource Management

ICS	International Chamber of Shipping
IETA	International Emissions Trading Association
IMO	International Maritime Organization
ISM	International Safety Management Code
KUP	Knowledge, Understanding, and Performance
MARPOL	International Convention for the Prevention of Pollution from Ships
MEPC	Marine Environment Protection Committee
MLC	Maritime Labor Convention
MRV	Monitoring, Reporting, and Verification
MTCC	Maritime Technology Cooperation Centre
PEB	Pro-Environmental Behavior
PSC	Port State Control
SEEMP	Ship Energy Efficiency Management Plan
SMS	Safety Management System
SPSS	Statistical Package for the Social Sciences
STCW	Standards of Training, Certification and Watchkeeping
TPB	Theory of Planned Behavior
TTT	Train-the-Trainer
UNCTAD	United Nations Conference on Trade and Development
UNFCCC	United Nations Framework Convention on Climate Change
VPMAS	Voyage Performance Monitoring and Analyzing System
VPOA	Voyage Performance Onboard Analyzer
WMU	World Maritime University

1

INTRODUCTION

The foundation and main ideas are outlined in the first chapter to establish the thesis. Comprised of six peer-reviewed papers, this thesis is systematically structured, with each paper interconnected with others. Within this framework, the thesis is accompanied by a comprehensive outline detailing the problem statement, existing research gaps, study motivation, research questions, and research objectives. It provides an exposition of the primary research inquiry and delineates the general methodology employed in the study. In conclusion, this chapter provides the synopsis of other chapters explored in the thesis.

1.1 Study Aims

The global economy relies on the marine industry because 90% of world trade is carried out by ships (BIMCO & ICS, 2015). By January 2023, the global fleet comprised 105,493 commercial vessels with a capacity of 100 gross tonnage (GT) or more, according to the United Nations Conference on Trade and Development (UNCTAD, 2023). The UNCTAD (2023) forecasted 2.4% shipping industry growth in 2023 and over 2% between 2024 and 2028. These massive commercial ships release CO_2 and other greenhouse gases (GHG) throughout their daily operations and propulsion, causing global warming and climate change due to their significant use of fossil fuels (Jun et al., 2001). The shipping industry contributes 2.2% (Smith et al., 2015) and 2.89% (Faber et al., 2020) of total human-generated CO_2 emissions, as the International Maritime Organization (IMO) reported. Smith et al. (2015) anticipated that maritime CO_2 emissions will grow significantly by 2050, ranging from 50% to 250%, regardless of regulation actions.

Climate change impacts oceanic processes and marine ecosystems through emissions, especially CO_2, which intensify problems like acidification, deoxygenation, and rising sea temperatures (Boucher, 2018). The adverse effects of ship emissions on human well-being, aquatic ecosystems, human health, glaciers, and polar ice caps, among other environmental factors, have drawn more attention globally (Cariou & Cheaitou, 2012; Ramanathan & Feng, 2009). Cropping carbon emissions and improving energy efficiency (EE) are key strategies for addressing global warming and climate change, as emphasized in worldwide treaties like the Kyoto Protocol as well as the Paris Agreement (IETA, 2019; UNFCCC, 2008). The Paris Agreement sets a 1.5 °C objective to keep the world average temperature below 2 °C, which is different from the 1.5 °C target set by industry. Our planet's average temperature is predicted to rise by 3°C to 5°C by 2100, according to recent studies (IETA, 2019).

The IMO has adopted measures to decrease CO_2 and other GHG emissions and improve EE in the maritime sector in response to such concerns (Hüffmeier & Johanson, 2021; Smith et al., 2015). International Convention for the Prevention of Pollution from Ships (MARPOL) Annex VI Chapter 4 outlines regulations devised to mitigate GHG emissions and air pollution associated with maritime activities (Bazari & Longva, 2011). Chapter 4 describes the EE regulations for designing and constructing new ships and maintaining existing and new commercially operational vessels. The Energy Efficiency Design Index (EEDI), a novel benchmark for ship design and construction, was implemented on January 1, 2013 (IMO, 2011). The Ship Energy Efficiency Management Plan (SEEMP) mandates ship operators to establish plans to enhance ships' EE and reduce carbon emissions while operating ships at sea (IMO, 2012).

The Energy Efficiency Operational Indicator (EEOI) evaluates vessel efficiency by considering factors such as cargo load, voyage distance, and fuel consumption (IMO, 2009a). The EEOI tool does not allow the tracking of CO_2 emissions for idle or anchored ships without cargo. The Annual Efficiency Ratio (AER) measures carbon intensity using the Poseidon Principles (Poseidon Principles, 2021). This metric is comparable to the "EEOI". Still, it estimates cargo carried based on the vessel's design Deadweight Tonnage (DWT) capacity rather than the actual load carried and the assumption that the vessel continually transports cargo. Although the IMO now requires AER, EEOI reporting is still optional. Based on the total annual deadweight distance divided by the amount of CO_2 emissions, one can calculate the operational carbon intensity of a ballast or loaded vessel. These efforts are supported by additional frameworks, including IMO's Data Collection System (DCS) and the European Union's Monitoring, Reporting, and Verification (MRV) system (IMO, 2016a; Nikitakos et al., 2018).

The IMO has Implemented new strategies: the Energy Efficiency Existing Ships Index (EEXI), which requires the assessment of technological retrofit requirements to crop carbon emissions, and the operational Carbon Intensity Indicator (CII) and CII ratings that specify operational demands for ships to enhance EE and cut carbon footprints from ships (IMO, 2022a, 2022b; Psaraftis & Kontovas, 2021). At the 76th Meeting of the MEPC of the IMO in June 2021, MARPOL Annex VI Chapter 4 was revised, which came into effect in January 2023 (Finska & Ringbom, 2022). Every existing vessel must have a technical file for EEXI before January 2023. To ensure compliance with the yearly operational CII requirement, recording and comparing the actual CII accomplished will be necessary. Furthermore, in the updated MEPC 80 strategy, ambitious targets are set for international shipping. A focused effort is being made to decrease carbon intensity (IMO, 2022a, 2022b). In addition, to attain net-zero emissions by 2050, the IMO's updated GHG strategy for 2023 seeks to cut the carbon intensity of shipping by 40% by 2030 and 70%–80% by 2040 (IMO, 2023).

Safe and efficient shipping is critical to global trade, and seafarers play a crucial part in this entire process. The energy efficiency of a vessel depends on seafarers' behavior and decision-making, so engaging and training them is crucial, according to Psaraftis & Kontovas (2013). The responsibility for ensuring safe and effective ship operations lies with onboard ship crews and onshore ship managers. The Safety Management System (SMS) handbook and the International Safety Management (ISM) Code contain the guidelines. The SMS manual provides comprehensive guidance on safety management, maintenance, and emergency plans. In contrast, the ISM Code establishes mandatory safety and pollution prevention standards for maritime vessels. To promote efficiency and safety during ship operations, distinct roles and responsibilities are assigned to various stakeholders, including ship crews and ship managers (ICS, 2022; IMO, 2018). Technical managers oversee vessel safety, efficacy, and environmental responsibility, as well as provide technical assistance (Panayides, 2017). The technical and operational EE measures must also be implemented to reduce shipping's environmental impact and improve efficiency. Ashore technical managers support shipmasters and chief engineers on technical and operational issues. In addition to coordinating with the vessel's chief engineer and master, environmental compliance managers implement all environmental regulations and standards enforced by IMO.

Successful implementation of the SEEMP onboard requires the ship's master to be fully dedicated. Deck officers and ratings work under the supervision of the Chief Officer in the deck department, which manages cargo, ballast, trim, and deck machinery operations. The chief engineer is responsible for maintaining, operating, and optimizing the propulsion and auxiliary engines, along with other equipment onboard ships. The second engineer, who works with the chief engineer, supervises the daily operation and maintenance of all machinery plants and equipment onboard ships and manages all engineer officers and ratings in the engine department. Data-driven intelligent energy management technologies can remotely monitor, execute, and enhance SEEMP measures from ashore. Eco-Voyage (Mak et al., 2014), and VPOA (Voyage Performance Onboard Analyzer) are examples of software applications used in ships to track and enhance ship performance (Lu et al., 2015).

The ship's crew is responsible for many tasks, including navigation, cargo handling, technical system maintenance, environmental protection, and ship security (Mika, V., & Czarnocka, M., 2019). To ensure safe and efficient operations, IMO has instituted comprehensive policies and regulations mandating proper training and education for seafarers. According to these requirements, seafarers must have the expertise, abilities, and skills to execute their responsibilities effectively and securely (Caesar et al., 2014). Compliance with IMO regulations and guidelines is critical for maintaining ship safety, security, energy efficiency, and environmental conservation. Maritime industries have experienced significant technological and economic advances, including larger vessels, globalized business operations, and communication, navigation, and automation (Manuel, 2017; Wu & Chen, 2018). As a result, seafarers are under growing pressure to enhance efficacy, cut expenses, and adhere to environmental standards. The shore management has dedicated more efforts and resources to enhance the effectiveness of ship operational systems in improving ship crews' abilities. As a result, the majority of crew members claim to have altered their old work culture after gaining knowledge from utilizing energy-efficient procedures during ship operations (Dewan & Godina, 2024b; Viktorelius et al., 2022). However, recent studies indicate that inadequate support from onshore organizations can exacerbate challenges for crew members striving to operate ships efficiently (Psaraftis & Kontovas, 2021; von Knorring, 2019). The enforcement of energy efficiency requirements by regulatory bodies can further compound stress among seafarers (Adamowicz, 2022). Furthermore, prolonged placements, irregular work schedules, and crew fatigue have emerged as significant challenges for the industry (Shan, 2022).

1.2 Problem Statement

Maritime EE has improved substantially over the past decade in the shipping industry. The main factor contributing to the one-third increase in EE for these operations between 2008 and 2018 was the implementation of EE operational and design features (Faber et al., 2020). Many shipping companies worldwide have benefited from these initiatives, including reducing fuel usage and carbon emissions. Even with these developments, there are still a number of obstacles and disparities preventing the maritime industry from widely implementing energy efficiency practices. Several studies conducted over the last two decades have identified these barriers and proposed solutions to overcome them (Armstrong, 2013; Armstrong & Banks, 2015; Cagno et al., 2015; Dewan et al., 2018; Ekanem & Bucknall, 2015; Ghaforian Masodzadeh et al., 2022; Hoang et al., 2022; Jafarzadeh & Utne, 2014; Poulsen et al., 2022). The successful execution of EE measures is impeded by various obstacles, including resource constraints, difficulty enforcing international regulations on ship emissions, and political determination (Bloor et al., 2015). Furthermore, the effective execution of SEEMP onboard ships relies heavily on the active involvement, awareness, and training of crew members (Banks et al., 2014; Beşikçi et al., 2021; Brynolf et al., 2016; DNV GL, 2015).

Seafaring is an exceptionally challenging and risky profession that imposes significant stress on individuals, both physically and mentally, which sets it apart from land-based careers (Slišković & Penezić, 2015). The maritime sector relies heavily on seafarers to perform operational duties, but shipboard culture and hierarchy profoundly impact their well-being and actions (Kim & Jang, 2018; Muslu, 2020). To address stress-related challenges, organizations need to support employees with effective training and fair treatment (Cahoon et al., 2014a). A reactive approach to human resource management hinders sustainable training and development in the industry (J. Wang, 2009). Onboard ships, seafarers encounter numerous obstacles and hazards that adversely impact their mental health and overall well-being. Long and unpredictable shifts, few opportunities for shore leave, stress at work, disturbed sleep patterns, heavy workloads, frequent and lengthy absences from home and family, work-life imbalance, social isolation, and physical dangers like engine noise, accidents, and pirate attacks are all part of the difficulties (Allen et al., 2008; Iversen, 2012; MacLachlan et al., 2012; Oldenburg et al., 2010).

Promoting low-carbon and energy-efficient ship operations depends critically on seafarers' motivation, ideas, and cultural nuances (Abou-Elkawam, 2015; Banks et al., 2014). SEEMP's effectiveness in mitigating environmental impacts can be undermined by insufficient engagement and training of ship crews (Hansen et al., 2020). Crewmembers often face difficulties operating ships due to unclear instructions provided by ship managers and service provider organizations ashore (Psaraftis & Kontovas, 2021; von Knorring, 2019). Additionally, studies show crew members lack education and awareness of EE practices, leaving a considerable gap in their knowledge and understanding (Banks et al., 2014; Dewan et al., 2018; Kitada & Ölçer, 2015). The successful execution of EE operational measures by complying with the MARPOL Annex VI Chapter 4 regulations in the shipping industry relies on the awareness and knowledge of seafarers, who are directly responsible for implementing SEEMP during ship operations (Banks et al., 2014; Dewan et al., 2018; Dewan & Godina, 2023c). It is imperative to focus on education and research to increase seafarers' knowledge and understanding of maritime EE regulations and required measures (Banks et al., 2014; Kitada & Ölçer, 2020). Resistance to change and resource limitations hamper the widespread adoption of innovative technologies and cost-effective operational measures (DNV GL, 2015; Ghaforian Masodzadeh et al., 2022). This study aims to formulate and propose an effective training framework for successfully implementing EE measures during ship operations. The maritime industry must adopt a strategic training framework to facilitate the effective execution of EE measures during ship operations and reduce carbon footprints. These frameworks must augment seafarers' knowledge, expertise, and understanding of maritime EE regulations and procedures.

1.3 Research Questions

After a decade of the IMO imposing maritime EE standards, this study aims to assess the effects of energy-efficient ship operations on seafarers. It is imperative to evaluate seafarers' knowledge and comprehension of energy-saving practices and how ships use them before progressing toward this objective. This study, however, concentrates mainly on the following research questions (RQs):

RQ1: What role do seafarers play in implementing operational EE measures onboard ships, and what challenges do they face in ensuring EEOS?

RQ2: What is the level of awareness and knowledge among seafarers regarding EE and low-carbon shipping practices after a decade of IMO regulation enforcement, and what is the effectiveness of training programs in EEOS?

RQ3: What strategic training framework can be developed to address seafarers' unique challenges, enhance their knowledge and competence in EEOS, and ensure the effective implementation of SEEMP onboard ships?

This study explores critical challenges in EEOS, focusing on barriers such as stress, resource limitations, and unclear instructions that impact seafarers' roles and motivation. It evaluates the effectiveness of current training programs, identifying significant gaps in seafarers' awareness, knowledge, and understanding of SEEMP-related practices after a decade of IMO regulation enforcement. Finally, the study addresses the need for a strategic training framework to enhance seafarers' expertise and ensure the effective execution of EE measures. The research aligns with the problem statement by emphasizing tailored solutions to improve seafarer engagement and operational efficiency in maritime energy practices.

1.4 Research Approach

Shipping companies around the world operate both new and old ships. Companies have to struggle hard to comply with MARPOL Annex VI regulations for second-hand old ships. Their first target is to abide by all MARPOL and other rules to run the shipping business in national and international waters. Like all other MARPOL regulations, they have also implemented EE regulations according to Chapter 4, MARPOL Annex VI. Many shipping companies worldwide have benefited financially and environmentally from adopting EE design and operational measures by saving fuel on every voyage. Seafarers working onboard ships and onshore offices are vital stakeholders in implementing EE operations on board ships.

Despite substantial progress in developing innovative approaches for modernizing ship automation and control, the ship crew still operates the vessel, maintains operating procedures, and validates all work to be executed onboard. Dewan et al. (2018) have pointed out that crewmembers, among other stakeholders, must acquire a broader understanding of energy management and incorporate various operational energy-saving practices. As a result of imprecise directives from ship managers ashore or land-based organizations, crew members at sea often encounter challenges when attempting to execute energy-efficient voyages onboard ships. According to Banks et al. (2014), a perception exists among a significant number of seafarers that they do not have adequate knowledge and awareness of the impact that CO_2 emissions have on the environment. The study conducted on 312 seafarers worldwide revealed that only 6% of these individuals considered themselves knowledgeable. Seafarers in the maritime industry have also been observed to lack sufficient knowledge, training, and motivation. After a decade of implementing EE regulations in the maritime sector, there is a lack of study to determine the impact of EEOS on seafarers.

In this study, we will establish our hypotheses by collecting various phenomena from the literature review, developing research design and comprehensive survey questionnaires, conducting a survey, managing data from the maritime industry, and testing conclusions to find a theory or prove a statement, as shown in Figure 1.1. Using an abductive approach, this study incorporates inductive and deductive reasoning (Spens & Kovács, 2006).

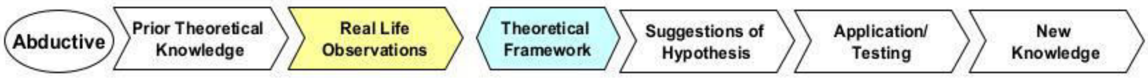


Figure 1. 1 - Abductive Research Approach

As part of the deductive phase, we develop a theoretical model based on recent studies on maritime EE, further augmented by industry observations and real-world data. During the inductive phase of our investigation, we examine new insights and theories formulated based on the survey data we collected. The main goal of a thorough evaluation of seafarers' knowledge and awareness of energy-efficient and low-carbon ship operations is to ensure compliance with IMO regulations. This can be achieved through a dual approach.

1.5 Research Objectives

Our research investigates the impact of operational EE practices on seafarers aboard vessels. The main aim of this study is to conduct a comprehensive analysis of multiple facets of awareness, understanding, participation, and difficulties seafarers encounter concerning EEOS.

For this overall goal, three distinct groups of research objectives have been established:

Group A: Seafarers' Engagement in Energy-Efficient Ship Operations

RO1: To identify roles and challenges faced by seafarers as they implement operational EE measures in ships.

RO2: To investigate how seafarers embrace new work cultures associated with the EEOS.

Group B: Seafarers' Awareness and Knowledge in Energy Efficient Operation of Ships

RO3: To evaluate seafarers' awareness and knowledge level regarding energy-efficient and low-carbon shipping practices following a decade of IMO regulation enforcement.

RO4: To evaluate the efficacy of existing training programs in improving seafarers' proficiency in EEOS.

Group C: Strategic Training Framework for Seafarers on Energy-Efficient Operation of Ships

RO5: To propose a strategic training framework for enhancing seafarers' competence in EEOS.

By examining these research objectives, this study intends to offer significant perspectives on the level of involvement, obstacles, awareness, and understanding of the operation of energy-efficient ships. Furthermore, it aims to assess the present norms for knowledge and awareness among maritime personnel working aboard ships and ashore offices, as well as determine the necessities for training concerning low-carbon and energy-efficient ship operations. This analysis provides a strategic training framework to promote seafarers' training, consequently contributing to the advancement of energy efficiency and low-carbon initiatives in the shipping industry.

1.6 Thesis Structure

This thesis comprises four peer-reviewed journal articles and two conference papers, which are structured with 5 Chapters according to Figure 1.2. Among the four peer-reviewed academic publications, three have been published in the Marine Policy journal, while one is now undergoing a second review process in the Heliyon journal.

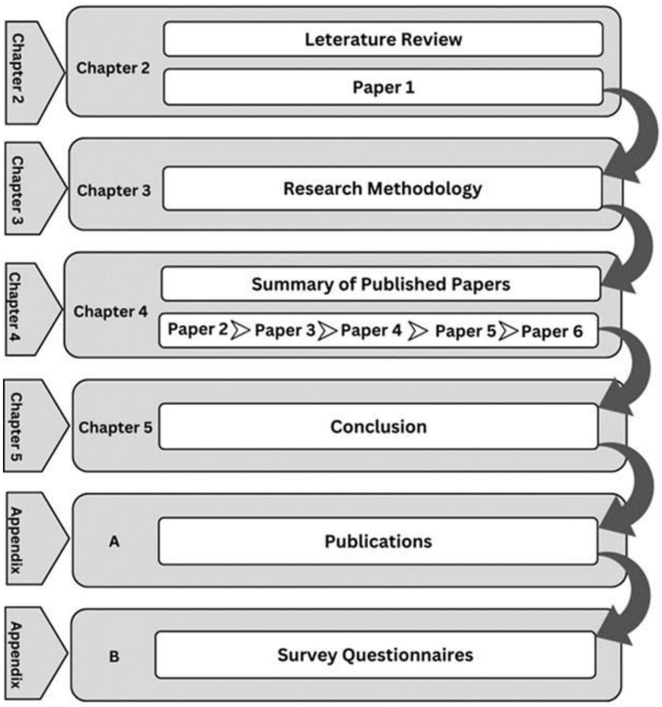


Figure 1. 2 - Arrangement of Chapters

The findings of this study were presented at the 4th and 5th International Conference on Industry 4.0 and Smart Manufacturing (ISM 2022 and ISM 2023) and subsequently published in the Procedia Computer Science journal. Table 1.1 provides a comprehensive overview of the published papers.

Chapters are explained further as the following:

- **Chapter 1**: **Introduction** – The background, research gaps, and aims of the study are explained in this chapter. An outline guides the reader through the thesis's sections, problem statement, inquiry issues, and aims.
- **Chapter 2**: **Literature Review** - Following an introductory section, the chapter discusses EEOS and SEEMP measures, crew participation in EE implementation, seafarers' training activities, and factors influencing seafarers' engagement in energy-efficient ship operations. This chapter is based on published paper 1. My responsibilities as an author of paper 1 included conceptualization, methodology, validation, formal analysis, investigation, resources, data curation, original draft preparation, and manuscript preparation.
- **Chapter 3: Research Methodology -** It thoroughly explores the research methodology utilized in our published papers 1 to 6. We delve into research design, encompassing the development of survey questionnaires, and elaborate on the steps taken to validate and ensure their reliability. Additionally, we discussed the chosen data analysis methods applied in our study.
- **Chapter 4: Summary of Published Papers -** This chapter synthesizes findings from multiple studies on seafarers' roles, challenges, and training in energy-efficient ship operations. Paper 2 identified seafarers' engagement and challenges in implementing EE measures. Paper 3 highlights their adaptation to new work cultures driven by EEOS. Paper 4 investigates their awareness and understanding of EE and low-carbon (LC) shipping practices. Paper 5 emphasizes the effectiveness of seafarers' training in EEOS, while Paper 6 assesses seafarers' knowledge, understanding, and proficiency from various training programs and proposes a strategic framework to enhance their competence on EEOS. As the author of Papers 2–6, I was responsible for conceptualization, implementation, validation, formal analysis, investigations, resource acquisition, and data management using tools like Microsoft Excel, Canva, yWorks, ANOVA Testing, SPSS Version 26, and SmartPLS Version 3.2.9. I also prepared original drafts and finalized manuscripts.
- **Chapter 5 - Conclusion** - It provides concluding remarks, the overall study outcomes, contributions to the shipping industry, and future research recommendations.

Table 1. 1 - Papers Comprising This Thesis

Title of Papers	Main Findings	Related Chapter
Paper 1: An overview of seafarers' engagement and training on energy efficient operation of ships. (Dewan, M. H., & Godina, R. (2024). An overview of seafarers' engagement and training on energy efficient operation of ships. Marine Policy, 160, 105980. https://doi.org/10.1016/j.marpol.2023.105980)	• Review paper based on Examining 58 articles spanning a decade (2013-2023), it pinpoints crucial attributes such as knowledge, education, and innovations in maritime energy efficiency.	Chapter 2
Paper 2: Roles and challenges of seafarers for implementation of energy efficiency operational measures onboard ships. (Dewan, M. H., & Godina, R. (2023). Roles and challenges of seafarers for implementation of energy efficiency operational measures onboard ships. Marine Policy, 155, 105746. https://doi.org/10.1016/j.marpol.2023.105746)	• Identified engagement of seafarers for execution of EE measures during ship operations according to their positions and responsibilities. • Identified challenges experienced by seafarers in implementing energy-efficient ship operations.	Chapter 4
Paper 3: Sailing Towards Sustainability: How Seafarers Embrace New Work Cultures for Energy Efficient Ship Operations in Maritime Industry. (Dewan, M. H., & Godina, R. (2024). Sailing Towards Sustainability: How Seafarers Embrace New Work Cultures for Energy Efficient Ship Operations in Maritime Industry. Procedia Computer Science, 232, 1930–1943. https://doi.org/10.1016/j.procs.2024.02.015)	• Identified EE operational measures implemented by seafarers working ashore and aboard ships. • Identified new working cultures adapted by seafarers for energy-efficient ship operations.	Chapter 4
Paper 4: Unveiling seafarers' awareness and knowledge on energy-efficient and low-carbon shipping: A decade of IMO regulation enforcement. (Dewan, M. H., & Godina, R. (2024). Unveiling seafarers' awareness and knowledge on energy-efficient and low-carbon shipping: A decade of IMO regulation enforcement. Marine Policy, 161, 106037. https://doi.org/10.1016/j.marpol.2024.106037)	• Assessed seafarers' general awareness and knowledge of CO2 emissions and source of general awareness and knowledge. Identified their efforts to improve EE and LC ship operations. • Investigated participant's interest in learning EE and LC ship operations.	Chapter 4
Paper 5: Effective Training of Seafarers on Energy Efficient Operations of Ships in the Maritime Industry. (Dewan, M. H., & Godina, R. (2023a). Effective Training of Seafarers on Energy Efficient Operations of Ships in the Maritime Industry. Procedia Computer Science, 217, 1688–1698. DOI link: https://doi.org/10.1016/j.procs.2022.12.369)	• Identified effective EEOS training programs for seafarers. • Identified shipping companies' training efforts for aboard seafarers and ashore ship managers.	Chapter 4
Paper 6: Exploring seafarers' knowledge, understanding, and proficiency in SEEMP: A strategic training framework for enhancing seafarers' competence in energy-efficient ship operations. (Dewan, M. H., Ahmed Mustafi, M. A., Matos, F., & Godina, R. (2024). Exploring seafarers' knowledge, understanding, and proficiency in SEEMP: A strategic training framework for enhancing seafarers' competence in energy-efficient ship operations. Heliyon, 10(17), e36505. https://doi.org/10.1016/j.heliyon.2024.e36505)	• Identified level of Knowledge, understanding, proficiency and satisfaction gained by seafarers from various EEOS Training programs. • Assessed Seafarers' level of Knowledge, Understanding, and Proficiency (KUP) in SEEMP. • Proposed a training framework for enhancing seafarers' competence in EEOS.	Chapter 4

1.7 Concluding Remarks

Introducing the thesis, this chapter describes the research problems and objectives. It investigates the impact of EEOS on seafarers, including their implementation of SEEMP in ships, involvement in low-carbon and EE practices, difficulties experienced, and evolving work cultures. It addresses knowledge gaps and existing training programs by emphasizing the crucial role of seafarers' training in EEOS. Highlighting the importance of Seafarers' Knowledge, Understanding, and Proficiency (KUP) in SEEMP regulations and measures, the chapter proposes a comprehensive training framework for successful SEEMP implementation onboard ships. Overall, it establishes a framework for recognizing seafarers' role in EE improvements and emphasizes the importance of effective EEOS training programs to improve their competence in implementing SEEMP onboard ships.

2

LITERATURE REVIEW

This chapter consists of published review paper 1: An Overview of Seafarers' Engagement and Training on Energy Efficient Operation of Ships.

2.1 Introduction

This study aims to investigate seafarers' contribution to addressing climate change by adopting energy-efficient ship operations. Examining 58 articles spanning ten years, it pinpoints crucial attributes such as knowledge, education, and innovation. As digital tools become more integrated, comprehensive training initiatives are critical. This review contributes to understanding the factors impacting seafarers' participation by shedding light on EEOS, pinpointing research deficiencies, and offering suggestions. It underscores significant gaps in research and proposes measures to augment comprehension of EEOS. Education and training initiatives for seafarers play a crucial role in promoting energy efficiency in the shipping industry. Effective collaboration between ship owners and managers is vital in advocating financial incentives and regulatory frameworks. The results offer significant implications for policymakers, academic institutions, and industry players in their efforts to increase the participation of seafarers, encourage sustainable and energy-efficient maritime strategies, and address environmental issues in the maritime industry.

2.2 Energy Conservation Practices in Shipping Industry Before Implementing SEEMP

A severe recession occurred in the maritime industry during the 1970s due to lowered freight rates, a surplus of tankers and bulkers, and soaring fuel costs, which accounted for over 50% of operational expenses (Böhme, 1983; Buxton, 1985). As a result of this energy crisis, the United States (US) Navy developed strategies to increase energy efficiency by reducing operating speeds and exploring waste recovery systems (Bertram et al., 1983). Several techniques for reducing shipboard energy consumption were implemented, including hull maintenance, machinery optimization, and crew training, to emphasize individual contributions. Even though a variety of fuel-saving measures have been identified, the importance of fostering crew understanding, motivation, and active participation was emphasized by maritime stakeholders (Bertram et al., 1983). As part of the implementation strategy, dedicated energy conservation managers were appointed, new procedures were explained to crew members, and internal communication was utilized to demonstrate performance. However, Shipboard energy conservation efforts were abandoned in 1989 due to the falling fuel prices.

Although the literature on energy conservation overlooks the period of low fuel prices between the 1990s and early 2000s (Poulsen & Sornn-friese, 2015), NAVSEA's Energy Conservation Program (ENCON) was established in the early 1980s to emphasize a persistent commitment to enhancing operational efficiency (Pehlivan, 2000). A computer model for analyzing shipboard energy (MOSES) was developed by (DeTOLLA, 1984) in support of Shneerson, (1981)'s recommendation for optimal ship speeds to minimize idle time in port. In the study of (Morisseau, 1985), innovative approaches were explored, including sail utilization and the Magnus effect, while slow steaming gained popularity as a way to save energy by reducing fuel consumption by up to 30% (Bertram et al., 1983). The crew members' crucial role highlighted the importance of crew motivation in optimizing propulsion and power generation efficiency in implementing these measures.

2.3 SEEMP Measures and Energy-Efficient Ship Operations

It is critical to recognize that most EEOS depend on various factors, including vessel type, cargo, and routes. The SEEMP promotes energy-efficient vessel operation by implementing various methods to reduce fuel consumption and GHG emissions. The MARPOL requires all ships to have a SEEMP onboard, with mandatory implementation beginning January 1, 2013, for both new and existing vessels (IMO, 2012). SEEMP sets targets for planning, action, measurement, and improvement stages, focusing on carbon intensity reduction and fuel data reporting. DNV's Energy Transition Outlook 2023 identifies six emerging technologies in the shipping industry, including solid oxide fuel cells and air lubrication systems, highlighting the significance of comprehending all available alternatives (DNV, 2023). Rehmatulla et al. (2017) claimed that retrofitting an existing ship with energy-efficient innovations such as hull air lubrication and waste heat recovery can significantly reduce fuel usage and carbon emissions. Furthermore, adopting low-carbon fuels like LNG and biofuels, as proposed by Balcombe et al. (2019) and Xing et al. (2021), significantly reduces emissions. DNV (2022b) suggests operational procedures such as voyage and trim optimization, contributing to additional fuel savings. Collaboration among ship owners, charterers, and regulatory organizations is critical in implementing these measures to achieve EEOS, which will reduce environmental impact and operational costs. The energy-efficient operation of ships can be mapped according to Figure 2.1 below:

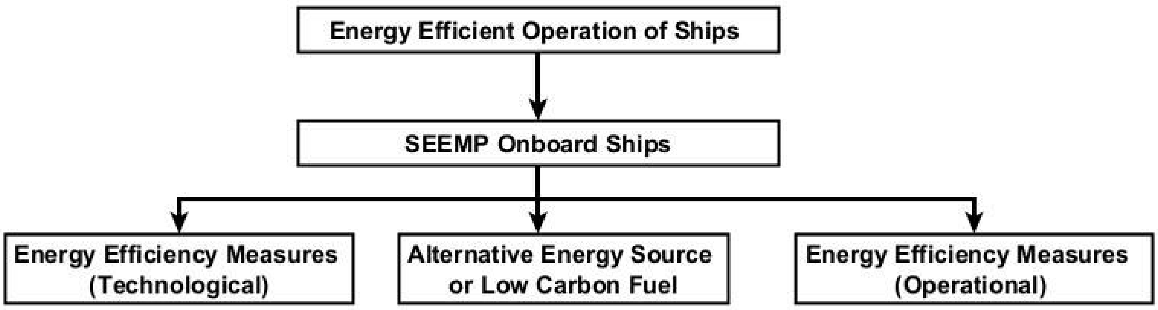


Figure 2. 1 - Mapping of Energy Efficient Ship Operations (Source: Paper 1)

To meet CO_2 and GHG emission regulations, ships must implement EE practices outlined in the SEEMP. Numerous studies have demonstrated that SEEMP enhances EE through operational measures such as weather routing, voyage planning, and speed optimization (Bännstrand et al., 2016; Bazari & Longva, 2011; Duan et al., 2023; Insel et al., 2018). Researchers have suggested many technological advances and operational techniques, such as dual-fuel ship alternatives, voyage management plans, and modular decision support systems (Armstrong & Banks, 2015; Papanikolaou et al., 2016; Surinov & Shemonayev, 2021; de Melo et al., 2021). Furthermore, utilizing big data analytics and the Internet of Things (IoT) in conjunction with SEEMP is consistent with energy-efficient ship operations (Ang et al., 2017; Meyer et al., 2009). Human aspects are essential for successfully applying energy-saving solutions, including crew awareness and knowledge (Banks et al., 2014; Viktorelius, 2018). Enhancing energy efficiency in the maritime sector to achieve net-zero emission targets requires comprehensive crew training and integration of modern digital technologies and Artificial intelligence (AI) driven decision support systems (Dewan & Godina, 2024b). Ship operators must work together to address technical and human aspects to reduce CO_2 emissions by cutting fuel usage in shipping operations (IMO, 2013).

2.4 Seafarers' Involvement for Execution of Energy Efficiency Operational Measures

Energy efficiency measures in shipping are strategies and practices designed to optimize energy consumption, reduce CO_2 and GHG emissions, and improve overall operational and technical performance in compliance with IMO regulations (Eide et al., 2011; IMO, 2009b). These measures include technical, design, and operational approaches. Measures encompass technical enhancements, including installing EE devices such as optimized propellers, variable frequency drives (VFD) for pumps and fans, and waste heat recovery systems, which improve energy utilization (Munk, 2009; Adland et al., 2018). Innovative design measures focus on improving hull forms and propulsion systems and optimizing trim and draft to minimize energy losses during voyages (Bazari & Longva, 2011; Reichel et al., 2014). Operational measures, including optimized voyage planning, weather routing, speed optimization, hull cleaning, and effective crew training, play a crucial role in improving EE and reducing carbon and GHG emissions (DNV GL, 2014; Psaraftis & Kontovas, 2014; IMO, 2012).

Several studies, including those by Eide et al. (2011) and Hoffmann et al. (2012), as well as recent works by Bännstrand et al. (2016) and DNV GL (2014), have identified cost-effective energy-saving strategies within the SEEMP. The measures encompass weather routing, trim and ballast optimization, slow steaming, and voyage planning, among others. Crew members play a crucial role in implementing these measures during ship operations to contribute directly to fuel-saving and emission-reduction initiatives. Dewan & Godina (2023c, 2023b) demonstrate how vessel masters and deck crews directly optimize navigation and port operations while chief engineers and engine crews oversee propulsion and power management to enhance energy efficiency. Shore technical managers supervise operations using advanced EE tools and software developed by researchers such as Zeng et al. (2022) to monitor and improve SEEMP measures remotely. Active crew participation, strict adherence to regulations, and ongoing improvement initiatives are vital for establishing sustainable and more environmentally friendly shipping practices (Lützen et al., 2017; Kitada & Ölçer, 2015). Adhering to energy efficiency regulations like EU MRV and IMO DCS is crucial to avoid monetary penalties and other repercussions for non-compliance (Adamowicz, 2022). Consistent reporting of ship data, such as propulsion engine RPM and fuel consumption, is crucial for effectively meeting regulations and monitoring EE measures (IMO, 2016a). As shown in Figure 2.2, ship owners, ship managers, and ship crews are all involved in implementing SEEMP onboard ships.

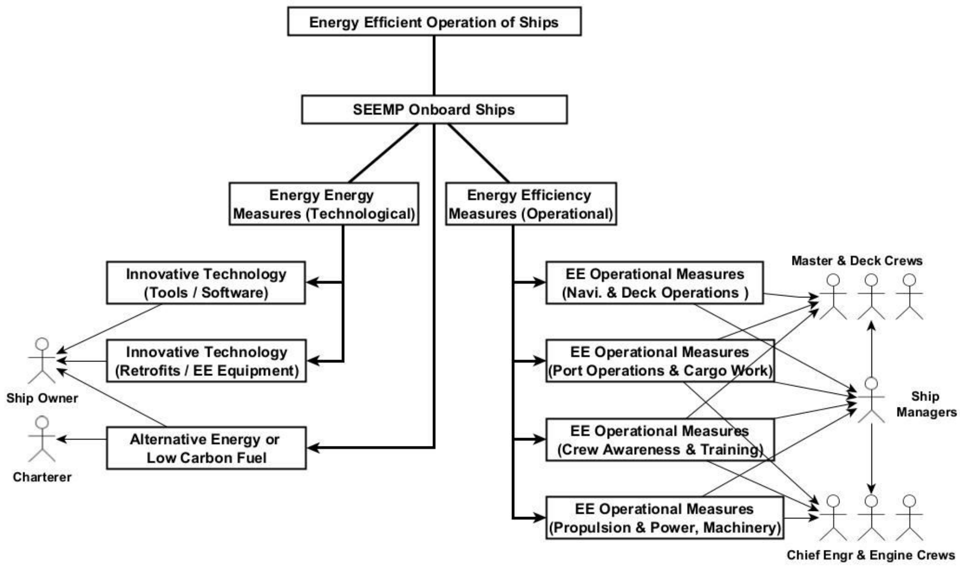


Figure 2. 2 - Involvement of Ship Owners, Ship Managers, and Ship Crews in Implementing SEEMP Onboard Ships (Source: Paper 1)

2.5 Energy Efficiency Education and Training in Maritime Domain

To ensure the successful implementation of SEEMP, the IMO's Resolution MEPC.213(63) highlights the significance of educating and training both onshore and onboard personnel

(IMO, 2012). Many crew members express the need for introduction or training in SEEMP despite their involvement in its development (Hansen et al., 2020; Viktorelius, 2018). The successful implementation of SEEMP relies on the crew member's ability to acquire new techniques, skills, and knowledge, as suggested by various studies (Banks et al., 2014; Beşikçi et al., 2021; DNV GL, 2015; Kitada & Ölçer, 2015). The IMO offers several training courses and workshops on maritime EE regulations and measures to facilitate the implementation of SEEMP (Ölçer et al., 2017). Global collaboration programs like GloMEEP, GIA, GMN, and GreenVoyage2050 aim to decrease GHG emissions and increase EE in the maritime sector (Ezinna et al., 2021; IMO, 2021). Numerous crew members are engaged in developing the SEEMP; however, they believe they are not receiving sufficient training and education to acquire the necessary competence (Kitada & Ölçer, 2020; Surinov & Shemonayev, 2021). Crew members must receive adequate quality training to comprehend and support SEEMP objectives (Dewan & Godina, 2023a).

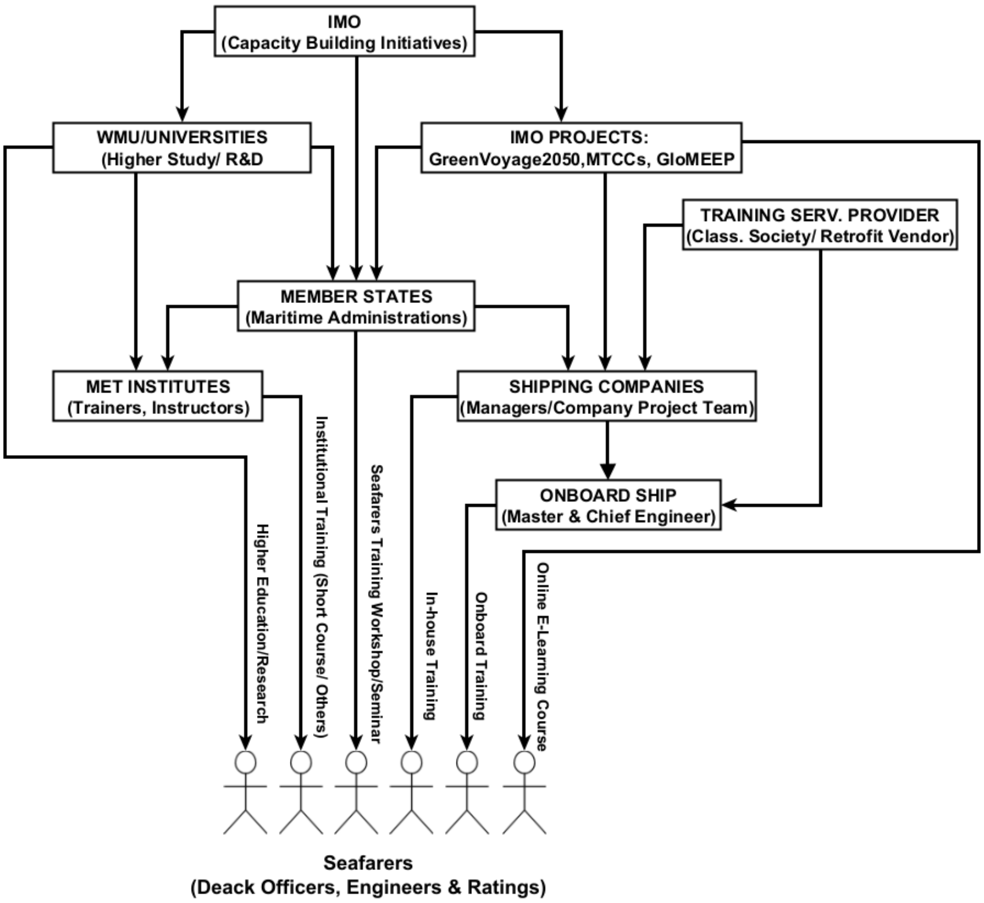


Figure 2. 3 - Mapping of EEOS Training Programs and Activities for Seafarers (Source: Paper 1)

Several studies investigated seafarer training programs and stressed the significance of integrating maritime EE training into seafarers' pre- and post-sea courses (de Melo et al., 2021; Hansen et al., 2020; Oliveira et al., 2016; Ziarati et al., 2017). In compliance with the IMO's updated GHG Strategy, which aims to reach net-zero emissions by 2050, the maritime industry requires effective training to support a decarbonized future (DNV, 2022a; Viktorelius, 2018). This involves integrating energy-saving regulations and practices into training programs and using different techniques, such as simulators and gamification tools (Jensen et al., 2018; Oliveira et al., 2016). The goal of the IMO's "Train the Trainer" course is to improve the energy-efficient ship operation courses already in place and to support initiatives to build capacity for trainer training (Bazari & Moon, 2016). Figure 2.3 illustrates the distribution of EEOS training programs and activities for seafarers on board vessels and onshore offices.

It is vital to have effective onboard training activities carried out by experienced and senior ship personnel to ensure the successful implementation of EE operational measures onboard ships (Dewan & Godina, 2023a). Despite the efforts of shipping companies, not all training initiatives yield fruitful results (Banks et al., 2014). Improving crew skills and promoting sustainable shipping practices requires focusing on EE training programs and activities.

2.6 Employee Behavior and Human Resource Management in Adoption of Energy Efficiency Measures

Studies reveal that Pro-Environmental Behavior (PEB) differs significantly between home and workplace settings, as individuals personally bear energy costs at home but not in organizational settings, where energy conservation is often not a formal job obligation (Gao et al., 2017; Murtagh et al., 2013). Industrial energy use is substantial, emphasizing the need for employee engagement in EEM (Abergel et al., 2017). The Theory of Planned Behavior (TPB) suggests that attitudes, social norms, and perceived control drive energy-saving intentions (Ajzen, 1991; X. Wang et al., 2018). However, factors such as personal norms (Schwartz & Howard, 1980), contextual elements and human errors also shape outcomes (Gerarden et al., 2015). Addressing barriers like individuality and practicality (Blake, 1999) could further support PEB in organizational settings. The extended TPB model effectively identifies performance-shaping factors, enhancing the prediction of workplace energy-saving behaviors (Steg & Vlek, 2009). Moreover, organizational factors play a crucial role in shaping EE behaviors, highlighting the need for management support and employee involvement (Vučković & Džunić, 2023). Empowering employees with resources and fostering a culture of EE is essential for sustainable practices (Reegård & Drøivoldsmo, 2020). Integrating energy-saving behaviors into routine work can promote sustained action and necessitate an organizational change to align with energy management goals (Johnson et al., 2013; Reegård & Drøivoldsmo, 2020). In their study, Jafarzadeh & Utne, (2014) found that organizational boundaries are a significant factor in energy performance assessments. According to Poulsen & Sornn-Friese, (2015), crew information and training are limited under third-party management, which hinders efforts to increase EE onboard ships. Thus, the maritime industry can navigate toward a more sustainable future by addressing organizational challenges and promoting a culture of energy efficiency.

Recent research underscores the paramount importance of employee engagement in contemporary organizations, highlighting its strong correlation with satisfaction, commitment, and involvement (Rameshkumar, 2020). Particularly within the maritime industry, where the human element is integral to operational success, seafarers' organizational behavior and well-being play a critical role (Kim & Jang, 2018; Muslu, 2020). Seafarers often face challenges from rigid organizational cultures and demanding work environments operating within the confines of hierarchical structures onboard ships (Muslu, 2020). These challenges can manifest in various forms, including high stress levels and limited opportunities for shore leave due to reduced time in port (Dimitrova & Blanpain, 2010; Oldenburg & Jensen, 2012). Additionally, poor human resource practices exacerbate grievances among seafarers, leading to high attrition rates and a lack of commitment to training obligations (J. Wang, 2009; Cahoon et al., 2014a). Addressing these challenges necessitates effective human resource management practices that promote a positive organizational culture and provide adequate support for seafarers (Cahoon et al., 2014a). Furthermore, the industry's reactive approach to training and retention exacerbates issues such as a volatile seafarer market and poor recruitment practices (Cahoon et al., 2014a).

However, successful implementation requires organizational change, dialogue between managers and workers, and incentives to motivate participation (Johnson et al., 2013; Kitada & Ölçer, 2020). Emphasizing the human element in energy management through education and research can further enhance awareness and facilitate the development of sustainable shipping practices (Kitada & Ölçer, 2020). In conclusion, to foster the effective adoption of EE measures, industries must integrate five key behavioral elements: Pro-Environmental Behavior (PEB), Theory of Planned Behavior (TPB), supportive Organizational Behavior, Human Resource Management (HRM), and Incentives with Dialogue for Change as highlighted in Figure 2.4. Encouraging PEB in workplace settings bridges personal and organizational values, while TPB shapes intentions through attitudes and norms. Strong organizational support and HRM practices enhance employee commitment, especially in challenging environments like maritime. Finally, incentives and open dialogue motivate participation, promoting sustainable practices and organizational alignment toward EE goals.

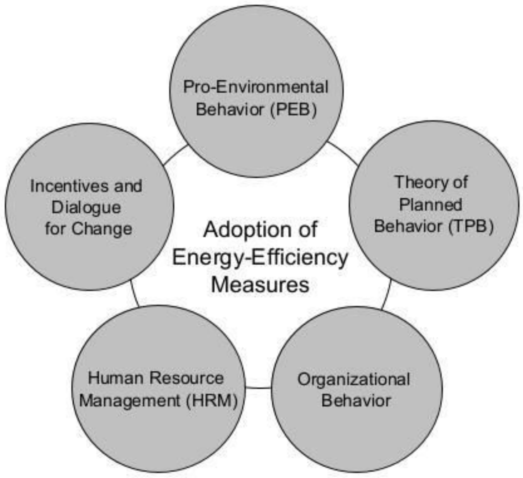


Figure 2. 4 - Employee Behavior Elements for Adoption of EE Measures

2.7 Factors Influencing Seafarer's Engagement in Energy-Efficient Ship Operations

Various factors impact seafarers' engagement in energy-efficient ship operations. Seafarers' understanding and beliefs about low-carbon practices substantially influence their involvement (Banks et al., 2014; Viktorelius, 2020). Comprehensive knowledge of EE practices and technologies is essential for successfully implementing aboard vessels (Viktorelius, 2020). Baldauf et al. (2013) reveal that seafarers need to receive on-the-job training, onboard learning, and decision-making support systems to gain the skills and knowledge required for the effective execution of EE practices aboard ships. The utilization of ship bridge simulators for training and energy monitoring tools was positively correlated with seafarers' engagement, according to Jensen et al. (2018). Communication skills and situational awareness are also influential (Hansen et al., 2020). Organizational culture, leadership, and training are essential social factors (Kitada & Ölçer, 2015). New technologies like dual-fuel vessels offer new opportunities (Surinov & Shemonayev, 2021), while decision support systems aid in informed decision-making (Insel et al., 2018). Organizational support and ship-shore cooperation enhance motivation (Viktorelius & Lundh, 2019). Audits, policies, and voluntary initiatives also affect engagement (Balcombe et al., 2019; Christodoulou & Cullinane, 2021; von Knorring, 2019). Incentive programs are crucial, but insufficient incentives, financial constraints, and infrastructure hinder participation (Dewan et al., 2018; Lu et al., 2015). Barriers like principal-agent problems and sector-specific challenges also impact involvement (Johnson et al., 2014; Johnson & Andersson, 2016; Rehmatulla & Smith, 2015). However, from the literature review, we discovered factors influencing seafarers' involvement in implementing EE operational measures, and it is crucial to understand these factors to encourage seafarers to participate in EE practices in shipping operations (Figure 2.5).

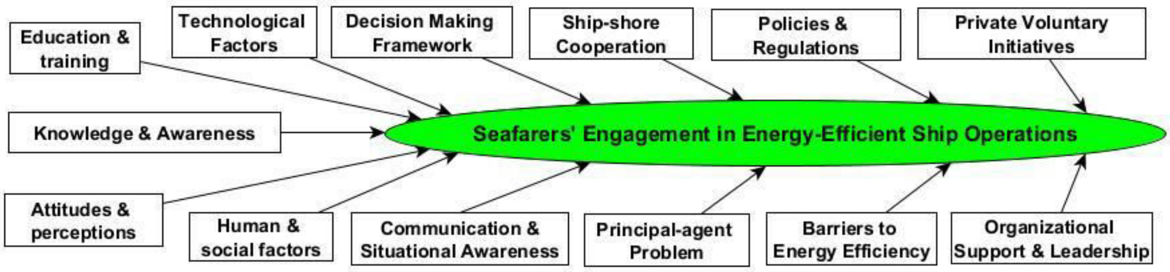


Figure 2. 5 - Factors Affecting Seafarers Engagement in EEOS (Source: Paper 1)

2.8 Concluding Remarks

The comprehensive analysis of a decade's worth of literature review has identified crucial elements that impact EEOS, such as awareness, understanding, training, incentives, social influencing elements, innovations, and obstacles to the engagement of seafarers. With the increasing importance of digital technologies in ship operations, there is a pressing need for customized training programs incorporating interactive tools and targeting deficiencies in knowledge and motivation among seafarers. Furthermore, this study emphasizes the transformative impact of digitalization, necessitating a reassessment of energy-efficient ship practices. This review provides a holistic understanding of the factors shaping EEOS by identifying critical research gaps and recommending future studies. It underscores the critical role of seafarers' education and training in driving EE during ship operations. These findings can be utilized by policymakers, educational establishments, and industry players to increase the involvement of seafarers and advocate for environmentally sustainable and EE practices for ship operations.

3

RESEARCH METHODOLOGY

This section discusses the methodology employed in our study. The design of our study is outlined, as well as the measures taken to validate and verify the validity of our survey questionnaires. In more detail, we also discussed the methodology selected for data analysis used in our study.

3.1 Research Design

Seafarers are crucial in ensuring safe and efficient cargo transportation worldwide through ship operations. To explore the engagement, challenges, knowledge, and effective training of seafarers in EEOS, it is essential to explicitly define their responsibilities in implementing energy-saving practices during ship operations. Identifying the precise duties of crew members on board and ship managers' offices ashore is necessary to adopt energy efficiency measures, which will help clarify the difficulties in maintaining energy-efficient ship operations. Given their technological complexity, seafarers need sufficient awareness and understanding to adopt EE standards and measures on ships successfully. After a decade of the IMO implementing regulations to improve EE in the maritime sector, assessing the awareness and understanding level is crucial. The training of seafarers in EEOS is often conducted through numerous channels, including institutional courses, in-house training provided by shipping companies, onboard training activities, and online e-learning courses offered by the IMO. Evaluating the effectiveness of these training courses or activities in equipping seafarers with the necessary awareness and knowledge to implement EE measures during ship operations is crucial. This study's literature review covers several important topics, including the IMO's regulatory bindings to improve maritime EE, the shipping industry's operational measures to improve EE, seafarers' roles in implementing operational measures, onboard documentation and reporting practices by crewmembers, and available training programs for seafarers to enhance their knowledge and understanding of EE practices in shipping operations. However, after the state-of-the-art literature review, we developed our survey questionnaires, which were tested with pilot surveys and validated through different procedures explained in this chapter.

3.2 Development of Survey Questionnaires

This study employs a blending method of qualitative and quantitative methodologies, with a pilot and three major surveys are driven by three research questions mentioned in Section 1.3 of this thesis, combining qualitative and quantitative data to achieve a comprehensive understanding of the research problem (Creswell & Creswell, 2018). The methodology implemented numerous data collection methods to optimize response rates and inclusivity, including telephone discussions, in-person interviews, and online forms. Firstly, online surveys were primarily directed at seafarers aboard vessels, providing an accessible platform that catered to their isolated environments. Secondly, in-person and telephonic interviews were conducted with participants onshore, which allowed for greater flexibility and facilitated the gathering of more nuanced qualitative insights. This dual approach was crucial for engaging seafarers onboard ships and onshore managers from various geographic locations.

The survey itself was structured into four parts: (1) the first part collected personal information detailing the background of participants; (2) the second part assessed training by evaluating participants' knowledge, understanding, proficiency, and satisfaction with ten available EEOS training courses; (3) the third part focused on SEEMP implementation, assessing participants' practical knowledge, the challenges they faced, and their proficiency in applying SEEMP measures; (4) finally, the fourth part included open-ended questions, allowing participants to provide feedback and suggest improvements for SEEMP implementation.

The survey questionnaire blended qualitative and quantitative methods and was carefully constructed using primary data from the literature review. Validation, employing the Content Validity Index (CVI) method (Davis, 1992; Polit & Beck, 2007), was conducted by academic and industrial experts. Subsequent testing by the pilot survey ensured the questionnaire's reliability and relevance.

3.3 Pilot Survey

A pilot survey was conducted between June 18 and June 28, 2022, involving 22 participants, including onboard crew (Masters and Chief Engineers) and onshore managers (Operational and Technical Managers) from Bangladesh, Denmark, Hong Kong, Malaysia, Saudi Arabia (KSA), and Singapore. The pilot survey served multiple objectives. It tested the instruments to ensure the survey questions were clear, relevant, and aligned with the research objectives. Additionally, it helped identify key constructs, including participants' roles in implementing SEEMP measures, challenges encountered, and the effectiveness of EEOS training programs. Insights gained from the pilot survey further guided the refinement of the main survey questionnaire, ensuring it effectively captured the nuances of EE practices.

During the pilot survey, participants responded to the following questions:

1) Can EE measures be successfully implemented if personnel onboard and onshore are made aware and trained as per MEPC.213(63)?
2) What specific training is needed to implement EE measures on ships?
3) What training have you received for implementing EE measures effectively?

Findings from the pilot survey confirmed that the implementation of SEEMP measures is closely tied to the quality and scope of training provided to seafarers and onshore staff.

3.4 Use of Likert-Type Scales

The surveys utilized Likert-type scales to measure key constructs such as participants' involvement in EE practices, perceived challenges, and attitudes toward adopting SEEMP measures. Each construct was assessed through multiple items, with responses ranging from 1 ("Strongly Disagree") to 5 ("Strongly Agree").

The constructs measured in the study encompassed several key areas:

First, the involvement of seafarers and the challenges they faced in EEOS were examined, focusing on their active engagement and the difficulties encountered in implementing SEEMP measures onboard.

Second, the study explored seafarers' awareness and knowledge of EE and low-carbon shipping, considering their roles both onboard ships and in shore-based companies.

Lastly, the effectiveness of training programs designed to enhance seafarers' capabilities in EEOS was assessed, evaluating the impact of these initiatives on their performance in both onboard and shore-based operations.

The Likert-type scales provided quantifiable data for evaluating the effectiveness of training programs in EEOS and participants' competencies. To ensure validity and reliability, the survey instrument was tested and refined using the CVI method (Davis, 1992; Polit & Beck, 2007).

3.5 Descriptive Analysis Methodology

This study employs descriptive analysis to comprehensively evaluate seafarers' engagement, knowledge, and training practices in EEOS. This approach aligns with the fundamental objectives of descriptive analysis, which aim to address questions regarding "what," "where," "who," and "to what extent" while refraining from making unwarranted inferences (Loeb et al., 2017). For example, in inclusive science education, descriptive analysis effectively highlights key themes, educational levels, and types of disabilities examined in academic studies. Despite increased publications on science education and inclusive education, this body of work remains relatively limited and concentrated in specific journals (Comarú et al., 2021). Recognized for its versatility, descriptive analysis is one of the most sophisticated tools in sensory research (Kemp et al., 2018), and it also stands independently as a research product, revealing previously uncharted patterns and phenomena that inform policies and practices (Loeb et al., 2017).

In my study, descriptive analysis was instrumental in exploring seafarers' roles, challenges, awareness, knowledge, and the effectiveness of training programs in EEOS following the enforcement of IMO regulations. The insights derived from this analysis are invaluable for policymakers, enabling them to create targeted policies to prepare seafarers to enhance energy-efficient ship operations and advance IMO's goal of achieving net-zero emissions by 2050 (DNV, 2023). Additionally, the method provided a systematic framework to identify deficiencies in SEEMP implementation and examine demographic and contextual factors, thereby facilitating the development of a tailored strategic training framework. Ultimately, descriptive analysis supports favorable policy-making and educational initiatives in the maritime energy management domain.

This study employs blending methods of qualitative and quantitative studies featuring a pilot and three main surveys aligned with the research questions in Section 1.3. The blending of qualitative and quantitative data (Creswell & Creswell, 2018) ensures comprehensive descriptive analysis. The survey was designed to effectively engage geographically dispersed participants, including shipboard crew members and shore-based managers.

3.5.1 Survey to Identify Roles and Challenges of Seafarers

A comprehensive questionnaire was developed for the main survey to ensure reliable and relevant data collection. The online survey was created using Google Forms, featuring single-answer, multiple-choice options, and checkboxes for selecting individual and multiple responses. The survey questions (SQs) covered the following areas:

SQ1- Current position aboard a ship or ashore shipping company
SQ2 - Rank experience onboard ships or ashore shipping offices
SQ3 - Types of ships operated or managed
SQ4 - Operational energy efficiency measures used to implement SEEMP
SQ5 - Challenges faced in implementing EE operational measures
SQ6 - Specific challenges experienced when implementing SEEMP
SQ7 - Impact of Energy-Efficient Ship Operation on traditional working culture
SQ8 - Rewards received for successful SEEMP implementation

The survey was distributed to onboard crew members and ashore ship managers working in shipping companies located in various countries through email, social media, and online platforms. Distribution channels included email, Facebook and LinkedIn messengers, and WhatsApp group platforms.

3.5.1.1 Sampling Strategy

The research population included ship operation and technical managers, environmental compliance managers working ashore, and crewmembers working in ships. A purposive sampling strategy was employed to select participants meeting specific criteria. Seafarers and ship managers from 42 shipping companies worldwide were contacted. The survey link was sent to:

1) Deck Crew - Seafaring professionals working as masters, chief officers, and watchkeeping officers in navigation bridges and decks

2) Engine Crew - Chief engineers, second engineers, and watchkeeping engineers working in engine rooms
3) Ship Manager - Technical and operations managers ashore

A total of 109 responses were obtained from active seafarers and shore managers who met the research criteria, of which 104 were accepted. Five (5) responses were excluded, as participants had not been involved in vessel operations since January 2013, when EE regulations were enforced. Consequently, the final dataset comprised 104 participants, offering valuable data for analysis.

3.5.1.2 Analysis of Survey Data

SPSS version 26 and Excel were utilized to analyze 104 survey responses. The data, initially saved in PDF format, was converted to CSV format to facilitate detailed examination. Charts were generated to display the percentage of respondents for each variable, with "N = Number of Participants" indicating the total responses per chart. Responses with blank variables in dependent rating questions were deemed invalid and excluded from the analysis. SPSS software and Excel spreadsheet formulas were employed to represent the data visually. Additionally, the ANOVA statistical tool was used to compare significant differences between groups, enhancing the depth of the analysis.

3.5.1.3 Profiles of Survey Respondents

The survey conducted among seafarers aimed to capture their professional profiles by posing survey questions no. 1 to 3, as mentioned in section 3.5.1. A total of 104 seafarers participated in the online survey, including 35 Chief Engineers, 23 Ship Masters, 23 Ship Managers, 5 Second Engineers, 2 Chief Officers, 6 Second Officers, and 10 Third Engineers, as shown in Figure 3.1(a). The results reveal that most responses were from Chief Engineers, who oversee SEEMP-related tasks such as reporting, documentation, and crew training aboard most vessels. It is shown in Figure 3.1(b) that the respondents were either employed onboard vessels or by shipping companies based ashore in 24 different countries around the globe. As illustrated in Figure 3.2(a), a majority of respondents indicated that they were actively involved in the operation and supervision of ships of various types of ships.

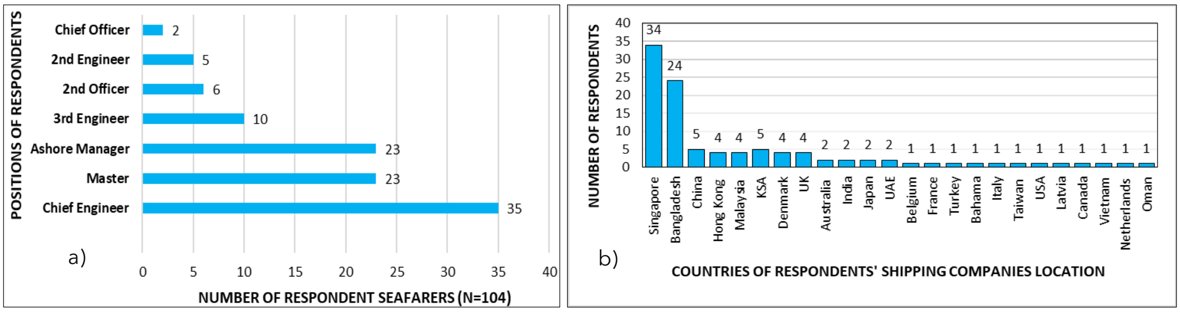


Figure 3. 1 - (a) Respondent Seafarers and (b) Location of Respondents' Companies

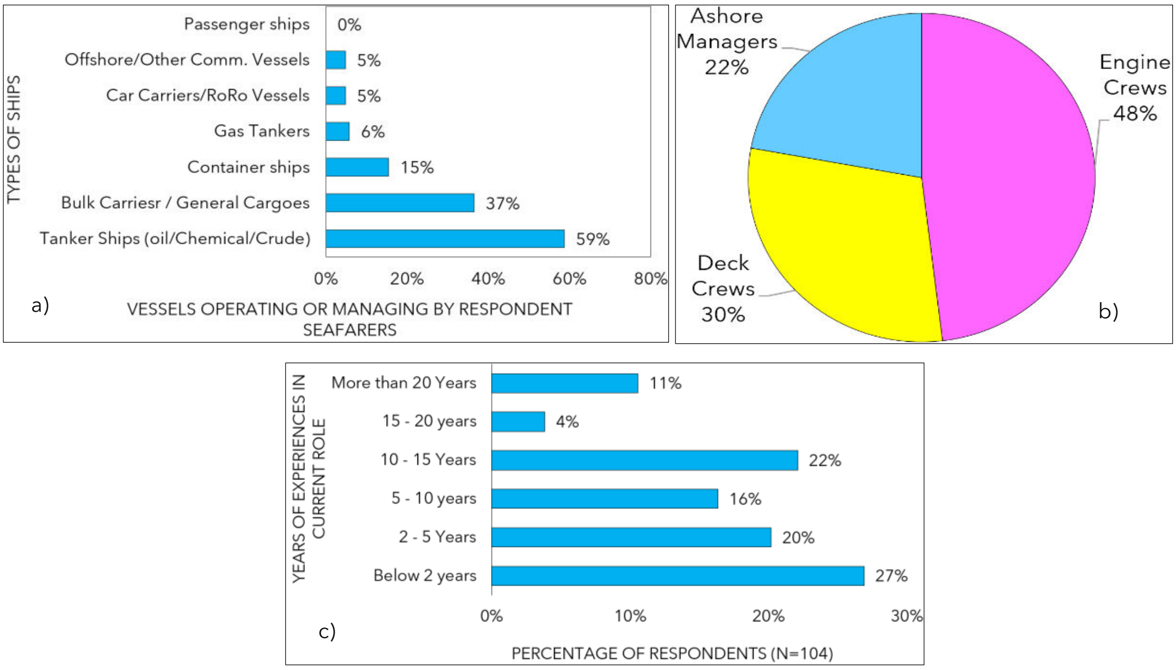


Figure 3. 2 - (a) Types of Ships; (b) Respondent Seafarers' Workplace; (c) Years of Experience of Respondent Seafarers in Their Current Role

Further breakdown in Figure 3.2(b) highlights that 22% of the respondents were shore-based managers, 30% were ship masters and deck crew, while 48% were engine department crew members. Figure 3.2(c) provides insights into respondents' years of experience in their current roles, explicitly focusing on Ship Managers, Masters, and Chief Engineers. This demographic profile ensures a comprehensive and representative sample of the maritime industry, lending credibility to the survey findings.

3.5.2 Study for Unveiling Seafarers' Awareness and Knowledge in Energy-Efficient and Low-Carbon Shipping

A well-structured questionnaire was designed to conduct the primary survey, aiming to gather accurate and relevant data for comprehensive analysis to assess seafarers' awareness and knowledge of EE and low-carbon shipping practices after a decade of enforcement of maritime EE regulations by the IMO.

3.5.2.1 Design and Distribution of Survey Questionnaires

The survey included a variety of question formats: single-answer and multiple-choice questions, Likert-type scale statements, checkboxes for single or multiple responses, and qualitative questions with predefined options complemented by an "others" field for open-ended inputs. The online survey was disseminated globally on June 5, 2023, through multiple channels such as individual and group emails, mobile apps (e.g., Facebook and LinkedIn Messengers, Viber, and WhatsApp), and direct distribution to 88 post-sea students enrolled in MET institutes in Bangladesh, Liberia, and Ghana.

The survey consisted of 12 research questions divided into the following four groups:

A. Profile of Participants

1) Details of participants: (i) Gender, (ii) Age, (iii) Current job role, (iv) Years of experience at sea or in sea and office roles, (v) Types of vessels participants currently work on or manage, and (vi) Country of the participant's shipping company.

B. Awareness and Knowledge of EE and LC Shipping

2) Awareness of CO2 and GHG emissions' impact on the environment.
3) Knowledge of CO2 and GHG emissions' effects.
4) Level of technical expertise in EE and LC shipping.
5) Methods of acquiring knowledge on CO2 and GHG emissions.
6) Training received to enhance awareness and knowledge of EE and LC shipping practices.

C. Seafarers' Efforts on EE and LC Shipping Practices

7) Interest in learning about EE and LC ship operations.
8) Efforts to improve EE and LC shipping based on technical expertise.

D. Perceptions on Carbon Emissions Mitigation in Shipping

9) Beliefs on reducing carbon emissions in shipping.
10) Suggestions for ship crews to minimize emissions.
11) Importance of carbon emissions reduction in shipping.
12) Opinions on incentivizing ship crews for EE and LC operations.

3.5.2.2 Sampling Strategy

A purposive sampling strategy was employed to evaluate seafarers' awareness and knowledge of EEOS, mainly focusing on implementing IMO regulations over the past decade. The survey targeted stakeholders actively involved in SEEMP implementation, including:

1) Ashore operations personnel (technical, operational, and environmental managers).
2) Onboard crew members (Masters, Chief Officers, Watchkeeping Deck Officers, Chief Engineers, 2nd Engineers, and Watchkeeping Engineers).
3) Female seafarers serving as deck officers and engineers in various positions.
4) Final-year marine engineering and nautical students in MET institutes who completed at least one year of onboard training.

The sample comprised 262 active seafarers, including 31 female participants, representing 41 shipping companies across the globe. Additionally, the survey included 88 final-year students from MET institutes in Bangladesh, Liberia, and Ghana, each with at least one year of sea service experience.

3.5.2.3 Data Analysis

Data collected from 262 respondents (231 males and 31 females) were analyzed using SPSS Version 26 and Excel formulas. Analysis methods included Percentage calculations based on total respondents, Graphical representation of data, Interpretation of qualitative responses, and Exclusion of incomplete or defective responses. Open-ended responses submitted under the "others" field were analyzed as qualitative data. Surveys with incomplete dependent variables in rating-based questions were excluded from the analysis.

3.5.2.4 Profile of Survey Respondents

The survey responses to Question 1 were collected from 262 individuals (231 males and 31 females), as shown in Figure 3.3(a). Participants included 26 senior engineers (chief and second engineers), 14 senior deck officers (masters and chief officers), 5 ship managers (technical/marine superintendents, operation managers, and environmental compliance managers), 72 junior engineers (3rd and 4th engineers), 57 junior deck officers (2nd and 3rd officers), and 88 final-year students studying marine engineering and nautical science programs at MET institutes in Bangladesh, Liberia, and Ghana who had completed 1 year or more period of onboard training.

Figure 3.3(b) illustrates the positions, while Figure 3.3(c) highlights the years of experience of respondents, categorized as 24 with over 15 years of experience, 19 with 11–15 years of experience, 29 with 6–10 years of experience, 102 with 1–5 years of experience and 88 post-sea cadets/students with one year of onboard experience.

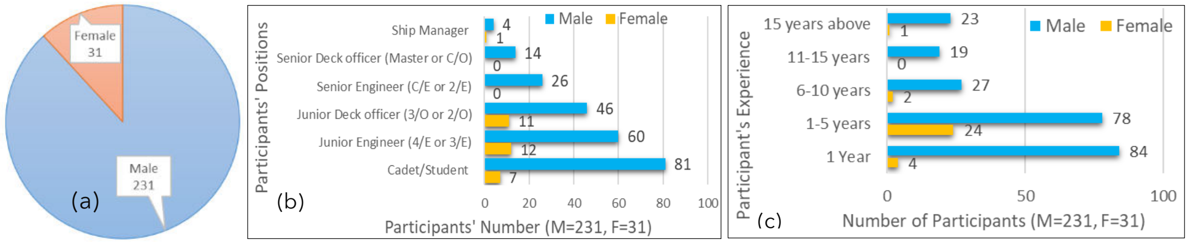


Figure 3. 3 - (a) Gender of Participant Seafarers; (b) Participants' Job Roles. (c) Participants' Years of Experience Onboard Ships/Ashore Offices.

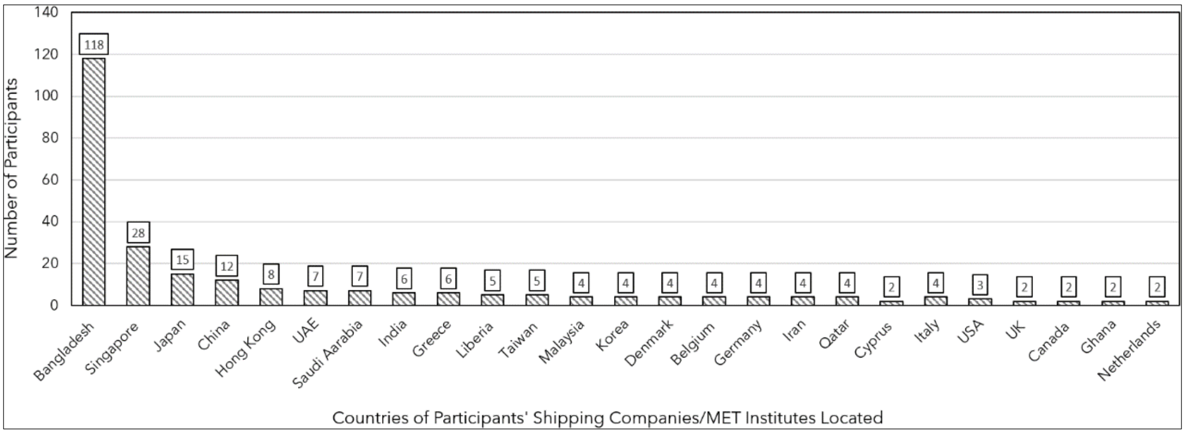


Figure 3. 4 - Countries of Participants' Shipping Companies/MET Institutes Located.

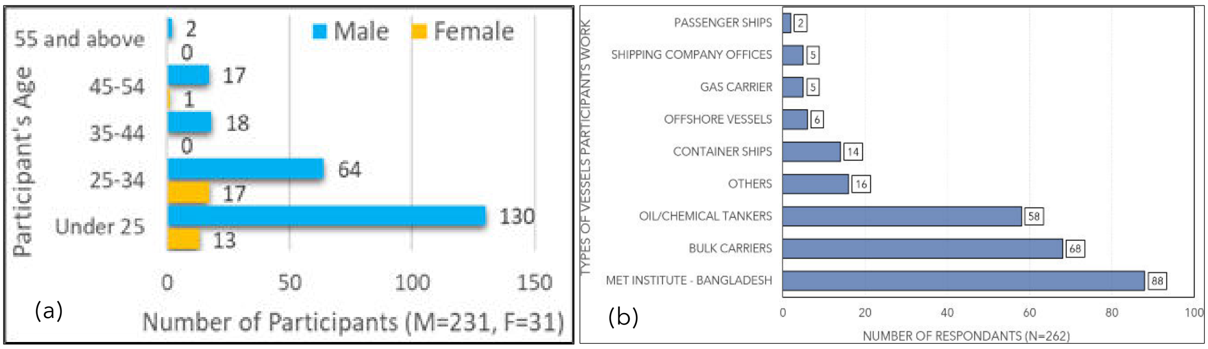


Figure 3. 5 - (a) Participants' Age; and (b) Types of Vessels Participants Work.

Participants represented onboard and ashore roles in shipping companies across 24 countries, including Bangladesh, Singapore, Japan, Greece, Liberia, and others (Figure 3.4). Figure 3.5(a) shows the age distribution, where 55% of participants were under 25, 31% were aged 25–34, 7% were in the 35–44 and 45–55 age groups, and 1% were above 55. Figure 3.5(b) highlights the diversity of vessel types operated, with most respondents working on tankers, bulk carriers, container ships, gas carriers, Ro-Ro ships, and offshore vessels.

3.5.3 Study for Assessing the Effectiveness of EEOS Training Programs

The study employed a comprehensive descriptive statistical analysis approach to evaluate seafarer training programs on EEOS by using four independent constructs: Knowledge, Understanding, Proficiency (KUP), and Satisfaction with tools SPSS version 26 and SmartPLS Ver. 3.2.9.

3.5.3.1 Designing of Online Survey Questionnaires

The study developed a comprehensive survey questionnaire based on primary data from the literature review. The survey was structured into four distinct parts:

1) Personal background information
2) Assessment of KUP and satisfaction with EEOS training courses
3) Evaluation of SEEMP implementation knowledge
4) Feedback on effective SEEMP implementation

The questionnaire was designed using Google Forms and included various question types such as single-answer, multiple-choice, and checkboxes. EEOS courses were rated on a 1-5 Likert-type scale based on respondents' KUP and satisfaction levels.

The online survey was distributed to seafarers and ship managers across various countries through email, social media, and other online platforms from February 7 to June 12, 2023. The survey's introduction provided a brief explanation of its objectives along with encouraging words to engage participants. During the four-month survey period, a total of 158 responses were collected from seafarers, with each participant allowed to respond only once. This methodology ensured a comprehensive approach to gathering data on seafarer training programs and SEEMP implementation, providing valuable insights into the effectiveness of current EEOS training practices.

3.5.3.2 Sampling Strategy and Participants' Profile

The study employed a purposive sampling strategy in Part 1 of the survey questionnaire, gathering information on participants' positions in shipping companies, years of experience, and organizational country. To mitigate potential non-response biases, the researchers utilized multiple communication channels to disseminate the survey link globally, reaching a diverse range of participants, including seafarers in various positions working in ships and also ship managers, surveyors, and maritime educators working ashore in shipping companies and various organizations.

The survey link was distributed to 38 shipping companies worldwide through email, instant messaging, and social media platforms. This approach ensured wide reach across different roles in the maritime industry. Out of 158 total responses received, 14 were excluded for not meeting the study criteria, resulting in 144 participants providing reliable and relevant data for analysis. The study presented participant profiles in Figures 3.6(a) and 3.6(b), illustrating the distribution of participants according to their positions and years of experience. This comprehensive sampling strategy enhanced the study's replicability and transparency, providing a robust foundation for analyzing seafarer training programs and SEEMP implementation.

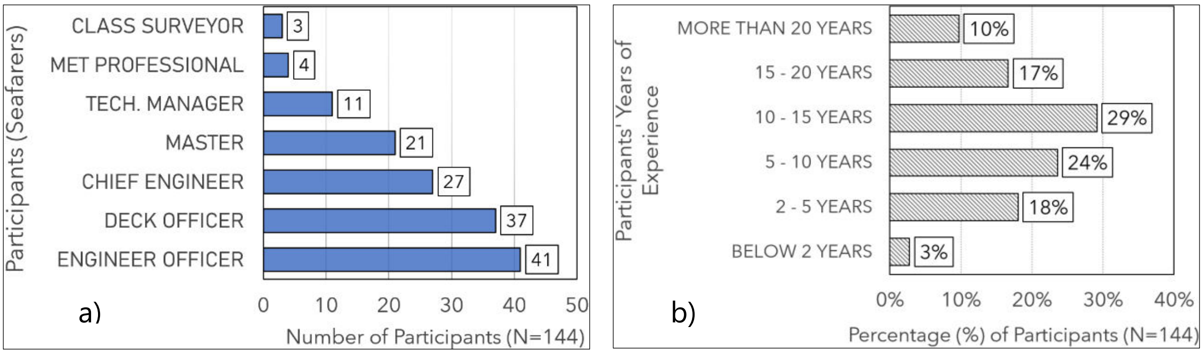


Figure 3. 6 - (a) Number of Participants According to Their Position in Shipping Companies; (b) Percentage (%) of Participants According to Years of Experience

3.5.3.3 Data Analysis for Seafarers' Training Programs/Activities on EEOS

Participants were asked the following questionnaires in Part 2 of the primary survey to assess their knowledge, understanding, proficiency, and satisfaction with all ten EEOS training programs or activities listed in Section 2.4 of the literature review:

1) Participants rated their knowledge level in executing SEEMP in ships ("Knowledge" coded as "1").
2) Participants rated their understanding level in executing SEEMP in ships ("Understanding" coded as "2").
3) Participants rated their knowledge level in executing SEEMP in ships ("Proficiency" coded as "3").
4) Participants expressed their level of satisfaction with the training programs, including learning outcomes and their relevance to SEEMP execution ("Satisfaction" coded as "4").

3.5.3.3.1 Conceptual Framework

The data analysis phase of this study, conducted using SmartPLS version 3.2.9, focuses on four pivotal elements: Knowledge, Understanding, Proficiency, and Satisfaction. To facilitate the analytical process, these components have been assigned numerical codes. Specifically, Knowledge=1, Understanding=2, Proficiency=3, and Satisfaction=4. This coding system allows for a systematic examination of these key factors, enabling a thorough exploration of their relationships and significance within the research context. The study explored the impact of four independent constructs, knowledge, understanding, proficiency, and satisfaction, highlighted in yellow in Figure 3.7, examined with different training types. These training types included:

1) IMO Training (IMOEL and IMOTTT)
2) Institutional Training (METIT and PSPST)
3) Shipping Company Training (OBT, CSBT, IHT, and CPTT)
4) Specialized Training (WMUP and MariEMSP)

The dependent construct in this research was the SEEMP, emphasizing the significance of these training types in achieving energy-efficient ship operations (Figure 3.7).

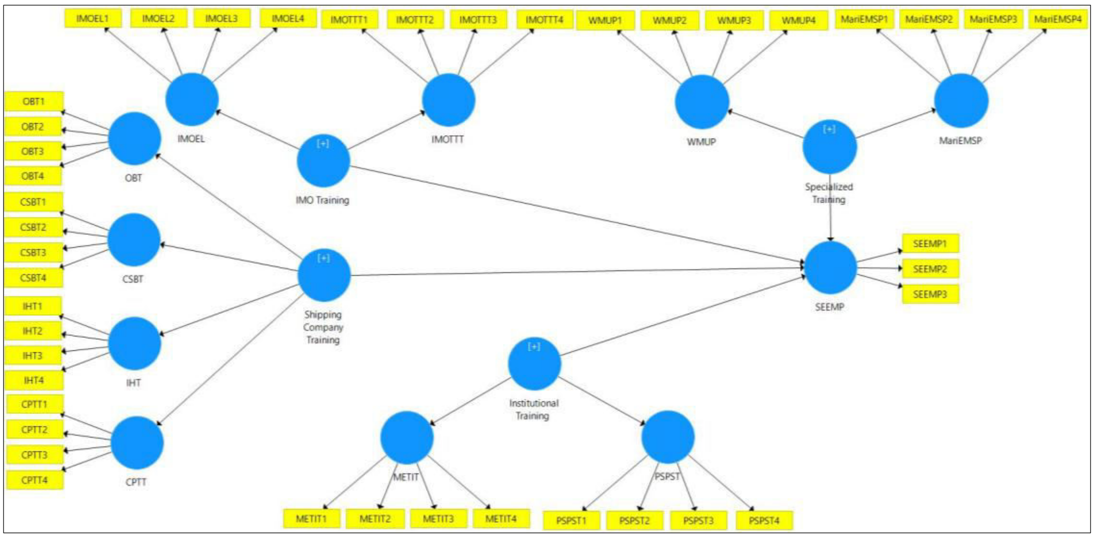


Figure 3. 7 - Conceptual Model (Source: SmartPLS 3.2.9)

3.5.3.3.2 Data Normality Assessment

The assessment of univariate normality for the latent constructs in this study was conducted by evaluating the skewness and kurtosis values of the collected data. According to Sposito et al. (1983), a skewness threshold of 3.3 is acceptable for normality. Table 3.1 provides a detailed summary of the descriptive statistics, including mean, standard deviation, skewness, and kurtosis values for each item. Most variables displayed skewness and kurtosis values within the acceptable range, confirming that the data closely followed a normal distribution. For instance, the skewness values ranged from -1.113 to 0.357, while the kurtosis values varied between -1.321 and 1.067. These findings validate the adequacy of the dataset for subsequent statistical analyses.

Table 3. 1 - Normality of Data

Items	Mean	SD	Kurtosis	Skewness
SEEMP1	3.188	0.858	-0.717	-0.240
SEEMP2	3.361	0.962	-0.920	0.165
SEEMP3	3.535	0.897	-0.172	-0.280
OBT1	3.201	1.011	0.014	-0.456
OBT2	3.410	0.908	0.476	-0.571
OBT3	3.451	0.919	0.476	-0.696
OBT4	3.569	0.998	0.202	-0.787
CSBT1	3.479	1.054	-0.272	-0.556
CSBT2	3.014	0.935	-0.423	0.127
CSBT3	3.569	0.879	1.067	-1.020
CSBT4	3.139	0.969	-0.780	-0.191
IHT1	3.431	0.796	0.936	-0.937
IHT2	3.493	0.898	0.034	-0.503
IHT3	3.306	0.915	-0.593	0.123
IHT4	3.653	0.776	-0.133	-0.387
METIT1	3.750	0.939	0.536	-0.699
METIT2	3.389	0.906	-0.937	-0.230
METIT3	3.444	0.806	-0.202	-0.501
METIT4	3.653	0.869	-0.094	-0.480
IMOEL1	3.549	1.079	-0.708	-0.328
IMOEL2	3.556	0.926	-0.327	-0.217
IMOEL3	3.708	0.857	0.458	-0.601
IMOEL4	3.375	0.942	0.311	-0.515
CPTT1	3.549	0.798	0.553	-0.575
CPTT2	3.583	0.854	0.107	-0.229
CPTT3	3.618	0.979	-0.229	-0.515
CPTT4	3.653	0.974	0.067	-0.574
PSPST1	3.764	1.208	0.357	-1.113
PSPST2	3.847	1.276	0.079	-1.086
PSPST3	3.972	1.280	0.915	-1.394
PSPST4	3.681	1.267	-0.147	-0.950
WMUP1	3.931	1.206	0.612	-1.211
WMUP2	3.792	1.258	0.223	-1.081
WMUP3	3.653	1.169	0.296	-1.034
WMUP4	2.931	1.295	-1.221	0.053
IMOTTT1	3.167	1.374	-1.255	-0.175
IMOTTT2	3.722	1.145	0.704	-1.119
IMOTTT3	3.153	1.174	-0.842	-0.041
IMOTTT4	2.944	1.373	-1.321	-0.062
MariEMSP1	2.764	1.338	-1.307	0.090
MariEMSP2	2.625	1.327	-1.073	0.357
MariEMSP3	2.750	1.233	-1.050	0.174
MariEMSP4	3.639	1.217	0.314	-1.146

(Source: SmartPLS 3.2.9)

3.5.3.3.3 Multivariate Normality

Multivariate normality was evaluated using Cook's Distance to identify influential data points and calculated using SPSS version 26. The analysis showed no cases with Cook's Distance exceeding 1, and most values were below 0.05, as illustrated in Figure 3.8. This indicates the absence of significant outliers or influential data points, confirming that the dataset adheres to multivariate normality assumptions. These results ensure the reliability of the data for SEM and other advanced statistical analyses.

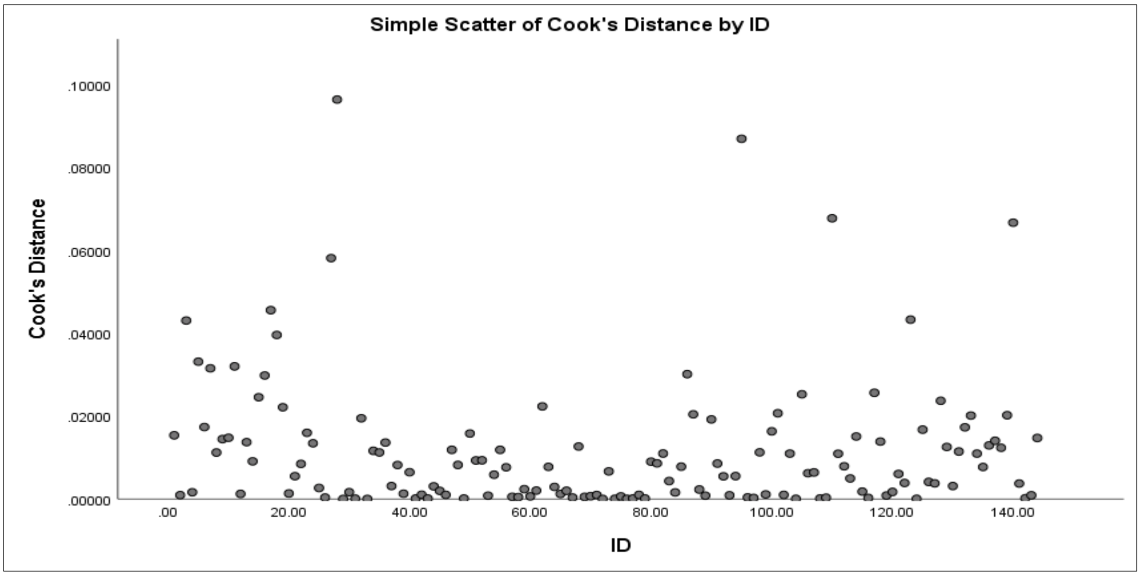


Figure 3. 8 - Multivariate Normality (Source: SPSS 26)

3.6 Research Outline

Day by day, the effect of ships' energy-efficient operation on seafarers increases with additional responsibilities, paperwork, and workload. Due to the changing EE regulations from one stage to another with more regulatory bindings, the researcher has reported a reasonable knowledge gap among maritime personnel working onboard ships and ashore offices (Banks et al., 2014; Dewan et al., 2018). This study aims to learn about engagement, challenges, knowledge level, and effective training of seafarers in energy-efficient ship operations. Therefore, to understand how the efficient operation of vessels affects seafarers, we need to focus on the following three elements as shown in Figure 3.9:

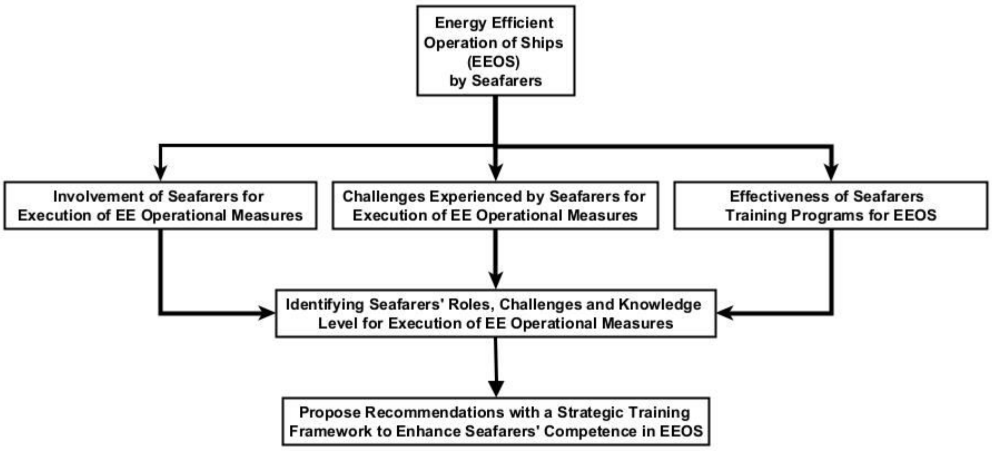


Figure 3. 9 - Flow Chart to Achieve Aimed Contributions

3.6.1 Involvement of Seafarers for Execution of EE Operational Measures

Various operational measures are essential for improving EE practices in maritime operations and reducing carbon emissions. While significant investments are required for innovative technologies and retrofit like propeller retrofit, shaft generator, air lubrication system on the hull, low loss hybrid system, modifying ship's bulbous bow, and installing wind and solar power systems in ships, there are also cost-effective measures that rely on the crew's involvement during ship operations. Deck officers primarily handle navigation and cargo-related tasks, while engineers manage machinery operations, monitoring, and maintenance of the ship's machinery and equipment. Technical and operation managers based on land oversee and manage the onboard crewmembers to ensure the safety and effectiveness of ship operations. Nevertheless, not every crew member participates directly in implementing these operational measures; their duties differ according to their respective areas of expertise and job positions. Identifying specific seafarers' participation in EE measures is vital. Through targeted training, knowledge enrichment, and increased awareness, this insight can shed light on their challenges.

3.6.2 Challenges Experienced by Seafarers for Execution of EE Operational Measures

As the maritime industry transforms, including the integration of new technologies, shorter port stays, and the establishment of ports in remote areas, seafarers face mounting challenges in their onboard duties (Oldenburg & Jensen, 2012). A number of factors, including these changes, greater workloads, smaller crews, and other developments, have contributed to the fading attraction of becoming a seafarer (Dimitrova & Blanpain, 2010). Organizational changes significantly impact on workers, particularly their daily routines, underscoring the importance of understanding these changes to fully comprehend the challenges of routine jobs governed by established policies and guidelines. Following increased regulatory requirements, the shipping industry provides substantial challenges and constraints for seafarers attempting to fulfill EE, carbon capture, and greenhouse gas emission standards. Organizational boundaries significantly influence the assessment of energy performance. Third-party ship management poses barriers to improving EE onboard, such as restricted crew information and training programs (Jafarzadeh & Utne, 2014; Poulsen & Sornn-Friese, 2015). The crew on board ships play a critical role in implementing EE operational measures during ship operations. However, they face difficulties since ship managers and shore organizations do not always provide clear instructions, which makes it difficult for companies to execute EE measures.

Utilizing specialized software tools or pre-approved forms is necessary to comply with the EU's MRV and IMO's DCS reporting standards. Failure to do so may result in fines and punishments (Adamowicz, 2022). The increasing workloads and heightened PSC inspections imposed by shipping companies exacerbate the accumulating pressure on seafarers.

3.6.3 Effectiveness of Seafarer's Training Programs for EEOS

Training programs enhance seafarers' awareness and knowledge to effectively implement EE operational measures (IMO, 2012). Shipping companies offer a range of in-house, institutional, and onboard training to shore-based technical managers and crew members, aiming to optimize SEEMP implementation across their fleets. Researchers have identified nine specific training programs or activities in the literature to improve seafarers' knowledge and skills in EE practices in shipping operations. These consist of training aboard led by technical management, the ship's master, and the chief engineer, along with computer-based training (CBT) on EEOS courses. Ship managers perform training sessions before crew members join, and maritime training institutions offer specialized courses (Dewan & Godina, 2024a). Additional programs include IMO's Train the Trainer (IMOTTT) workshops, EEOS E-Learning (IMOEL) courses, specific training by business project teams or retrofit suppliers, pre-sea and post-sea training with an energy management curriculum (PSPST), and simulator-based training (SBT) on EEOS (Baldauf et al., 2013; Dewan & Godina, 2023a; Jensen et al., 2018; Ölçer et al., 2017; Oliveira et al., 2016). Despite this, Banks et al. (2014) show that seafarers lack desire and awareness, with 74% showing interest in lowering ship CO_2 emissions. The efficacy of these training programs has not been thoroughly investigated. Identifying their effectiveness can help shipping companies train their crews and managers to implement EE operational measures efficiently.

3.6.4 Recommendation of a Strategic Training Framework for Energy-Efficient Ship Operations

The maritime industry needs to invest in comprehensive education and training initiatives to prepare for the IMO's revised net-zero emission target by 2050 (UNCTAD, 2023). With technological advancements revolutionizing the sector, seafarers must transition into digital operators proficient in digitalization, information technology (IT), and artificial intelligence (AI) to navigate the complexities of decarbonization. Digital tools enhance operational efficiency, aid in adopting alternative fuels, and contribute to achieving the 2050 net-zero emissions objective. DNV Maritime Forecast estimates that by 2050, 1.8 million seafarers will require decarbonization training to meet industry demands (DNV, 2023). Despite seafarers' existing knowledge of EE measures, challenges persist in implementing EE operational measures (Dewan et al., 2018). It underscores the importance of effective training programs tailored to seafarers to implement net-zero emissions by 2050 and enhance EE practices in shipping operations.

A strategic training framework has been developed by identifying individual seafarers' engagement, addressing challenges encountered during EEOS, and evaluating the efficacy of training programs. This framework will standardize training methods, operational procedures, and technical systems, allowing seamless integration into any shipping company or vessel type, thereby facilitating smoother and more EEOS for seafarers and shipping companies. The study is explained in Figure 3.10 with a mapped process to prepare a strategic training framework for seafarers.

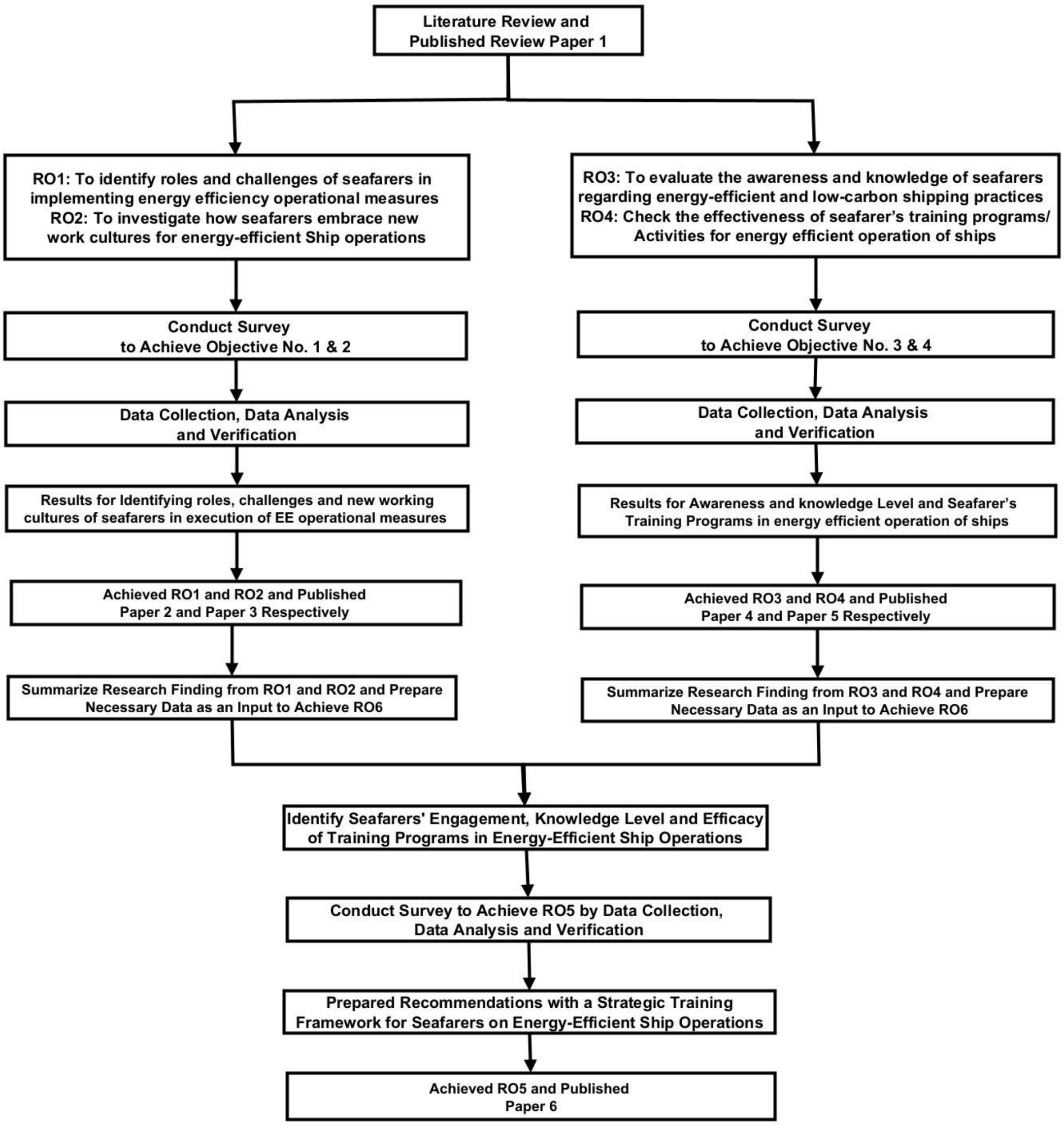


Figure 3. 10 - Mapping for Research Works to Prepare a Strategic Training Framework for Seafarers

3.7 Concluding Remarks

The overall research methodology utilized in this study has been outlined in this chapter, providing a comprehensive overview of our research endeavors. However, further elaboration on the research methodology can be found in each published paper, including details on software, tools, and data analysis techniques employed.

4
SUMMARY OF PUBLISHED PAPERS

In this section, the aims of each appended paper are outlined with existing research gaps, and the study findings are summarized concisely. There is a detailed explanation of the methodologies employed in all these studies in the section "Research Methodology" as well as in the individual papers.

4.1 Paper 2 - Roles and challenges of seafarers for implementation of energy efficiency operational measures onboard ships

This section consists of the summary of Paper 1, based on the study related to RQ1.

4.1.1 Study Aims

To achieve the IMO's emission reduction targets for shipping worldwide, this study will focus on seafarers' vital role in implementing EE operational measures. Although the IMO has established rules and regulations to boost EE, little is known regarding the unique difficulties mariners encounter when implementing SEEMP on board their vessels (Banks et al., 2014; Dewan et al., 2018). The intricacy of the sector, scarcity of resources, and differing political degrees will all make regulatory enforcement difficult (Bloor et al., 2015). Furthermore, crewmembers' active participation and skill development are crucial to the success of EE programs (Beşikçi et al., 2021). Attitudes toward environmental protection and compliance are impacted by cultural, professional, and economic disparities among seafarers (Abou-Elkawam, 2015). The efficacy of onboard programs like the SEEMP can be compromised due to a lack of crew engagement and training (Hansen et al., 2020).

Despite a decade of IMO enforcement of SEEMP, research remains scarce on the program's effectiveness and its impact on seafarers in operating energy-efficient ships. This study addresses this knowledge gap by clarifying the roles and responsibilities of maritime personnel onboard and in shore-based offices in achieving emission targets and overcoming the challenges of SEEMP implementation. Focusing on specific insights from collected data, the research highlights the key issues mariners face in enhancing EE in ship operations. Furthermore, by discussing the difficulties of implementing EE measures in the shipping industry in the face of rising regulatory demands, the study adds to the larger body of literature on the topic of seafarer health and wellbeing.

4.1.2 Results and Discussion

104 individuals working in the maritime industry responded to the online survey, including chief engineers (35), ship masters (23), ship managers (23), second engineers (5), chief officers (2), second officers (6), and third engineers (4). chief engineers, commonly responsible for SEEMP-related tasks, constituted the largest respondent group. Responses were gathered from onboard vessel employees and shipping company personnel across 24 countries globally. There were 22% of respondents who were ashore managers, 30% who were masters and deck officers, and 48% who were chief engineers and other engineers.

4.1.2.1 Engagement of Seafarers in Implementing EE Operational Measures in Ships

The implementation of EE operational measures in the shipping industry involves a collaborative effort between onboard ship crews and ashore ship managers. The study identified 15 operational "Low-Hanging-Fruit" measures that are cost-effective and easily implementable within shipping companies, forming an integral part of the SEEMP. As illustrated in Figure 4.1(a), the execution of these measures varies significantly among crew members based on their specific roles. Masters and deck crews are primarily responsible for navigation, cargo, deck, and port-related measures, including voyage execution, crew training, speed optimization, weather routing, and trim optimization. On the other hand, chief engineers and engine crews focus on propulsion and power-generating machinery operations, monitoring auxiliary and main engines, ship power, waste heat recovery, and performance optimization (Figure 4.1(b)).

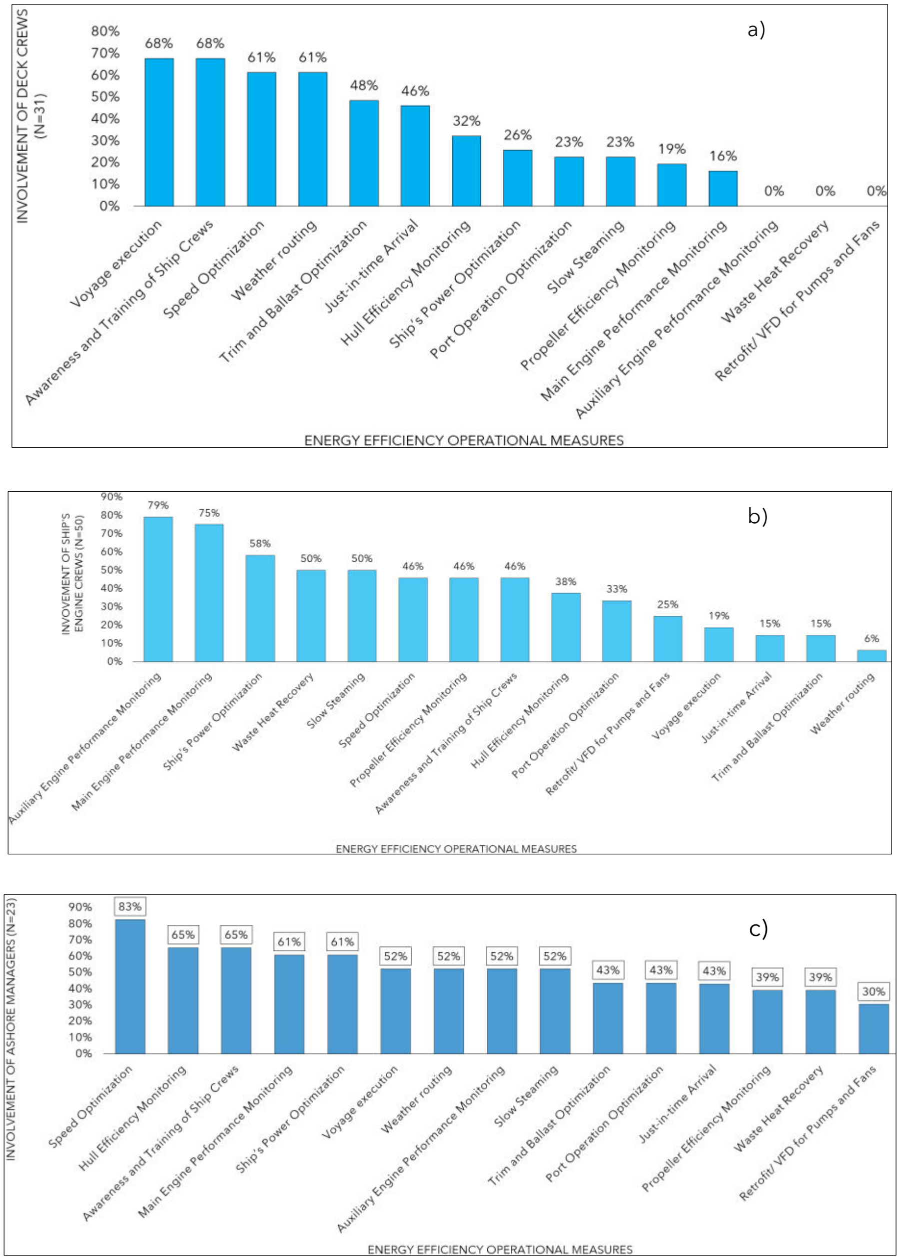


Figure 4. 1 - (a) Execution of EE Measures by Ship's Master & Deck Crews; (b) Execution of EE Measures by Ship's Chief Engr & Engine Crews; (c) Involvement of Ashore Ship Managers (Source: Paper 2)

Ashore ship managers, particularly technical and marine superintendents, play a crucial role in overseeing and supporting the implementation of EE measures. Figure 4.1(c) shows that they supervise masters and chief engineers in implementing various measures such as speed optimization, hull efficiency monitoring, crew training, ship power optimization, and engine performance monitoring. Figure 4.2 demonstrates that ashore managers are involved in a wide range of environmental initiatives, directly and indirectly, impacting operations onboard ships and across the fleet. This integrated approach ensures a comprehensive strategy for EE, combining the practical expertise of shipboard personnel with the strategic coordination of shore-based management, highlighting the maritime industry's commitment to improving operational efficiency and reducing environmental impact.

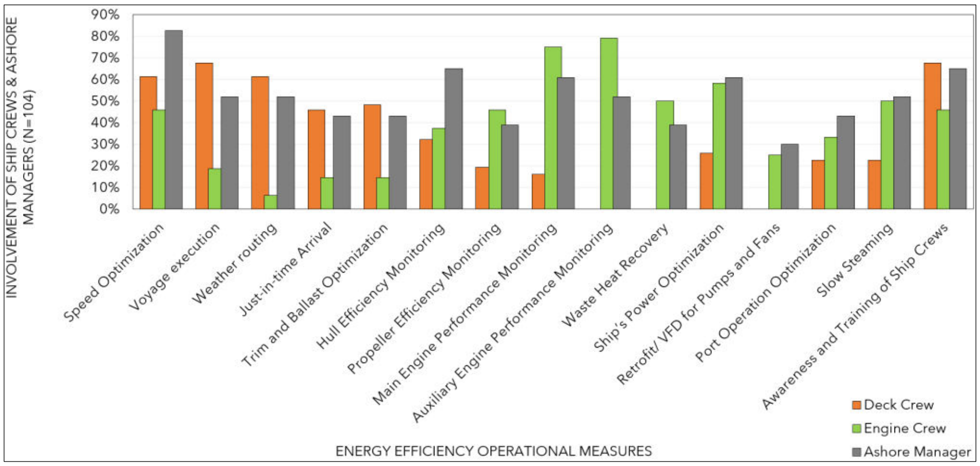


Figure 4. 2 - Involvement of Ship Crews and Ashore Managers (Source: Paper 2)

4.1.2.2 Seafarers Involvement in Implementing EE Measures (Comparison of Difference Between Groups Based on ANOVA Testing)

Energy efficiency operational measures in maritime operations can be categorized into four main groups: Engine Efficiency, Crew Performance, Port and Routing Efficiency, and Retrofit and Monitoring (Table 4.1).

1) Engine Efficiency encompasses operational measures such as main and auxiliary engine performance monitoring, ship's power optimization, and waste heat recovery.
2) Crew Performance includes awareness and training of ship crews, speed optimization, and voyage execution.
3) Port and Routing Efficiency covers operational measures just-in-time arrival, port operation optimization, weather routing, and trim and ballast optimization.
4) Retrofit and Monitoring includes hull efficiency monitoring, retrofit/VFD for pumps and fans, slow steaming, and propeller efficiency monitoring.

These measures are implemented by crew members onboard ships and ship managers in shore offices. This research investigates the efficacy of these EE measures across three key groups: Deck Crew, Engine Crew, and Ashore Managers, as shown in Table 4.1. These measures are crucial in optimizing ship operations, enhancing EE, and reducing CO_2 and other GHG emissions. The effectiveness of these measures may differ across operational roles due to variations in responsibilities, technical expertise, and training. The study employs a one-way Analysis of Variance (ANOVA) to quantify and identify these differences. This statistical method allows for comparing mean performance levels across groups, determining whether observed variations are statistically significant or due to chance. By grouping the measures into broader themes, this study aims to comprehensively understand performance disparities and identify areas for targeted improvement. The findings from this analysis will provide valuable insights for optimizing EE strategies and enhancing operational effectiveness in maritime operations.

Table 4. 1 - Involvement of Deck Crew, Engine Crew, and Ashore Manager for Execution of EE Measures

Energy Efficiency Operational Measures	Deck Crew	Engine Crew	Ashore Manager	Category
8 - Main Engine Performance Monitoring	16.129%	75.000%	61.000%	Engine Efficiency (1)
9 - Auxiliary Engine Performance Monitoring	0.000%	79.167%	52.000%	
11 - Ship's Power Optimization	25.806%	58.333%	61.000%	
10 - Waste Heat Recovery	0.000%	50.000%	39.000%	
15 - Awareness and Training of Ship Crews	67.742%	45.833%	65.000%	Crew Performance (2)
1 - Speed Optimization	61.290%	45.833%	82.609%	
2 - Voyage execution	67.742%	18.750%	52.000%	
4 - Just-in-time Arrival	46.000%	14.583%	43.000%	Port and Routing Efficiency (3)
13 - Port Operation Optimization	22.581%	33.333%	43.000%	
3 - Weather routing	61.290%	6.250%	52.000%	
5 - Trim and Ballast Optimization	48.387%	14.583%	43.000%	
6 - Hull Efficiency Monitoring	32.258%	37.500%	65.000%	Retrofit and Monitoring (4)
12 - Retrofit/ VFD for Pumps and Fans	0.000%	25.000%	30.000%	
14 - Slow Steaming	22.581%	50.000%	52.000%	
7 - Propeller Efficiency Monitoring	19.355%	45.833%	39.000%	

Table 4.2 provides an overview of the EE operational measures across three categories (Deck Crew, Engine Crew, and Ashore Manager). For Deck Crew, the mean percentage of effectiveness is highest for Crew Performance (65.59%) with low variability (SD = 3.72%), while Engine Efficiency has the lowest mean (10.48%) and the highest variability (SD = 12.73%). Engine Crew shows the highest mean for Engine Efficiency (65.63%, SD = 13.77%), while Port and Routing Efficiency has the lowest mean (17.19%, SD = 11.46%). For the Ashore Manager, Crew Performance has the highest mean (66.54%, SD = 15.36%), and Engine Efficiency shows a relatively high mean (53.25%,

SD = 10.40%). Across all groups, Ashore Managers demonstrate the highest overall mean effectiveness (51.97%, SD = 13.37%), followed by Engine Crew (40.00%, SD = 21.64%) and Deck Crew (32.74%, SD = 24.53%). This suggests that different categories prioritize and perform differently across operational measures, with Ashore Managers generally achieving higher overall percentages.

Table 4.3 presents the one-way ANOVA analysis, which reveals significant differences in EE measures among groups for the Deck Crew and Engine Crew, while no significant differences are observed for the Ashore Manager. For the Deck Crew, the between-group variability (Sum of Squares = 6583.87, Mean Square = 2194.62) is considerably higher than the within-group variability (Mean Square = 167.53). This results in an F-value of 13.10 and a p-value of 0.001, indicating statistically significant differences across the groups. The high F-value underscores that these differences are unlikely due to random chances and suggests considerable variability in how Deck Crew members approach or perform across the various EE measures. For the Engine Crew, the results similarly indicate significant differences across groups. The between-group variability (Sum of Squares = 4739.51, Mean Square = 1579.84) is larger than the within-group variability (Mean Square = 165.10), yielding an F-value of 9.57 and a p-value of 0.002. Although the differences are statistically significant, the F-value is lower than that for the Deck Crew, suggesting that the variability between groups is slightly less pronounced within the Engine Crew. In contrast, the Ashore Manager group does not exhibit significant differences across EE measures. The between-group variability (Sum of Squares = 943.40, Mean Square = 314.47) is relatively small, and the resulting F-value of 2.22 with a p-value of 0.143 indicates no statistically significant differences. This suggests that Ashore Managers perform consistently across the different EE measures, potentially due to uniform policies or standardized approaches within this group. Overall, the results highlight significant differences in performance across the Deck Crew and Engine Crew groups, suggesting that these teams may require targeted interventions or specialized training to address the variability. Conversely, the consistency observed among Ashore Managers suggests effective standardization or uniformity in their approach to EE measures. These findings provide valuable insights for tailoring EE strategies across different operational roles.

Moreover, Table 4.4 presents pairwise comparisons from the post hoc tests that reveal significant differences in performance across categories for Deck Crew and Engine Crew, while Ashore Managers show consistent performance across measures. For Deck Crew, Engine Efficiency significantly underperforms compared to Crew Performance (-55.11%, p = 0.001) and Port and Routing Efficiency (-34.08%, p = 0.015), highlighting a clear gap in this area. Engine Crew also shows significant differences, with Engine Efficiency outperforming Port and Routing Efficiency (48.44%, p = 0.001), though differences with other categories approach significance. In contrast, Ashore Managers exhibit no significant differences between any categories, indicating uniform performance across operational measures. These results suggest that Deck Crew and Engine Crew require targeted interventions to address specific inefficiencies, while Ashore Managers benefit from consistent, standardized practices.

The mean plot (Figure 4.3) illustrates the differences across categories and groups, emphasizing the pronounced variability in Deck Crew and Engine Crew groups compared to the consistent performance of Ashore Managers.

In conclusion, the findings reveal significant variability in performance among the Deck Crew and Engine Crew, highlighting the need for targeted, role-specific interventions. This could include additional training or allocating resources to address underperforming areas, such as Engine Efficiency within the Deck Crew group. In contrast, the consistent performance observed among Ashore Managers suggests the effective implementation of standardized measures. This consistency positions Ashore Managers as a potential benchmark for developing and refining EE strategies applicable to other operational groups.

Table 4. 2 - Descriptives

Descriptives	Category	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean Lower Bound	95% Confidence Interval for Mean Upper Bound	Minimum	Maximum
Deck Crew	Engine Efficiency	4	10.48%	12.73%	6.37%	-9.78%	30.75%	0.00%	25.81%
	Crew Performance	3	65.59%	3.72%	2.15%	56.34%	74.84%	61.29%	67.74%
	Port and Routing Efficiency	4	44.56%	16.12%	8.06%	18.91%	70.22%	22.58%	61.29%
	Retrofit and Monitoring	4	18.55%	13.53%	6.76%	-2.98%	40.07%	0.00%	32.26%
	Total	15	32.74%	24.53%	6.33%	19.16%	46.33%	0.00%	67.74%
Engine Crew	Engine Efficiency	4	65.63%	13.77%	6.88%	43.72%	87.53%	50.00%	79.17%
	Crew Performance	3	36.81%	15.64%	9.03%	-2.04%	75.65%	18.75%	45.83%
	Port and Routing Efficiency	4	17.19%	11.46%	5.73%	-1.05%	35.42%	6.25%	33.33%
	Retrofit and Monitoring	4	39.58%	11.02%	5.51%	22.04%	57.12%	25.00%	50.00%
	Total	15	40.00%	21.64%	5.59%	28.02%	51.98%	6.25%	79.17%
Ashore Manager	Engine Efficiency	4	53.25%	10.40%	5.20%	36.69%	69.81%	39.00%	61.00%
	Crew Performance	3	66.54%	15.36%	8.87%	28.37%	104.70%	52.00%	82.61%
	Port and Routing Efficiency	4	45.25%	4.50%	2.25%	38.09%	52.41%	43.00%	52.00%
	Retrofit and Monitoring	4	46.50%	15.29%	7.64%	22.18%	70.82%	30.00%	65.00%
	Total	15	51.97%	13.37%	3.45%	44.57%	59.38%	30.00%	82.61%

Table 4. 3 - One Way ANOVA Between Groups

Constructs	Groups	Sum of Squares	df	Mean Square	F	Sig.
Deck Crew	Between Groups	6583.87	3	2194.62	13.10	0.001
	Within Groups	1842.85	11	167.53		
	Total	8426.71	14			
Engine Crew	Between Groups	4739.51	3	1579.84	9.57	0.002
	Within Groups	1816.05	11	165.10		
	Total	6555.56	14			
Ashore Manager	Between Groups	943.40	3	314.47	2.22	0.143
	Within Groups	1558.49	11	141.68		
	Total	2501.88	14			

Table 4. 4 - Multiple Comparisons (Tukey HSD)

Dependent Variable	(I) Category	(J) Category	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
Deck Crew	Engine Efficiency	Crew Performance	-55.10753%*	9.89%	0.001	-84.86%	-25.36%
		Port and Routing Efficiency	-34.08065%*	9.15%	0.015	-61.63%	-6.54%
		Retrofit and Monitoring	-8.06%	9.15%	0.815	-35.61%	19.48%
	Crew Performance	Engine Efficiency	55.10753%*	9.89%	0.001	25.36%	84.86%
		Port and Routing Efficiency	21.03%	9.89%	0.204	-8.72%	50.78%
		Retrofit and Monitoring	47.04301%*	9.89%	0.003	17.29%	76.79%
	Port and Routing Efficiency	Engine Efficiency	34.08065%*	9.15%	0.015	6.54%	61.63%
		Crew Performance	-21.03%	9.89%	0.204	-50.78%	8.72%
		Retrofit and Monitoring	26.02%	9.15%	0.066	-1.53%	53.56%
	Retrofit and Monitoring	Engine Efficiency	8.06%	9.15%	0.815	-19.48%	35.61%
		Crew Performance	-47.04301%*	9.89%	0.003	-76.79%	-17.29%
		Port and Routing Efficiency	-26.02%	9.15%	0.066	-53.56%	1.53%
Engine Crew	Engine Efficiency	Crew Performance	28.82%	9.81%	0.056	-0.71%	58.35%
		Port and Routing Efficiency	48.43750%*	9.09%	0.001	21.09%	75.78%
		Retrofit and Monitoring	26.04%	9.09%	0.063	-1.30%	53.39%
	Crew Performance	Engine Efficiency	-28.82%	9.81%	0.056	-58.35%	0.71%
		Port and Routing Efficiency	19.62%	9.81%	0.246	-9.92%	49.15%
		Retrofit and Monitoring	-2.78%	9.81%	0.992	-32.31%	26.76%
	Port and Routing Efficiency	Engine Efficiency	-48.43750%*	9.09%	0.001	-75.78%	-21.09%
		Crew Performance	-19.62%	9.81%	0.246	-49.15%	9.92%
		Retrofit and Monitoring	-22.40%	9.09%	0.121	-49.74%	4.95%
	Retrofit and Monitoring	Engine Efficiency	-26.04%	9.09%	0.063	-53.39%	1.30%
		Crew Performance	2.78%	9.81%	0.992	-26.76%	32.31%
		Port and Routing Efficiency	22.40%	9.09%	0.121	-4.95%	49.74%
Ashore Manager	Engine Efficiency	Crew Performance	-13.29%	9.09%	0.490	-40.65%	14.07%
		Port and Routing Efficiency	8.00%	8.42%	0.779	-17.33%	33.33%
		Retrofit and Monitoring	6.75%	8.42%	0.852	-18.58%	32.08%
	Crew Performance	Engine Efficiency	13.29%	9.09%	0.490	-14.07%	40.65%
		Port and Routing Efficiency	21.29%	9.09%	0.147	-6.07%	48.65%
		Retrofit and Monitoring	20.04%	9.09%	0.182	-7.32%	47.40%
	Port and Routing Efficiency	Engine Efficiency	-8.00%	8.42%	0.779	-33.33%	17.33%
		Crew Performance	-21.29%	9.09%	0.147	-48.65%	6.07%
		Retrofit and Monitoring	-1.25%	8.42%	0.999	-26.58%	24.08%
	Retrofit and Monitoring	Engine Efficiency	-6.75%	8.42%	0.852	-32.08%	18.58%
		Crew Performance	-20.04%	9.09%	0.182	-47.40%	7.32%
		Port and Routing Efficiency	1.25%	8.42%	0.999	-24.08%	26.58%

* The mean difference is significant at the 0.05 level.

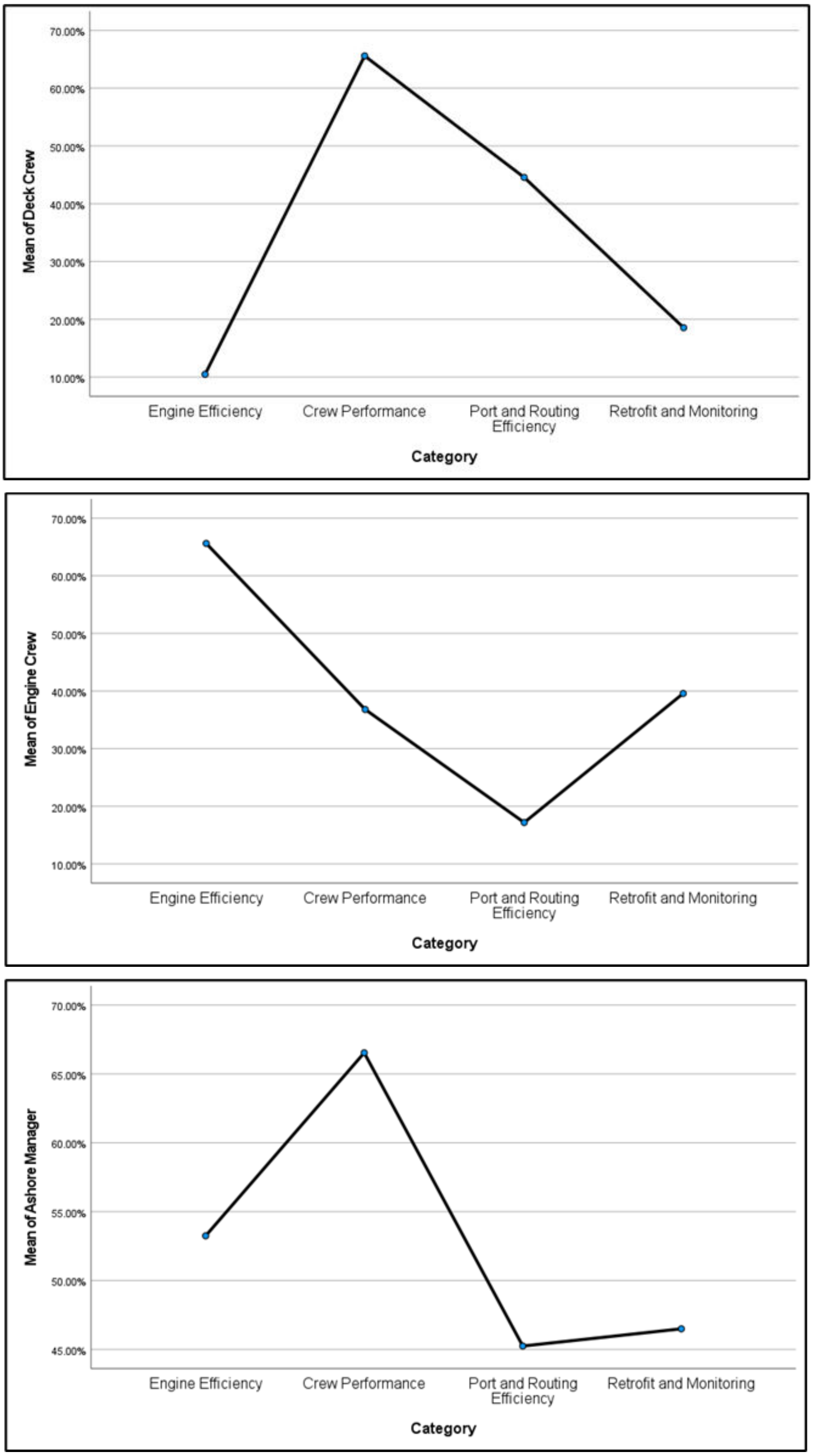


Figure 4. 3 - Differences Via Mean Plot

4.1.2.3 Seafarers' Challenges for Executing SEEMP Measures Onboard Ships

The survey investigated the difficulties encountered in implementing SEEMP procedures on maritime vessels, encompassing both land-based and on-board seafarers. Figure 4.4 illustrates a comprehensive analysis of the challenges, including increased paperwork, more workload, additional inspections by the Port State Control (PSC) or third parties, more planned maintenance tasks, technical complexities, changes in traditional work practices, additional training on board or at home, extended working hours, and the need to work outside regular hours. Both seafarers and ship managers encountered these challenges.

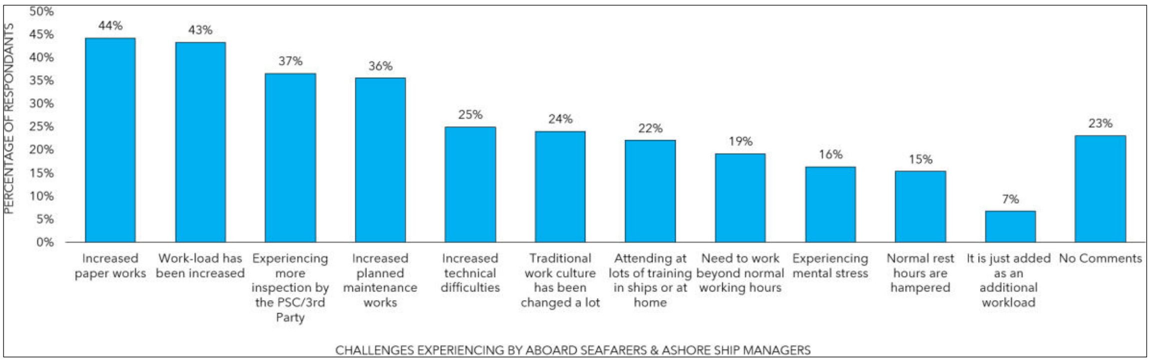


Figure 4. 4 - Challenges faced by Seafarers Aboard Ships and Ashore Ship Managers (Source: Paper 2)

4.1.2.4 Rewards Received by Seafarers for effective implementation of SEEMP Onboard Ships

A study was conducted to determine whether seafarers received recognition and financial incentives for adopting SEEMP onboard ships. The shipping industry was asked this question despite the economic and environmental benefits of implementing energy efficiency measures. 79% of respondents met the organization's goals but did not receive rewards, according to Figure 4.5. Merely 8% of participants received financial incentives, 6% were granted yearly bonuses, and the company acknowledged 4%.

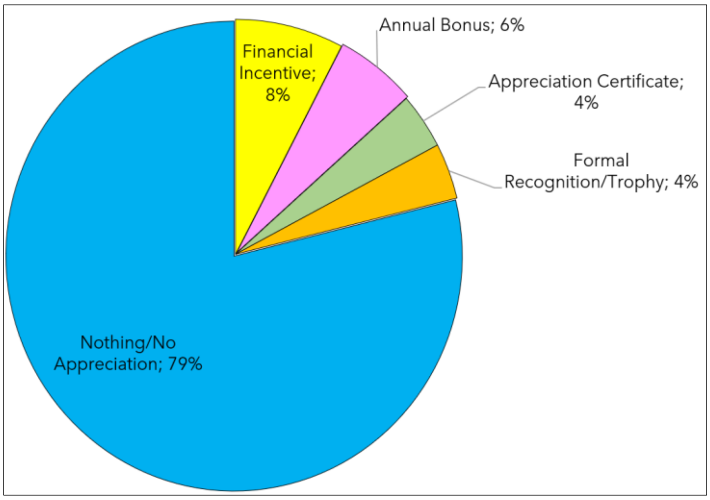


Figure 4. 5 - Appreciation or Awards Received by Seafarers for Successful Execution of SEEMP in Ships (Source: Paper 2)

4.1.3 Concluding Remarks

The study highlights seafarers' active engagement in EE practices onboard ships, with different responsibilities divided among crew members. However, challenges such as increased workload, paperwork, and technical difficulties hinder effective implementation. These stressors and regulatory demands may negatively impact seafarers' mental health. Fatigue, stemming from long hours and disrupted sleep patterns, poses risks to well-being and environmental safety, emphasizing the need for support and mitigation strategies.

4.2 Paper 3 - Sailing Towards Sustainability: How Seafarers Embrace New Work Cultures for Energy-Efficient Ship Operations in Maritime Industry

This section consists of the summary of Paper 3, based on the study related to RQ1.

4.2.1 Study Aims

Over the past decade, international ship operations have shown a 33% increase in EE, signifying significant progress in adopting EE measures (Faber et al., 2020). However, despite advancements, challenges persist in implementing EE practices onboard ships. Numerous studies have addressed technological advancements, economic viability, and environmental benefits of EE measures, yet gaps remain regarding the impact on seafarers' working cultures and the role of incentives (Acciaro et al., 2013; Dewan et al., 2018; Johnson & Andersson, 2016; Rehmatulla & Smith, 2015). It is recognized that operational EE measures have economic benefits (Eide et al., 2011; Hoffmann et al., 2012; IMO, 2009b). However, seafarers need to cope with increased workloads and technical complexities, which affect their ability to implement EE measures (Dewan & Godina, 2023b). Integrating Industry 4.0 technologies offers solutions by optimizing operational procedures, reducing errors, and enhancing decision-making processes (Zhu et al., 2023). Despite this, little research has been done on how these changes affect the traditional working culture of seafarers (Dewan & Godina, 2023b). This study explores newly adopted working cultures among seafarers to bridge this gap and understand the influence of financial incentives or rewards on EE practices. By addressing these aspects, the research strives to advance sustainable practices in the maritime sector and enhance EE implementation aboard ships.

4.2.2 Study Findings and Discussion

This section emphasized our main study findings and discussed their significance in the maritime industry.

4.2.2.1 Implementation of Operational EE Measures by Seafarers Onboard Ships

As shown in Figure 4.6, the study identified various cost-effective operational EE measures commonly integrated into SEEMP across diverse shipping companies. These measures, including voyage planning, weather routing, trim optimization, hull and propeller monitoring, engine performance optimization, and crew training, were reported to be widely implemented onboard ships. Respondents highlighted optimizing speed, monitoring engine performance, training crew members, and optimizing power as the most frequently adopted measures. Other measures like adaptive autopilot, hull efficiency monitoring, waste heat recovery, trim and ballast optimization, optimization of port operation, just-in-time arrival, retrofit/VFD for pumps and fans and similar operational measures implemented by installing retrofits were also prevalent. The findings emphasize the importance of these measures in enhancing EE practices onboard ships and contribute valuable insights into SEEMP implementation.

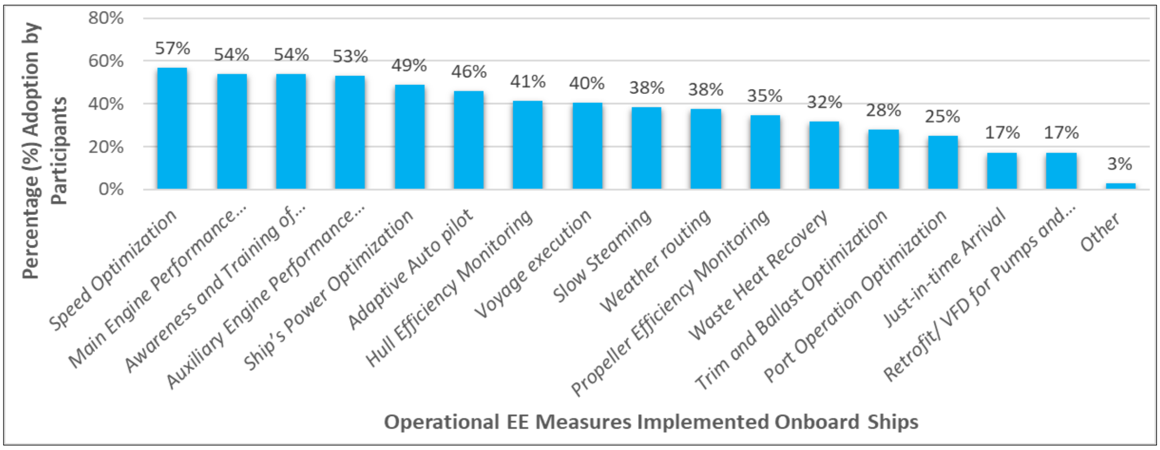
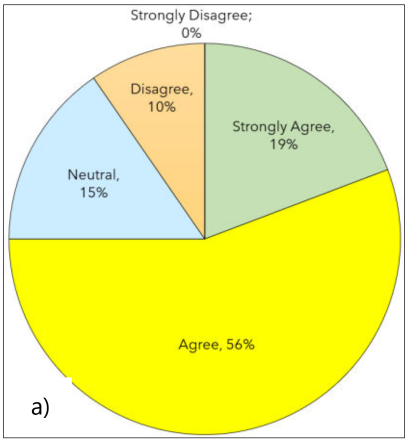


Figure 4. 6 - Operational Energy Efficiency Measures Implemented in Ships by Seafarers (Source: Paper 3)

4.2.2.2 Identifying Adaption of Working Culture of Seafarers for Implementation of SEEMP Onboard Ships

As depicted in Figure 4.7(a), a significant portion of seafarers, comprising 19% who strongly agreed and 56% who agreed, acknowledged the impact of EEOS on traditional working cultures over the past decade. Conversely, only 10% expressed disagreement, with none strongly disagreeing. Additionally, 15% maintained a neutral stance on the matter. Figure 4.7(b) highlights the adoption of various EE practices and cultures by seafarers, including meticulous fuel consumption data recording (98%), adherence to the Planned Maintenance System (PMS)

(88%), and readiness for PSC inspections (84%). Other notable practices include SEEMP-guided energy-saving operational measures, engine maintenance, and prompt actions to save energy and fuels. Few seafarers provided additional comments on these working cultures.



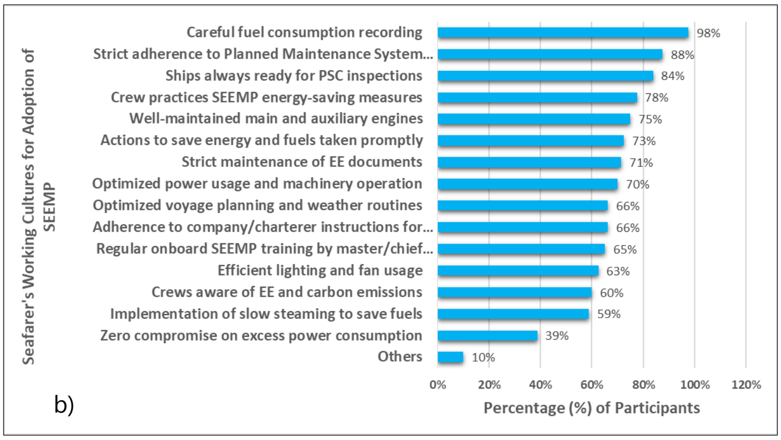


Figure 4. 7 - (a): Seafarers' Opinion on Adoption of New Working Culture; (b): Adopted New Practices and Work Cultures by Seafarers for EEOS (Source: Paper 3)

4.2.3 Concluding Remarks

Seafarers are essential frontline figures in the maritime realm, grappling with stringent regulations, cargo demands, and the imperative of safe, eco-friendly ship operations. Despite the challenges posed by heavy workloads and adherence to the Maritime Labor Convention (MLC), 2006 guidelines, seafarers diligently implement operational EE measures onboard ships. Our findings underscore a significant shift in work cultures, with 75% acknowledging the transformative impact of EEOS. However, the lack of recognition or financial incentives highlights a pressing need for policymakers to prioritize seafarers' well-being and integrate Industry 4.0 technologies to alleviate their burdens and enhance compliance with EE regulations.

4.3 Paper 4 - Unveiling Seafarers' Awareness and Knowledge of Energy-Efficient and Low-Carbon Shipping: A Decade of IMO Regulation Enforcement

This section consists of the summary of Paper 4, based on the study related to RQ2.

4.3.1 Study Aims

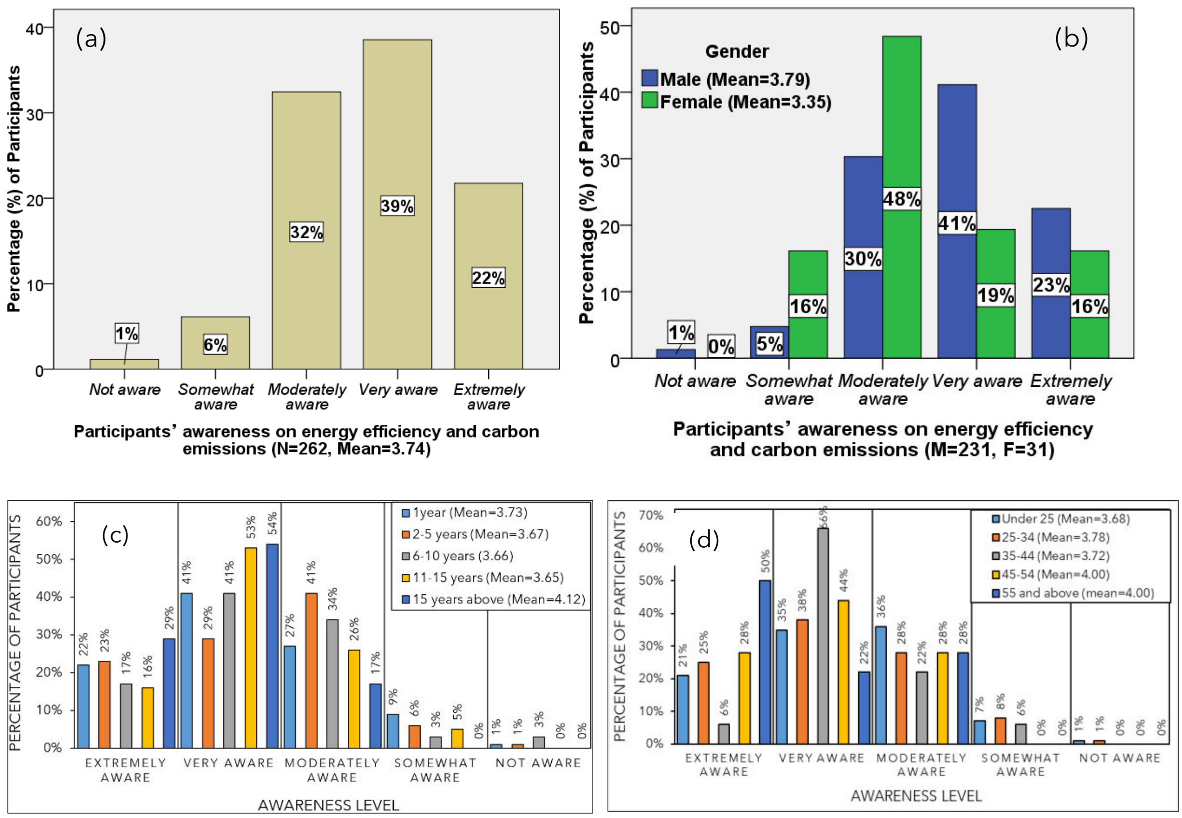
Several studies have identified cost-effective operational measures to enhance EE of vessels over the past two decades (Bännstrand et al., 2016; DNV GL, 2014; Faber et al., 2011). Although DNV GL, (2015) identified reluctance to change and low levels of education as major barriers, Dewan et al., (2018) and Jafarzadeh & Utne, (2014) identified operational difficulties and information gaps as barriers. The significance of educating ship personnel and onshore technical managers has been underscored by recent research (DNV GL, 2015; Kitada & Ölçer, 2015; Viktorelius & Lundh, 2019). Hansen et al. (2020) discovered that insufficient training and crew participation can impede the SEEMP's efficacy in upholding ship safety and minimizing environmental effects. Despite these insights, there remains a considerable knowledge gap among maritime stakeholders, particularly onboard crews (Dewan et al., 2018). Furthermore, unclear guidance from onshore technical managers impedes seafarers' ability to implement EE practices effectively. It is necessary for seafarers to have knowledge and comprehension of maritime EE legislation, as well as technical and operational EE measures, to implement SEEMP on board vessels successfully. To address this research gap, this study assesses seafarers' knowledge, motivation, and cognizance regarding EEOS after IMO regulations. By examining seafarers' viewpoints, this study aims to offer significant contributions to the body of knowledge regarding the rewards and obstacles that arise during operational EE practices on board vessels. Moreover, the results' implications offer policymakers recommendations on enhancing EE practices within the maritime industry. Evaluating ship crews' and ship managers' awareness and understanding of pertinent regulations and standards achieves this goal. In addition, the research aims to identify potential avenues for improving human engagement and advancing green shipping by employing and extending EEOS.

4.3.2 Study Findings and Discussion

In order to effectively implement such practices onboard ships, seafarers must be aware of and understand maritime EE regulations, technical measures, and carbon emissions (Banks et al., 2014; Dewan & Godina, 2023a; Kitada & Ölçer, 2015). The importance of crew awareness, knowledge, motivation, and participation in EEOS was emphasized by Bertram et al. (1983). While technical advancements have streamlined operational practices, seafarers' understanding remains indispensable during real-time decision-making (Balcombe et al., 2019; Beşikçi et al., 2021; Rehmatulla et al., 2017).

4.3.2.1 Seafarers' General awareness and knowledge of CO_2 emissions

Our study underscores seafarers' varying levels of awareness regarding CO_2 and greenhouse gas emissions, with 22% demonstrating extreme awareness, 39% very aware, and 32% moderately aware (Figure 4.8(a). Notably, male seafarers exhibit higher awareness levels than their female counterparts (Figure 4.8(b)). Experience and age significantly influence awareness, with seafarers having 15 years or more experience showing the highest levels (Figure 4.8(c) and (d)). Similarly, According to Figure 4.8(e), knowledge levels vary across age groups and maritime positions, emphasizing the necessity of tailored training programs.



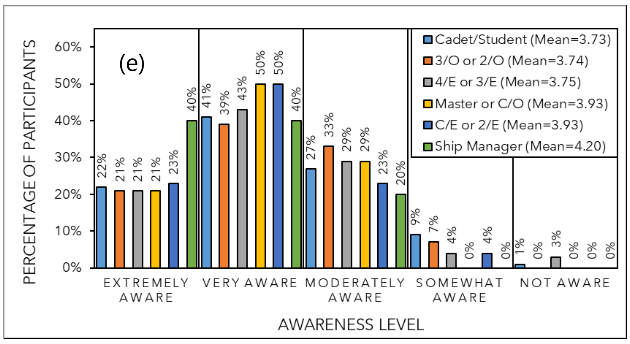
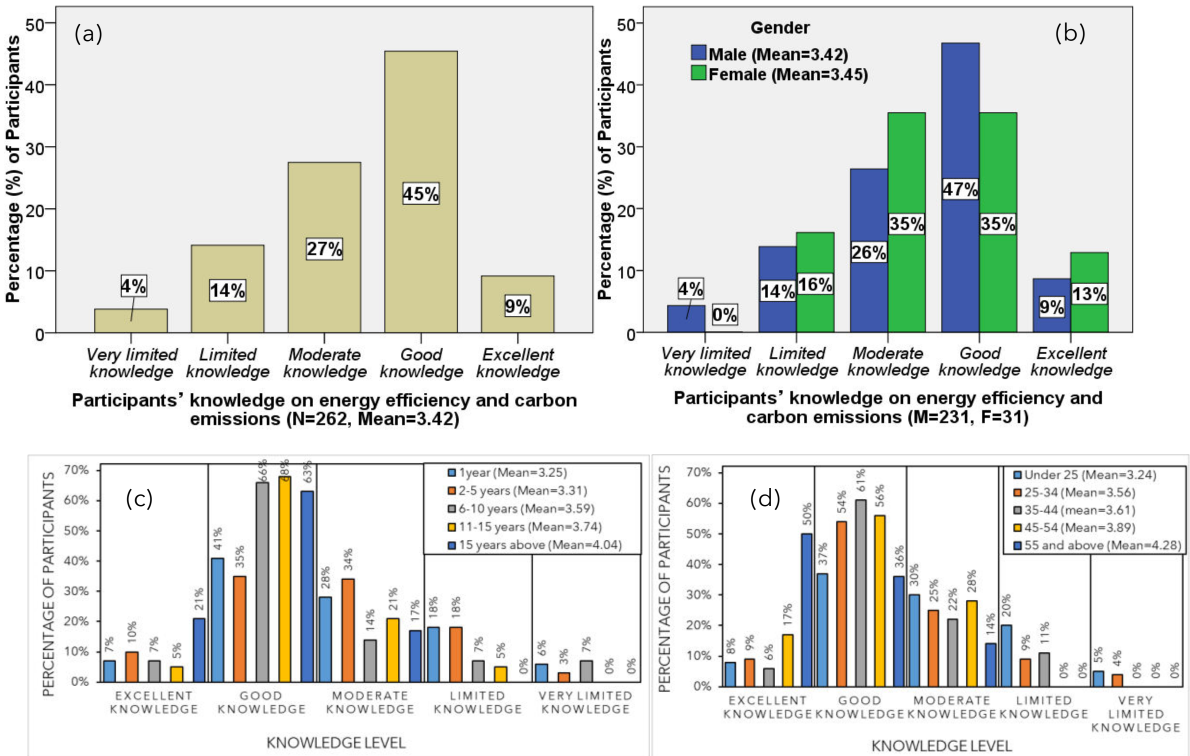


Figure 4. 8 - (a) Participants' Awareness of Energy Efficiency and Carbon Emissions (N=262); (b) Based on Gender (M=231, F=31); (c) Based on Years of Experience; (d) Based on Age; (e) Based on Positions (Source: Paper 4)

Figure 4.9(a) reveals that 54% of seafarers have excellent or good knowledge of EE and carbon emissions. Figures 4.9(c), (d), and (e) indicate that the ship's technical managers, senior engineers, and senior deck officers exhibit greater expertise than their junior colleagues. The study emphasizes the significance of customized training programs to improve awareness and knowledge among seafarers of different ages and experience levels based on the correlation between experience, age, and knowledge levels. Insights from the study offer valuable guidance for developing targeted training programs to enhance seafarers' awareness and knowledge, ultimately contributing to the EEOS.



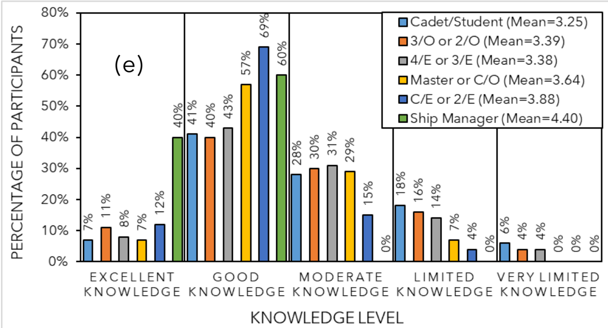


Figure 4. 9 - (a) Participants' Knowledge of Energy Efficiency and Carbon Emissions (N=262); (b) Based on Gender (M=231, F=31); (c) Based on Years of Experience; (d) Based on Age; (e) Based on Positions (Source: Paper 4)

4.3.2.2 Source of General Awareness and Knowledge on EE and LC Emissions

Crew members must undergo education and training programs to implement energy-saving measures in ship operations successfully. According to MEPC.213(63) Resolution, both onshore and onboard personnel require increased awareness and training for the success of the SEEMP and energy-efficient ship operations (IMO, 2012). As illustrated in Figure 4.10, 54% of maritime personnel acquire knowledge regarding EE, CO_2 emissions, and other GHG emissions through social media platforms and educational programs. This information originates from reputable news sources affiliated with the IMO and the UN. Figure 4.10 reveals that 43% of seafarers report an improvement in their awareness due to maritime training programs at the maritime training Institutes, both before and after sea. Contrasting these factors reveals that 32% of individuals gain information through interactions with colleagues, while 41% rely on television news or documentaries. Modern seafarers increasingly rely on social media platforms for information more than traditional sources like books and newspapers. These findings emphasize the significance of employing social media platforms to distribute pertinent information on carbon emissions and environmental sustainability through focused training and awareness initiatives.

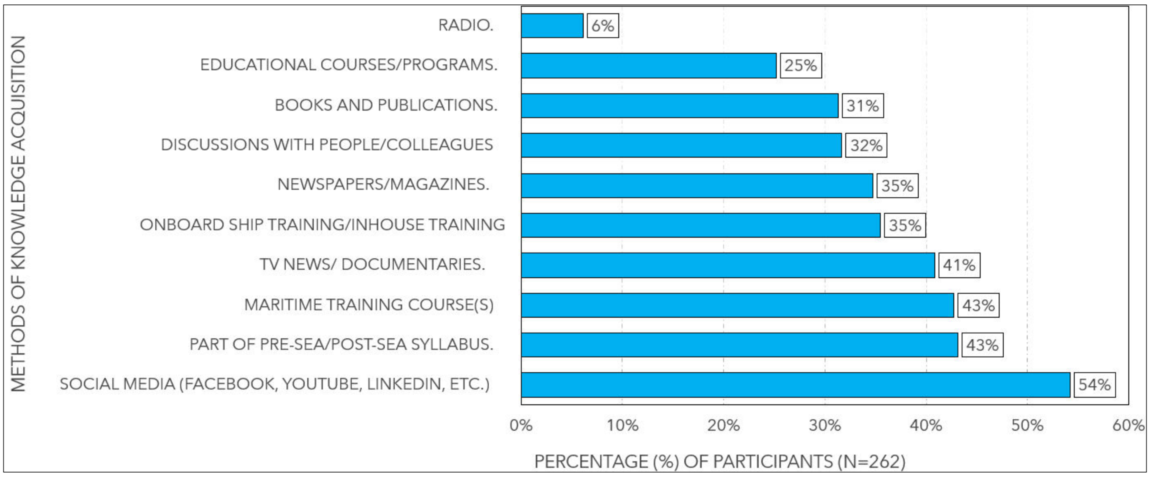
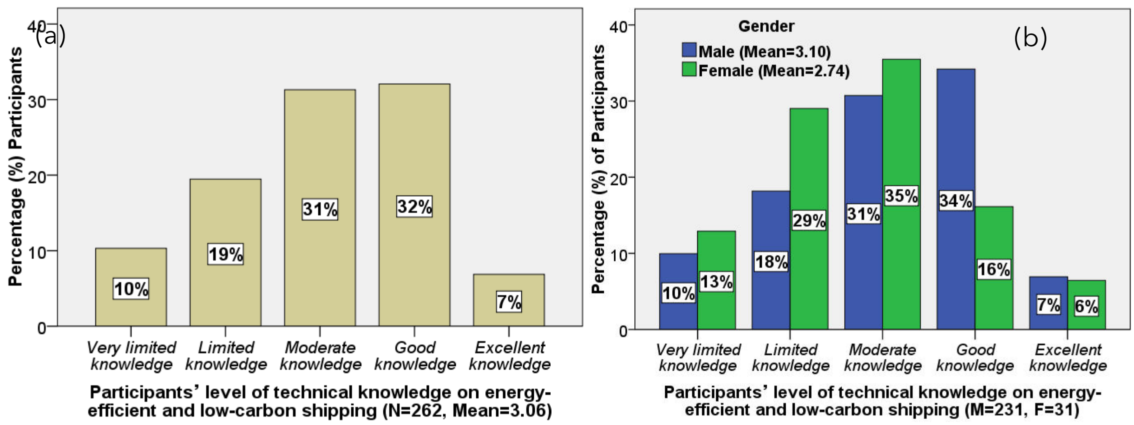


Figure 4. 10 - Participants' Awareness and Knowledge Acquisition Methods (Source: Paper 4)

4.3.2.3 Seafarers' Current Level of Technical Knowledge on EE and LC Shipping

The survey uncovered different levels of technical knowledge among seafarers on carbon emissions and EE in the shipping industry. Figure 4.11(a) reveals that 39% have excellent or good knowledge, and 31% have moderate technical knowledge of EE and LC shipping practices. Evidence reveals that male seafarers possess more excellent technical proficiency than female seafarers, as shown in Figure 4.11(b). Experience is strongly related to technical knowledge, according to the survey (Figure 4.11(c)). Specifically, 66% of respondents with 15+ years of experience demonstrated good or excellent knowledge of the subject. Figure 4.11(d) indicates that older seafarers also demonstrate greater skill. Many younger personnel and cadets lack technical understanding, highlighting the need for specific training programs (Figure 4.11(e)).



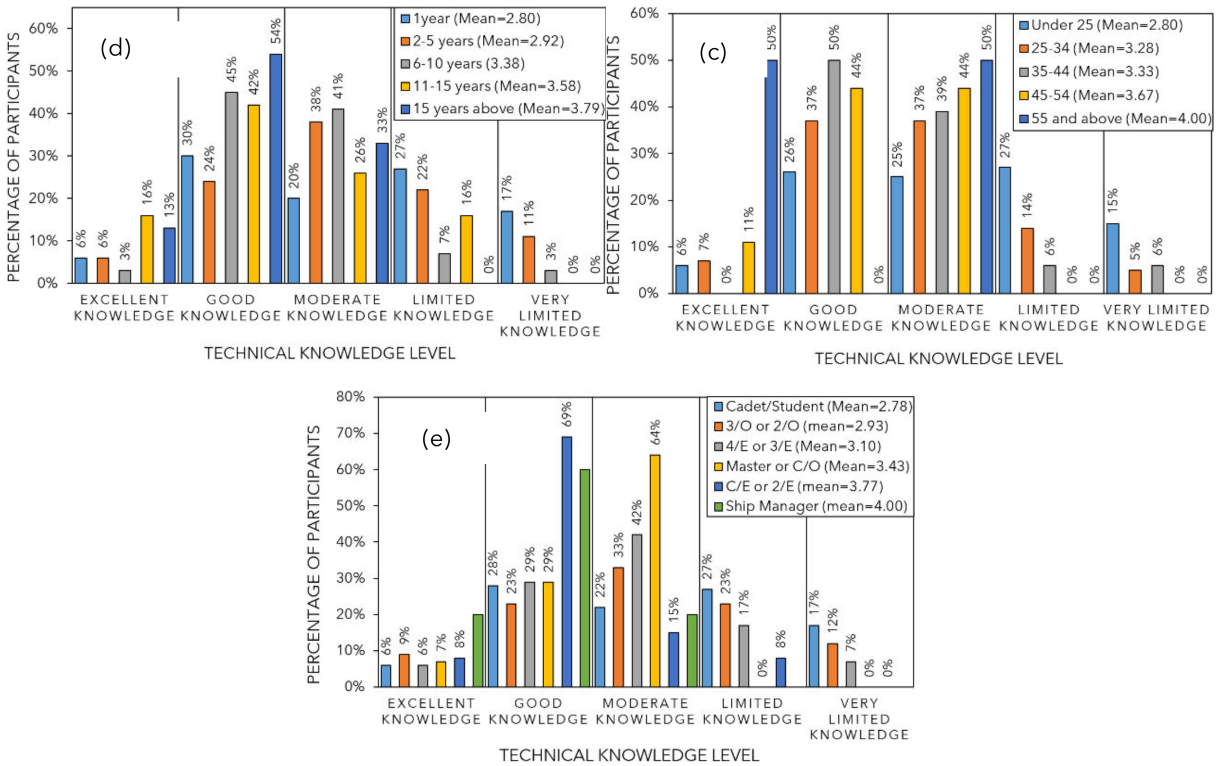


Figure 4. 11 - (a) Participants' Level of Technical Knowledge on Energy-Efficient and Low-Carbon Shipping (N=262); (b) Based on Gender (M=231, F=31); (c) Based on Years of Experience; (d) Based on Age; (e) Based on Positions (Source: Paper 4)

4.3.2.4 Efforts to Improve EE and LC Ship Operations Based on Level of Technical Knowledge

Based on technical expertise, our study demonstrates seafarers' attempts to improve EE and LC practices in vessel operations. Figure 4.12(a) reveals that among experienced seafarers, 47% displayed extensive or considerable efforts, while 53% showed moderate to minimal engagement, a slight decrease from previous studies. Male seafarers exhibited higher dedication than females (Figure 4.12(b)). Effort positively correlated with experience, with 71% of those with 15+ years showing significant commitment, declining among younger age groups. Ship technical managers demonstrated the most commitment, followed by senior engineers and deck officers. However, disparities across genders, ages, and roles highlight the need for tailored interventions to bolster EE practices, particularly among those with limited technical knowledge (Figure 4.12 (c), (d), and (e)).

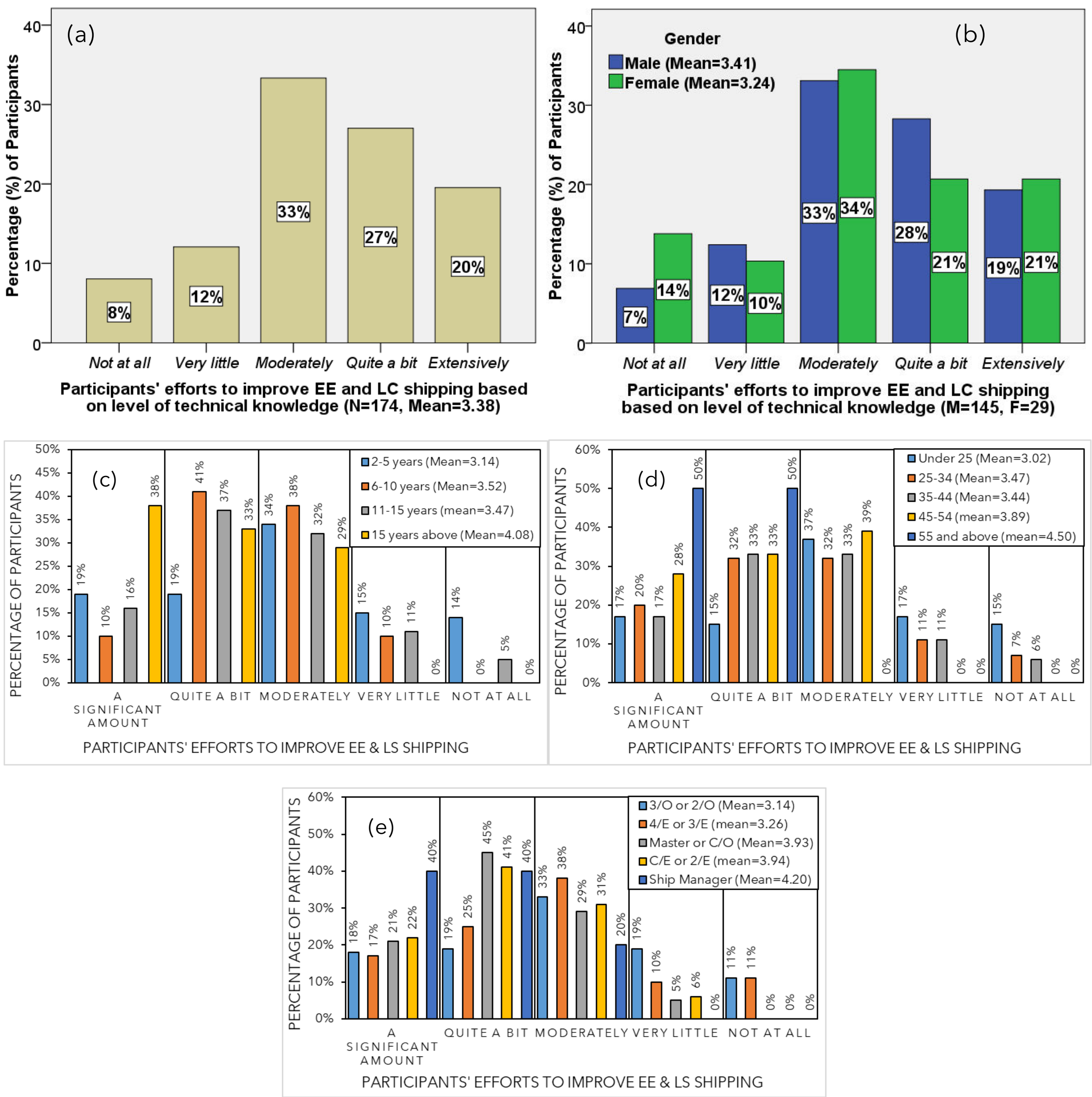


Figure 4. 12 - (a) Participants' Efforts to Improve EE and LC Ship Operations Based on Level of Technical Knowledge (N=174, Mean=3.38); (b) Based on Gender (M=145, F=29); (c) Based on Years of Experience; (d) Based on Age; (e) Based on Positions (Source: Paper 4)

4.3.2.5 Participant's Interest in Learning EE and LC Ship Operations

Based on the study's findings, it is clear that seafarers have a significant interest in gaining knowledge about EE and LC ship operations. According to the data presented in Figure 4.13(a), 84% are extremely or significantly interested, while 13% have shown a moderate interest in learning more. Interestingly, just 3% of female respondents indicated they had no interest, indicating that male seafarers have a slightly greater interest level (4.23) than female respondents (4.06) (Figure 4.13(b)).

Across experience levels, Figure 4.13(c) indicates a high interest in EE and LC shipping, with percentages ranging from 77% to 95%. Similarly, age-related trends in interest are evident (Figure 4.13(d)), with older seafarers showing higher interest levels. Figure 4.13(e) illustrates consistent enthusiasm across maritime roles. This contrasts with the findings of Banks et al. (2014), where 74% expressed interest, and 27% were less enthusiastic. Our study suggests a significant industry shift towards the IMO's net-zero emissions goal, with seafarers from diverse backgrounds keen to learn and contribute to EE and LC shipping practices.

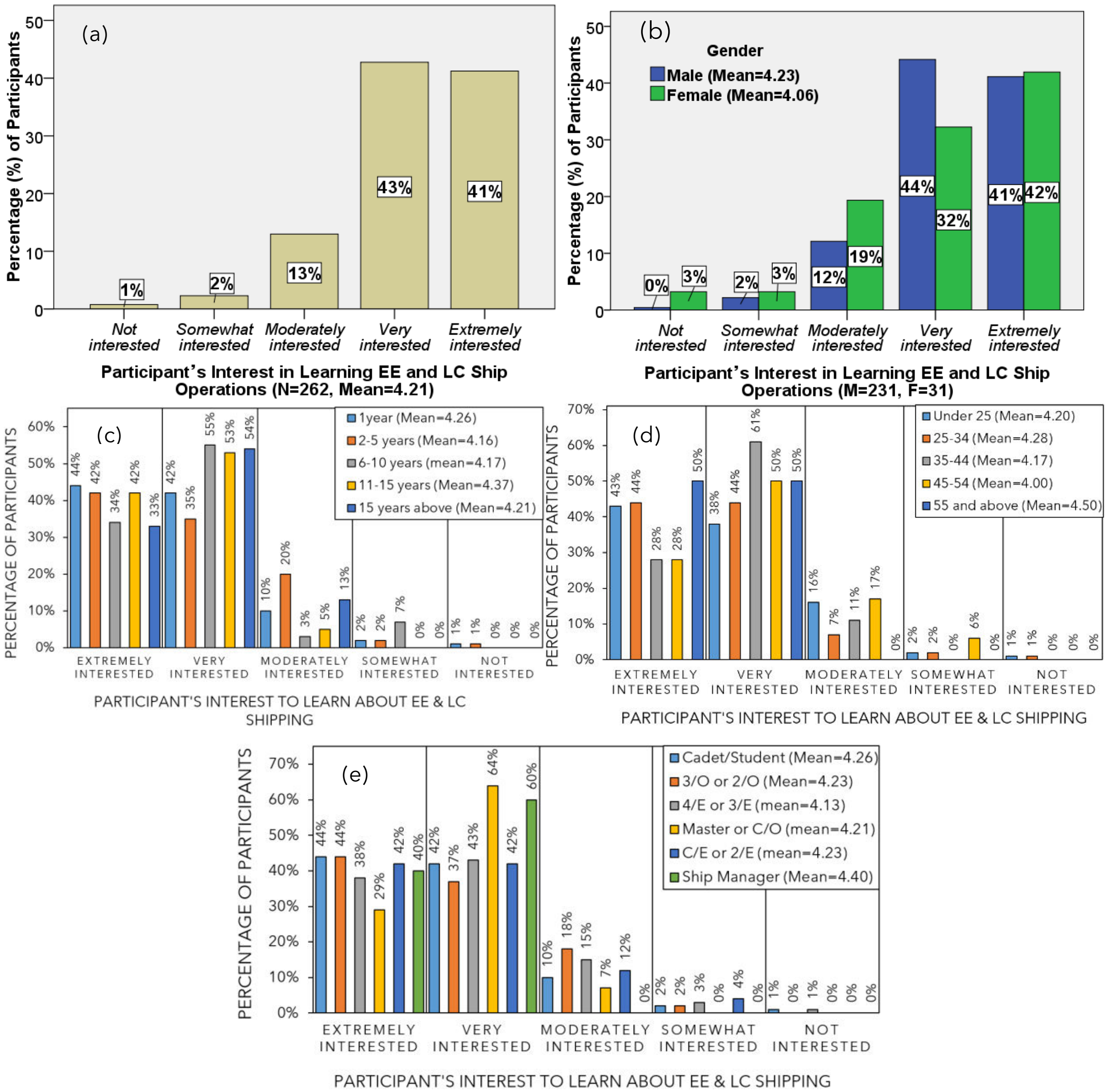


Figure 4. 13 - (a) Participant's Interest in Learning EE and LC Ship Operations (N=262, Mean=4.21); (b) Based on Gender (M=231, F=31); (c) Based on Years of Experience; (d) Based on Age; (e) Based on Positions (Source: Paper 4).

4.3.3 Concluding Remarks

Seafarers in this study demonstrate notable awareness and knowledge of the environmental implications of low-carbon and EEOS. Despite this, young and female maritime personnel still need more training and education, so developing targeted training programs is essential for bridging the knowledge gap. Experience is a crucial aspect that positively correlates with knowledge, highlighting the significance of long-term maritime service. Elderly seafarers in leadership roles exhibit greater awareness and technical proficiency. Female mariners in junior jobs are generally less informed and experienced than their male counterparts. EE and LC shipping operational strategies highlight financial incentives and formal recognition as crucial motivators. Policymakers need to focus on implementing thorough education and training programs to support the industry's shift towards a decarbonized future in line with the IMO's net-zero emissions goals. Customized techniques are essential to close knowledge disparities and encourage sustainable practices among different groups in the maritime sector.

4.4 Paper 5 - Effective Training of Seafarers on Energy-Efficient Operations of Ships in the Maritime Industry

This section consists of the summary of Paper 5, based on the study related to RQ3.

4.4.1 Study Aims

The implementation of MARPOL Annex VI Chapter 4 Energy Efficiency regulations in shipping companies is primarily driven by compliance with international standards set by the IMO (Bazari & Longva, 2011). Some companies remain hesitant due to perceptions that maritime EE will not result in significant environmental and financial benefits despite extensive research on the subject over the past two decades (Johnson et al., 2013). Barriers to implementing SEEMP measures include inadequate knowledge and competence among ship crews, operational challenges, and lack of stakeholder coordination (Dewan et al., 2018; Tijan et al., 2019). Additionally, there is a need to enhance understanding and implementation of EE measures among maritime stakeholders, including ship crews, due to a lack of clarity and guidance (Psaraftis & Kontovas, 2021; von Knorring, 2019). Furthermore, the study conducted by Banks et al. (2014) found that many seafarers perceive themselves as more knowledgeable than aware of the effects of CO_2 emissions, indicating that maritime personnel do not receive adequate training and motivation. Consequently, more studies are necessary to determine the most efficient training programs for seafarers to implement EE measures successfully during ship operations.

4.4.2 Study Findings and Discussion

The enforcement of EEDI and SEEMP regulations became mandatory for transportation companies in January 2013 (IMO, 2013). Both onshore and onboard seafarers need to be informed about SEEMP measures, which have been in place for some time. According to MEPC.213(63), all participants agree that raising awareness and providing training is necessary (IMO, 2013). In particular, 100% of seafarers ashore and aboard affirmed the importance of training and education for effective SEEMP implementation. As a result, seafarers acknowledge unanimously that education and training are vital in ensuring the successful execution of SEEMP onboard vessels. However, drawing from literature reviews and pilot survey results, our study developed survey questionnaires focusing on training programs to enhance seafarers' effective implementation of EEOS. The study findings are as follows:

4.4.2.1 Effective Energy-Efficient Operation of Ships (EEOS) Training Programs for Seafarers

As shown in Table 4.5, 39% of respondents engaged in "Onboard Training by Ship Managers/Masters and Chief Engineers," followed by 36% who participated in "Computer and Simulator-Based Training (CSBT) on the EEOS course onboard ships." Participants strongly endorsed training courses, including computer- and simulator-based training, onboard training by ship managers or masters and chief engineers, and training on executing the SEEMP measures by ship managers, as the most effective EEOS training programs. 52% highly endorsed CSBT as the most beneficial. Institutional or e-learning EEOS courses were deemed less effective and less preferred by maritime personnel. These findings highlight the need for tailored, hands-on training approaches to enhance EEOS implementation onboard ships.

Table 4. 5 - Effectiveness of Energy-Efficient Operation of Ships Training Programs and Activities (Source: Paper 5)

Sl. No.	Energy-Efficient Operation of Ships (EEOS) Training Programs	Attended by Seafarers (%)
1	Onboard Training by Technical managers or Master and Chief Engr	39%
2	Computer-and Simulator-Based Training (CSBT) on EEOS Course	36%
3	Training on EEOS by Ship Manager before Joining	23%
4	Energy Efficient Operation of Ships (EEOS) Course by MET Institute	13%
5	IMO Train the Trainer Course/Workshop	13%
6	EEOS E-Learning Course by GMN-IMO/DNV	10%
7	Special training by the Company Project Team/Retrofit Vendor	9%
8	Pre-sea training with Ship Energy Management Syllabus	5%
9	EEOS - 4.05 Training by immersive/ non-immersive simulators	3%

Participants highly recommended training programs, as indicated in Figure 4.14, including CSBT courses, onboard instruction led by technical managers, captains, and chief engineers, and instruction provided by ship managers on how to implement the SEEMP measures.

The study evaluates the effectiveness of various training programs for implementing the SEEMP measures based on participant feedback, using a Likert-type scale (1–5), where 1 represents "Strongly Disagree" and 5 represents "Strongly Agree." The analysis methodology involves categorizing the responses into thresholds (1.00–1.80: Strongly Disagree, 1.81–2.60: Disagree, 2.61–3.40: Neutral, 3.41–4.20: Agree, and 4.21–5.00: Strongly Agree) to assess participant agreement levels. The results in Figures 4.14 and 4.15 indicate that

Computer/Simulator-Based Training is the most effective, with 52% of participants strongly agreeing (score: 4.21–5.00). Other recommended training programs that received "Agree" ratings (3.41–4.20) include onboard training conducted by the Ship Manager, Master, or Chief Engineer, pre-joining training on SEEMP measures by the Ship Manager, and specialized training from Company Project Teams or Retrofit Vendors. In contrast, institutional and e-learning courses, such as those by the IMO-GMN Project, were less effective. These findings emphasize the importance of hands-on, immersive, and context-specific training approaches in equipping seafarers to implement EEOS successfully. Further study has been carried out and explained in more detail in Section 4.5.3.1.

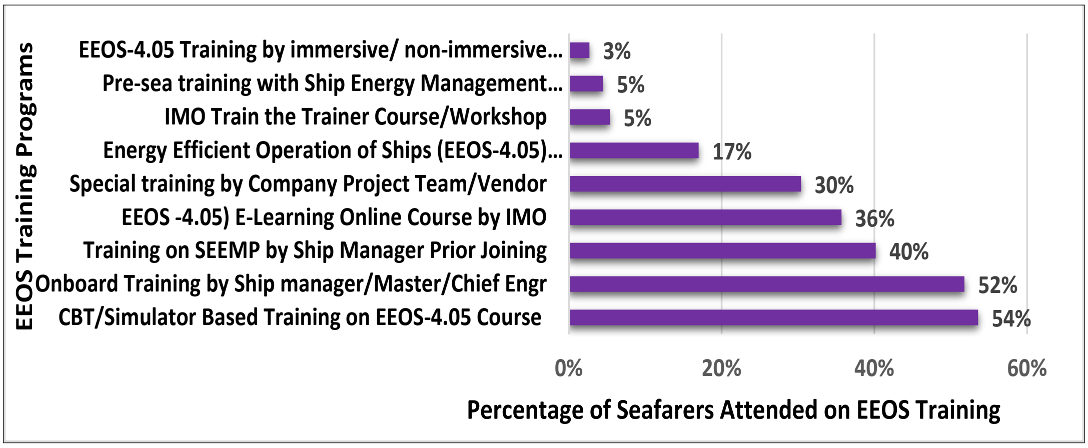


Figure 4. 14 - Recommended as Effective EEOS Training Programs by Participants (Source: Paper 5)

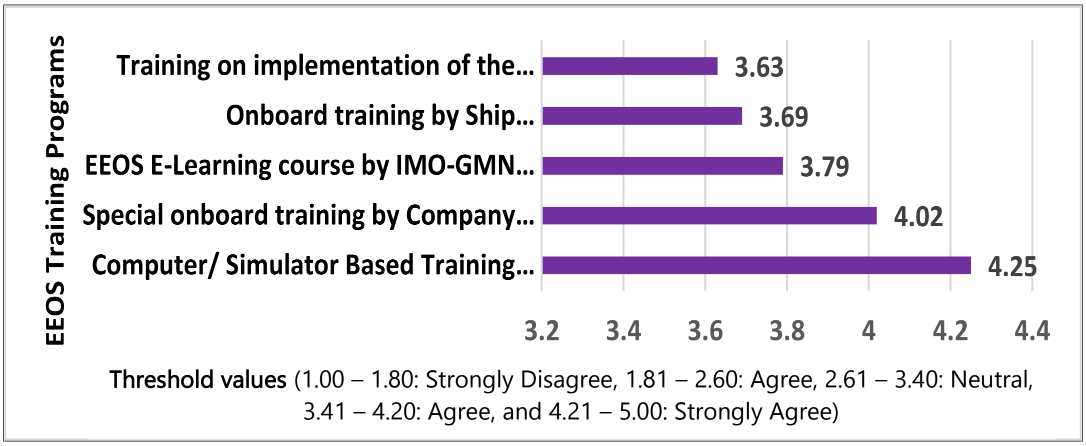


Figure 4. 15 - Effectiveness of EEOS Training Programs and Activities (N=112) (Source: Paper 5)

4.4.2.2 Shipping Companies Training Initiatives for Aboard Seafarers and Ashore Ship Managers

In a survey, seafarers were asked about shipping companies' efforts to raise awareness of the SEEMP. According to Figure 4.16(a), 64% of respondents believe shipping companies adequately implement SEEMP measures and raise awareness onboard and onshore, while 36% disagree. Additionally, perceptions of shipping companies' training programs varied: 50% considered them ineffective (Figure 4.16(b)), 41% found them effective, and 9% expressed a need for further training to enhance SEEMP implementation awareness onboard ships. These findings highlight diverse perceptions among seafarers, suggesting areas for improvement in both company efforts and training program effectiveness.

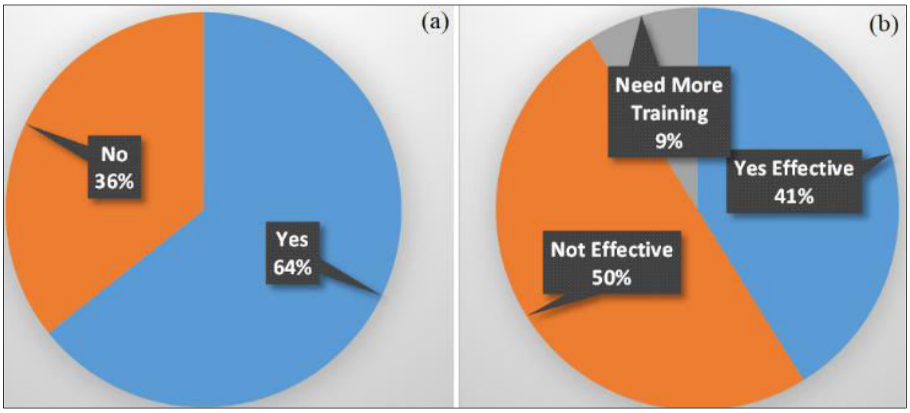


Figure 4. 16 - (a) Percentage of Sufficient Efforts Made by Shipping Companies for Seafarers (N=112); (b) Effectiveness of Shipping Company's Training Activities for Seafarers (N=112) (Source: Paper 5)

4.4.3 Concluding Remarks

This study highlights seafarers' awareness and knowledge challenges regarding EE regulations and measures in the maritime industry. Acknowledging the importance of training in building technical expertise for effective EE implementation, stakeholders have introduced various training initiatives. Although seafarers have engaged in multiple training programs, their effectiveness has been inconsistent. Notably, CSBT emerges as highly effective, along with onboard training led by technical and ship managers and special training by project teams and retrofit vendors. While shipping companies demonstrate efforts in training seafarers, there is room for improvement in the efficacy of training programs. The most effective way to foster seafarers' commitment to pollution-free shipping is through enhanced training programs and corporate motivation.

4.5 Paper 6 - Exploring Seafarers' Knowledge, Understanding, and Proficiency in SEEMP: A Strategic Training Framework for Enhancing Seafarers' Competence in Energy-Efficient Ship Operations.

This section consists of the summary of Paper 6, based on the study related to RQ3.

4.5.1 Study Aims

The maritime sector heavily relies on seafarers for operational duties, but their well-being and behavior are profoundly influenced by shipboard culture and hierarchy (Kim & Jang, 2018; Muslu, 2020). Organizational support, including effective training and fair treatment, is crucial to address stress-related challenges (Cahoon et al., 2014b). However, the industry's reactive human resource practices hinder sustainable training and development efforts (J. Wang, 2009). In addition, SEEMP requirements in the past decade have created different technological and operational measures, such as new technologies and low-carbon fuels, to decrease GHG emissions from ships. Ship energy efficiency has been hampered by low levels of education and reluctance to embrace change, according to DNV GL (2015). Similarly, Dewan et al. (2018) have identified several barriers to adopting cost-effective EE operational measures, including a lack of information, crew training and competency deficiencies, and operational complexity. Enhancing seafarers' awareness and knowledge regarding EE requires a concerted effort towards education and research (Banks et al., 2014; Kitada & Ölçer, 2020). Effective collaboration between stakeholders and the IMO is essential for overcoming these barriers, requiring technical cooperation, capacity-building programs, and guideline publications (Ghaforian Masodzadeh et al., 2022). Nevertheless, the effective execution of EE measures is hindered by crewmembers' lack of knowledge and training (Hansen et al., 2020; Psaraftis & Kontovas, 2021). This study aims to bridge this gap by developing a comprehensive training framework to improve seafarers' consciousness, expertise, and proficiency regarding EE practices. This study acknowledges the necessity of efficient training initiatives for both seafaring crew members and managerial personnel ashore. Over the past decade, regulations on maritime EE have spurred the introduction of various operational and technical measures, including low-carbon fuels and innovative technologies, aimed at curbing CO_2 and other GHG emissions from vessels.

4.5.2 Research Hypotheses

Effective implementation of EE operational measures in the maritime industry relies on seafarers' knowledge and awareness. Training programs are pivotal in equipping seafarers with the necessary skills and understanding to prioritize EE in their duties and align with company strategies. These programs, categorized into Shipping Company Training, Institutional Training, IMO Training, and Specialized Training, offer diverse avenues for enhancing EEOS (Dewan & Godina, 2023a). Notably, IMO initiatives like E-Learning (IMOEL) (IMO, 2019) and Train the Trainer (IMOTTT) courses aim to bolster EE understanding and SEEMP implementation (IMO, 2016b). Institutional Training, exemplified by MET Institute Training (METIT) and pre-sea/post-sea training (PSPST), integrates theoretical and practical components to foster comprehensive knowledge. Shipping Company Training encompasses onboard (OBT), in-house (IHT), and computer/simulator-based training (CSBT), enhancing crewmembers' skills and awareness. Moreover, Specialized Training programs like the WMU Program (WMUP) (Ölçer et al., 2017) and MariEMS Program (MariEMSP) offers advanced education in maritime energy management, emphasizing sustainable solutions and emissions reduction (Ziarati et al., 2017). Hypotheses derived from comprehensive literature reviews underline the significance of these training programs in SEEMP implementation:

H1: The training programs offered by the IMO on EEOS (IMOEL and IMOTTT) for seafarers positively impact the effective implementation of SEEMP aboard ships.

H2: The institutional training courses on EEOS (METIT and PSPST) for seafarers significantly influence SEEMP implementation onboard ships.

H3: The shipping companies' training activities on EEOS (OBT, CSBT, IHT, and CPTT) for Seafarers have a significant positive relationship with SEEMP implementation onboard ships.

H4: The specialized training programs on EEOS (WMUP and MariEMSP) significantly impact SEEMP implementation onboard ships.

4.5.3 Knowledge, Understanding, and Proficiency Requirements of the STCW in Maritime Training

In 1995, the STCW convention established a competency-based training framework that mandates qualified maritime officers to demonstrate essential knowledge, understanding, and proficiency (KUP) in their respective roles (Gundić et al., 2020). The STCW Code outlines a detailed catalogue of competencies, specifying the requisite KUP levels necessary for effective evaluation and demonstration. This framework also delineates educational and training objectives alongside standards of competence, ensuring that assessments and examinations are aligned with appropriate levels of KUP. To fulfil the KUP requirements set forth by the STCW Code, the MET institutions integrate theoretical instruction with practical training methodologies. These include hands-on experiences, virtual training via simulators, and on-the-job training conducted at sea (Renganayagalu, 2019).

To acquire licenses and certificates that comply with STCW standards, graduates must fulfill assessments based on KUP, as well as accumulate the necessary sea service. The training designed to meet STCW requirements effectively bridges the divide between practical experience and academic knowledge, fostering experiential learning (Satterwhite & Moorhead, 2023). The maritime industry demands a balanced integration of KUP to develop cognitive, affective, and psychomotor skills in seafarers (Bloom, 1993; Edirisinghe et al., 2022). Knowledge pertains to the understanding of theoretical concepts, understanding involves applying this knowledge to unfamiliar situations, and proficiency represents the ability to carry out tasks with skill and efficiency. Mastering these competencies is essential for those aiming to attain proficiency and expertise in maritime operations. Bloom's Taxonomy outlines three learning domains: cognitive, psychomotor, and affective (Bloom & Krathwohl, 2020). Although the STCW Code extensively emphasizes cognitive and psychomotor domains, it lacks explicit learning outcomes for the affective domain (Gundić et al., 2020). In this context, the research methodology employed survey questionnaires to assess seafarers' learning outcomes from various EEOS courses. This study included inquiries focused on KUP and overall satisfaction with individual courses.

4.5.4 Study Findings and Discussion

4.5.4.1 Effectiveness of Seafarers Training Programs and Activities on EEOS

Utilizing SmartPLS Version 3.2.9, this study assessed the efficacy of various maritime training programs in enhancing the EEOS. Among the eleven training factors evaluated, findings highlighted significant contributions from several programs.

4.5.4.1.1 Measurement Model Investigation

The CSBT yielded substantial advancements in knowledge, understanding, proficiency (KUP), and satisfaction among seafarers, with an Average Variance Extracted (AVE) value of 0.534, as shown in Table 4.6. CPTT also demonstrated positive outcomes, providing essential knowledge and satisfaction, with an AVE value of 0.737. In contrast, the IHT fell short of expectations regarding participant satisfaction despite offering adequate knowledge and proficiency. Conversely, programs like IMOEL and IMOTTT showcased significant gains across all parameters, with AVE values of 0.623 and 0.651, respectively. The analysis also revealed strong validity and reliability indicators for the research model, with all constructs exhibiting acceptable values for Cronbach's Alpha (CA) and Composite Reliability (CR) according to the reliability indexes and criteria mentioned in Table 4.7 with references. Moreover, the study identified a robust correlation between model indicators, supporting convergence validity. These results underscore the importance of tailored training programs in equipping seafarers with the necessary skills and knowledge to implement EEOS measures onboard ships effectively, thereby contributing to a more sustainable and energy-efficient maritime industry.

Table 4. 6 - Exploratory Factor Analysis with Indicator Reliability and Model Fitting Information (Source: Paper 6)

Factors Name	Associations	Factor Loading	SM	SD	T Statistics	IR	CA	CR	AVE
1. Computer and Simulator-Based Training (CSBT)	Knowledge (1)	0.730	0.726	0.052	14.032	0.533	0.710	0.820	0.534
	Understanding (2)	0.640	0.637	0.074	8.698	0.410			
	Proficiency (3)	0.760	0.759	0.043	17.795	0.578			
	Satisfaction (4)	0.785	0.783	0.042	18.556	0.616			
2. Classification Society and Project Team Training (CPTT)	Knowledge (1)	0.799	0.798	0.035	23.156	0.638	0.880	0.918	0.737
	Understanding (2)	0.876	0.876	0.019	45.185	0.767			
	Proficiency (3)	0.891	0.890	0.019	46.684	0.794			
	Satisfaction (4)	0.864	0.863	0.023	36.883	0.746			
	Knowledge (1)	0.799	0.794	0.046	17.446	0.638	0.641	0.807	0.586

3. Inhouse Training (IHT)	Understanding (2)	0.852	0.854	0.026	32.362	0.726			
	Proficiency (3)	0.628	0.621	0.076	8.208	0.400			
4. IMO E-Learning (IMOEL)	Knowledge (1)	0.786	0.779	0.105	7.516	0.618	0.796	0.868	0.623
	Understanding (2)	0.882	0.875	0.111	7.974	0.778			
	Proficiency (3)	0.754	0.745	0.112	6.752	0.569			
	Satisfaction (4)	0.726	0.718	0.100	7.282	0.527			
5. IMO Train the Trainer (IMO)	Knowledge (1)	0.851	0.606	0.058	14.650	0.724	0.821	0.881	0.651
	Understanding (2)	0.689	0.468	0.052	13.360	0.475			
	Proficiency (3)	0.815	0.563	0.058	13.990	0.664			
	Satisfaction (4)	0.859	0.604	0.060	14.410	0.738			
6. MET Institute Training (METIT)	Knowledge (1)	0.861	0.637	0.045	19.090	0.741	0.727	0.830	0.620
	Proficiency (3)	0.788	0.530	0.054	14.570	0.621			
	Satisfaction (4)	0.695	0.404	0.061	11.350	0.483			
7. Onboard Training (OBT)	Understanding (2)	0.883	0.884	0.017	50.756	0.780	0.773	0.868	0.687
	Proficiency (3)	0.843	0.842	0.033	25.646	0.711			
	Satisfaction (4)	0.755	0.744	0.073	10.355	0.570			
8. Pre-sea & Post-sea Training (PSPST)	Knowledge (1)	0.823	0.819	0.052	15.958	0.677	0.903	0.932	0.776
	Understanding (2)	0.912	0.911	0.019	48.029	0.832			
	Proficiency (3)	0.889	0.888	0.023	38.539	0.790			
	Satisfaction (4)	0.897	0.896	0.019	47.212	0.805			
9. Ship Energy Efficiency Management Plan (SEEMP)	Knowledge (1)	0.687	0.687	0.070	9.850	0.472	0.782	0.870	0.693
	Understanding (2)	0.893	0.892	0.016	56.297	0.797			
	Proficiency (3)	0.900	0.898	0.019	47.526	0.810			
10. Maritime Energy Management System program (MariEMSP)	Knowledge (1)	0.844	0.842	0.030	28.285	0.712	0.838	0.892	0.674
	Understanding (2)	0.876	0.874	0.029	30.568	0.767			
	Proficiency (3)	0.827	0.825	0.038	21.725	0.684			
	Satisfaction (4)	0.729	0.731	0.033	22.272	0.531			
11. World Maritime University Program (WMUP)	Knowledge (1)	0.923	0.922	0.020	46.575	0.852	0.876	0.924	0.802
	Understanding (2)	0.879	0.877	0.025	35.121	0.773			
	Proficiency (3)	0.883	0.882	0.032	27.948	0.780			

(Source: SmartPLS 3.2.9)

Here, Sample Mean (SM), Standard Deviation (SD), Indicator Reliability (IR), Cronbach's Alpha (CA), Composite Reliability (CR), and Average Variance Extracted (AVE) were calculated using SmartPLS Version 3.2.9.

Table 4. 7 - Reliability Indexes and Criteria

Reliability Indexes	Criteria	Reference
Average Variance Extracted (AVE)	>0.50	(Hair et al., 2011; Ringle et al., 2015; Sarstedt et al., 2017)
Composite Reliability (CR)	>0.80	(Henseler et al., 2014)
Cronbach's Alpha (CA)	>0.60	(Nunnally & Bernstein, 1994)
Indicator Loading Value (ILV)	0.60 to 0.70	(Hair et al., 2011; Hulland, 1999; Ringle et al., 2015; Sarstedt et al., 2017)

4.5.4.1.2 Discriminant Validity

Discriminant validity was evaluated using the Fornell-Larcker criterion (Fornell & Larcker, 1981), which requires that the square root of the AVE for each latent construct be more significant statistically than its correlations with other constructs. In the correlation matrix and diagonal, the square roots of the AVE coefficients must be confirmed (Hair et al., 2011). This ensures that each construct uniquely represents its intended dimension without overlapping with others. As shown in Table 4.8, the results confirm that all constructs meet this requirement. For instance, the square root of the AVE for CSBT (0.731) is greater than its correlations with CPTT (0.635) and other variables, highlighting its distinctiveness. Similarly, IMOEL (0.789) demonstrates stronger discriminant validity than its correlations with constructs such as METIT (0.721). These findings validate that each construct captures a unique aspect of the seafarers' training programs, ensuring the model is free from redundancy and measurement overlap. This robust discriminant validity supports the model's reliability in analyzing the relationships between training programs and their influence on energy-efficient ship operations.

Table 4. 8 - Model Discriminant Validity

	CSBT	CPTT	IHT	IMOEL	IMO TTT	METIT	OBT	PSPST	SEEMP	Mari EMSP	WMUP
CSBT	0.731										
CPTT	0.635	0.858									
IHT	0.673	0.683	0.766								
IMOEL	0.595	0.637	0.530	0.789							
IMOTTT	0.084	-0.067	-0.069	0.049	0.807						
METIT	0.593	0.694	0.577	0.721	-0.020	0.788					
OBT	0.642	0.573	0.485	0.613	-0.024	0.586	0.829				
PSPST	-0.089	0.155	0.088	-0.018	-0.598	0.125	0.027	0.881			
SEEMP	-0.023	0.106	0.013	0.035	-0.794	0.051	0.023	0.438	0.821		
MariEMSP	0.502	0.593	0.463	0.549	0.016	0.458	0.522	0.061	0.035	0.832	
WMUP	-0.017	0.192	0.099	0.012	-0.575	0.175	0.005	0.686	0.511	0.056	0.895

(Source: SmartPLS 3.2.9)

4.5.4.1.1 Heterotrait-monotrait ratio (HTMT)

The Heterotrait-Monotrait Ratio (HTMT) was used to assess convergent validity in the constructs. HTMT compares construct relationships to a predefined threshold, commonly set at 0.85 or 0.90. A value below the threshold confirms robust convergent validity, indicating expected interrelationships without excessive overlap. As demonstrated in Table 4.9, all constructs in the study achieved HTMT values below 0.85, confirming strong convergent validity. For example, the HTMT value for CSBT and IHT is 0.67, and for IMOEL and METIT, it is 0.81, which is well below the threshold.

Table 4. 9 - HTMT Ratio

	CPTT	CSBT	IHT	IMOEL	IMOTTT	METIT	MariEMSP	OBT	PSPST	SEEMP	WMUP
CPTT											
CSBT	0.789										
IHT	0.79	0.67									
IMOEL	0.778	0.769	0.72								
IMOTTT	0.1	0.147	0.149	0.108							
METIT	0.781	0.834	0.816	0.81	0.119						
MariEMSP	0.137	0.128	0.094	0.083	0.748	0.078					
OBT	0.68	0.824	0.65	0.773	0.071	0.813	0.068				
PSPST	0.173	0.149	0.172	0.106	0.723	0.146	0.477	0.049			
SEEMP	0.684	0.643	0.605	0.657	0.088	0.611	0.1	0.621	0.107		
WMUP	0.218	0.089	0.154	0.113	0.728	0.185	0.547	0.053	0.783	0.075	

(Source: SmartPLS 3.2.9)

These findings indicate no evidence of multicollinearity or overlap between constructs, ensuring the model captures distinct dimensions of seafarers' training programs. The results underscore the precision in distinguishing the impacts of various training methods, validating the robustness and reliability of the study's framework. By meeting HTMT criteria, the constructs demonstrate a high level of discriminative and convergent validity essential for interpreting the training's influence on EEOS.

4.5.4.1.2 Common method bias test

The study assessed common method bias using Variance Inflation Factors (VIFs) to detect potential multicollinearity among variables. VIF values typically range from 1 to 10, where a value of 1 indicates no correlation, values between 1 and 5 suggest moderate correlation, and values above 5 indicate high multicollinearity (Hair et al., 1998). In this analysis, the maximum observed VIF was 2.285, as shown in Table 4.10, which is well below the critical threshold of 3.3 suggested by (Kock, 2015). This confirms that the model does not suffer from pathological collinearity or inflated variance, which could lead to common method bias. Since all VIF values in the model were below this threshold, it can be concluded that the model is free from common method bias. This ensures the reliability of the findings and the validity of the relationships among constructs.

4.5.4.1.3 Structural Equation Model Analysis and Hypotheses Testing

Using variance-based structural equation modelling (SEM), the structural model investigated five EEOS training constructs: IMO Training, Institutional Training, Shipping Company Training, Specialized Training, and SEEMP implementation. The SEM analysis results are presented in Table 4.10 and Figure 4.17.

Table 4. 10 - Path Model (Source: Paper 6)

Hypotheses	Beta (β)	SM	SD	LL	UL	t Statistics	p Values	Comment	VIF
IMO Training -> SEEMP	0.196	0.200	0.090	-0.057	0.399	2.180	0.038	Supported	2.285
Institutional Training -> SEEMP	0.028	0.036	0.107	-0.194	0.227	0.262	0.794	Not Supported	2.027
Shipping Company Training -> SEEMP	0.478	0.494	0.099	0.248	0.647	4.831	0.000	Supported	2.278
Specialized Training -> SEEMP	0.044	0.026	0.094	-0.128	0.241	0.464	0.643	Not Supported	2.108
R2	0.408								
Q2	0.405								

(Source: SmartPLS 3.2.9)

Sample Mean (SM), Standard Deviation (SD), Lower Limit (LL), Upper Limit (UL), Variance Inflation Factor (VIF), Coefficient of Determination (R2), and Predicted Relevance (Q2) were measured and analyzed using SmartPLS 3.2.9.

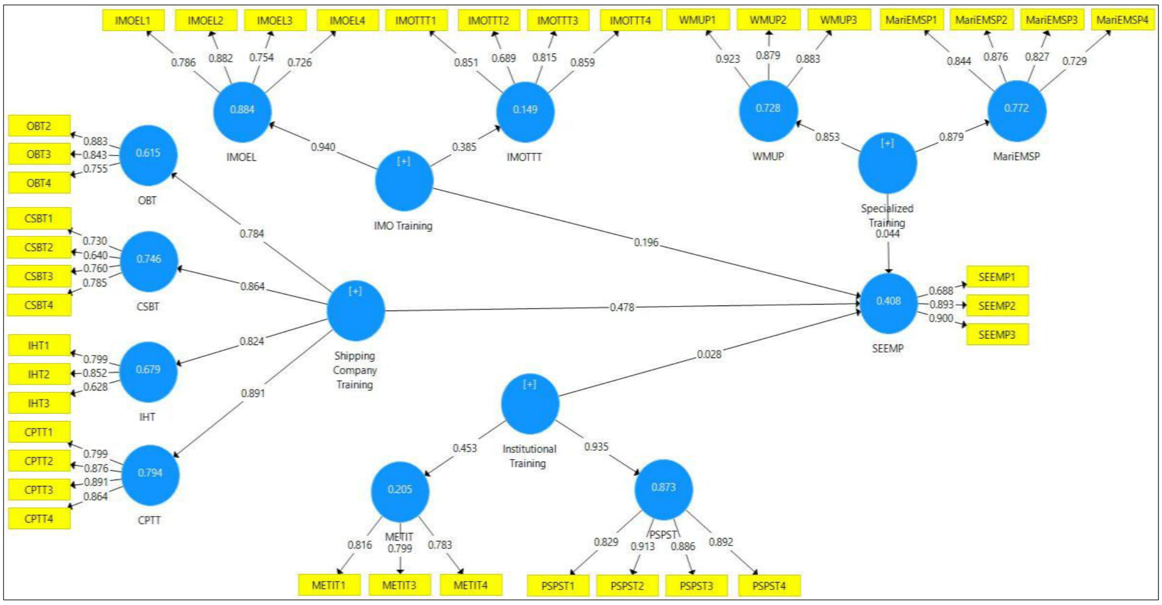


Figure 4. 17 - Path Model (Source: SmartPLS 3.2.9)

The results are summarized and presented as hypotheses testing:

1) **Supported Hypotheses**

H1: A significant positive relationship was found between IMO Training and SEEMP implementation ($\beta = 0.196$, $t = 2.180$, $p < 0.05$), suggesting the effectiveness of programs like IMOEL and IMOTTT.

H3: Shipping Company Training has a significant positive relationship with SEEMP implementation onboard ships ($\beta=0.478\beta=0.478$, $t=4.831t=4.831$, $p<0.05p<0.05$), suggesting the effectiveness of programs like (OBT, CSBT, IHT, and CPTT).

These findings support H1 and H3, suggesting that IMO-led training (IMOEL and IMOTTT) and shipping company training programs (OBT, CSBT, IHT, and CPTT) are effective in providing seafarers with the essential KUP required for the successful implementation of SEEMP on ships.

2) Not Supported Hypotheses

H2: Institutional Training does not significantly influence SEEMP implementation ($\beta=0.028\beta=0.028$, $t=0.262t=0.262$, $p>0.05p>0.05$).

H4: Specialized Training programs do not significantly impact SEEMP implementation ($\beta=0.044\beta=0.044$, $t=0.464t=0.464$, $p>0.05p>0.05$).

The H2 and H4 hypotheses were not supported, indicating that institutional training programs (METIT and PSPST) and specialized training initiatives (WMUP and MariEMSP) are ineffective for seafarers in implementing SEEMP in ships, likely due to their limited scalability and lack of practical applicability.

4.5.4.1.4 Model Fit and Predictive Relevance

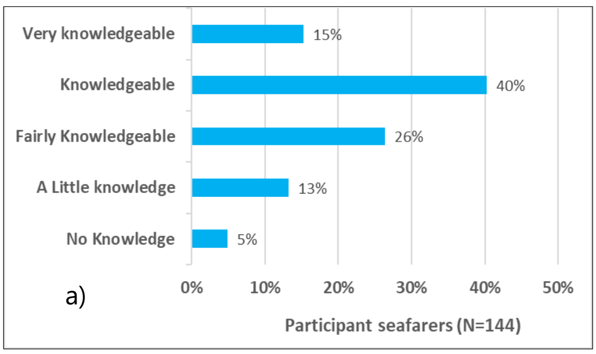
The coefficient of determination $R^2=0.408$ indicates that 40.8% of the variance in SEEMP implementation is explained by the independent constructs included in the model which, namely, IMO Training, Institutional Training, Shipping Company Training, and Specialized Training. This result demonstrates the model's strong predictive power (Cohen, 1988), underscoring the effectiveness of these targeted training programs, particularly those provided by IMO (IMOEL and IMOTTT) and shipping companies (OBT, CSBT, IHT, and CPTT) , in supporting SEEMP implementation. Furthermore, the predictive relevance of the model is confirmed by the Q^2 value of 0.405 (Table 6, Figure 5), which exceeds the threshold of zero and indicates that the constructs included are highly relevant to the effective implementation of SEEMP (Hair Jr et al., 2013).

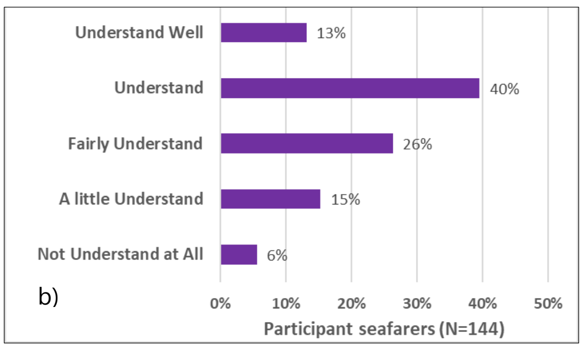
The unexplained variance of 59.2% indicates that additional factors not accounted for in the model may significantly impact the implementation of SEEMP. These factors may include external influences such as regulatory changes, market conditions, and human or organizational behaviors (Dewan et al., 2018; Jafarzadeh & Utne, 2014). Other critical elements include crew motivation, insufficient incentives, financial constraints (Lu et al., 2015; Dewan et al., 2018), organizational support, and effective ship-to-shore collaboration (Viktorelius &

Lundh, 2019) influence seafarers in implementing SEEMP in ships. Moreover, principal-agent problems and sector-specific challenges also impact the involvement of seafarers in adopting SEEMP onboard ships (Johnson et al., 2014; Johnson & Andersson, 2016; Rehmatulla & Smith, 2015). Recent studies reveal that audits, policies, and voluntary initiatives play a role in shaping seafarers' engagement with SEEMP implementation in the shipping industry (Balcombe et al., 2019; Christodoulou & Cullinane, 2021; von Knorring, 2019). Some unexplained variances might also stem from measurement errors, data collection challenges, or model design limitations (Lowry & Gaskin, 2014). While the R^2 value underscores the model's strength, it is essential to acknowledge that real-world scenarios, particularly in the complex domain of energy-efficient ship operations, involve intricate dynamics that extend beyond the constructs analyzed in this research. Technological factors and potential measurement errors might also contribute to the unexplained variance (Kock, 2015). Despite this, the high Q^2 value indicates that the constructs included in the model are highly relevant and provide meaningful insights into SEEMP implementation, even if the complex nature of the maritime industry suggests room for further exploration

4.5.4.2 Seafarers' Knowledge, Understanding, and Proficiency (KUP) in SEEMP

Ship crew members are vital for vessel operation and cargo transportation. They play a key role in implementing technical and operational measures to enhance energy efficiency, as outlined in the SEEMP. The survey data analysis focused on assessing crew members' KUP in SEEMP implementation. Results showed that 55% of participants are highly knowledgeable Figure 4.18(a), 53% understand or understand well (Figure 4.18(b)), and 58% are proficient or highly proficient in implementing SEEMP measures onboard ships (Figure 4.18(c)). Nearly half of current seafarers, both onboard and ashore, possess the necessary expertise in EE regulations and procedures for effective implementation onboard ships.





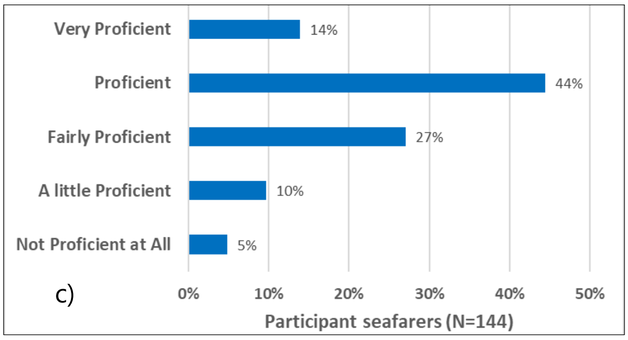


Figure 4. 18 - (a) Participants' Knowledge; (b) Understanding and (c) Proficiency in Implementing SEEMP Onboard Ships (Source: Paper 6)

4.5.5 Strategic Training Framework for Enhancing Seafarers' Competence in Energy-Efficient Ship Operations

The maritime industry is undergoing a profound transformation driven by technological advancements and digitalization, necessitating a corresponding evolution in the roles and responsibilities of seafarers. Achieving EEOS and meeting net-zero emission targets demands that seafarers become adept digital operators, underscoring the critical need for continuous education and training frameworks. DNV Maritime Forecast estimates that by 2050, decarbonization training will be necessary for 1.8 million seafarers to enhance their competencies (DNV, 2023). DNV and Lloyd's List Intelligence underscored in a recent safety report the importance of skilled crew members in ensuring the security of vessels in the face of digital technology's improvements in operational efficiency and ease of switching to alternate fuels (DNV, 2022a). This study was undertaken to determine the efficacy of different training programs designed for seafarers in the maritime sector in preparation for implementing the SEEMP on a global scale. The findings of the study (Dewan et al., 2024) reveal that programs such as IMO Training, Institutional Training, Shipping Company Training, and Specialized Training significantly contribute to effective seafarer training, accounting for 40.8% of SEEMP implementation efficacy, as explained in Section 4.5.4.1.4.

We illustrate their effectiveness by mapping the training courses and programs in EEOS from Dewan & Godina, (2024) alongside our study findings in Figure 4.19. By their different types of shipboard responsibilities, blue and orange represent deck officers and engineering officers, respectively. Green and light brown colors distinguish between effective and less effective training programs.

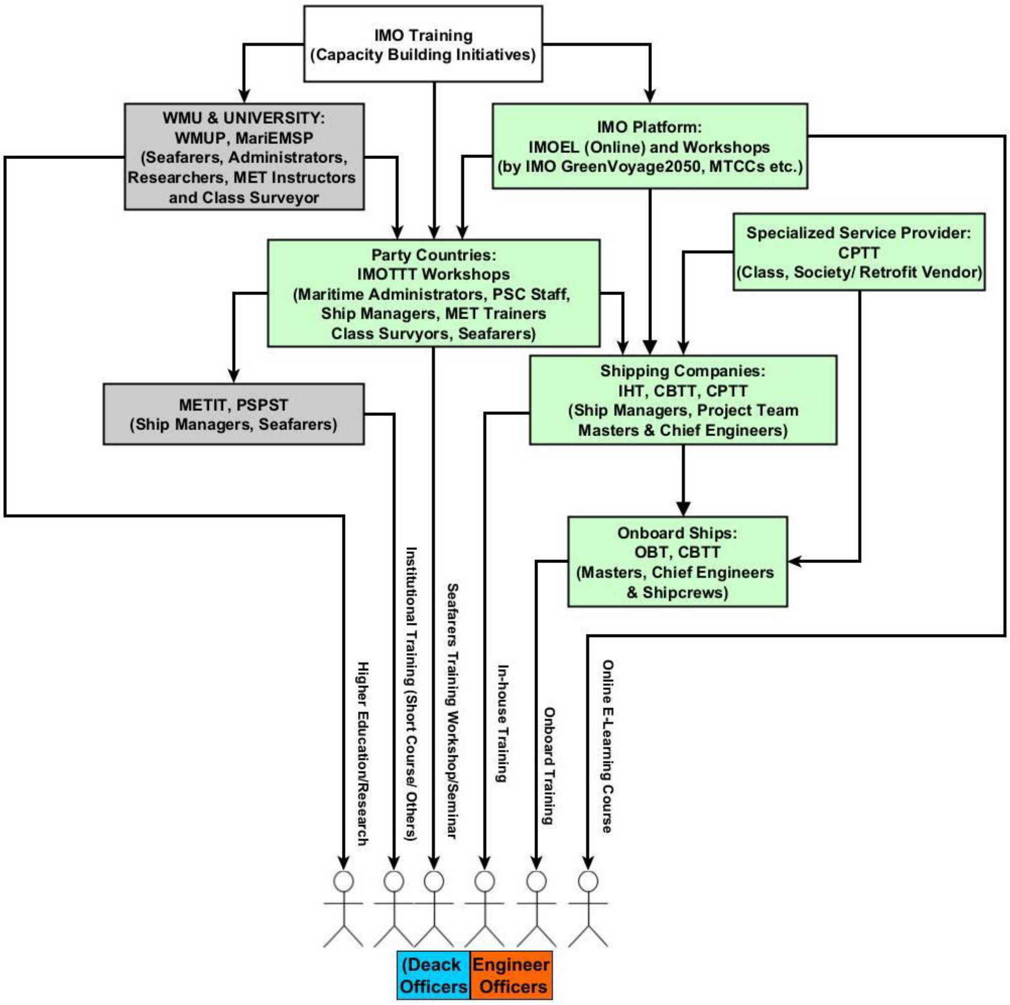


Figure 4. 19 - Mapping of EEOS Training Programs and Activities for Stakeholders (Source: Paper 6)

Drawing on existing EEOS training courses and our study findings, we propose a strategic training framework tailored to seafarers in different positions with different responsibilities, as presented in Figure 4.20:

1. **IMO Introductory Training:** Ship crew members, including masters, chief engineers, and shore-based managers, should undergo the IMOEL course on EEOS as foundational training.

   IMO Trainer Programs: Ship masters, chief engineers, and managers are encouraged to participate in the IMOTTT program to enhance their knowledge and serve as trainers for crew members.
2. **Formal Institutional Training:** Deck officers and engineers onboard ships should receive METIT, featuring CSBT, for comprehensive understanding and proficiency.

3. **In-House Training:** Ship managers, project teams, and crew members should receive in-house training at company offices facilitated by classification societies, retrofit vendors, and training providers using simulators.
4. **Onboard Training:** Regular OBT sessions supervised by masters, chief engineers, or project teams, integrating CBT or modern software, is recommended for all crew members.
5. **Specialized Education:** Seafarers and stakeholders seeking advanced education can enroll in postgraduate programs at the WMU or participate in EU-funded MariEMS programs for research opportunities.

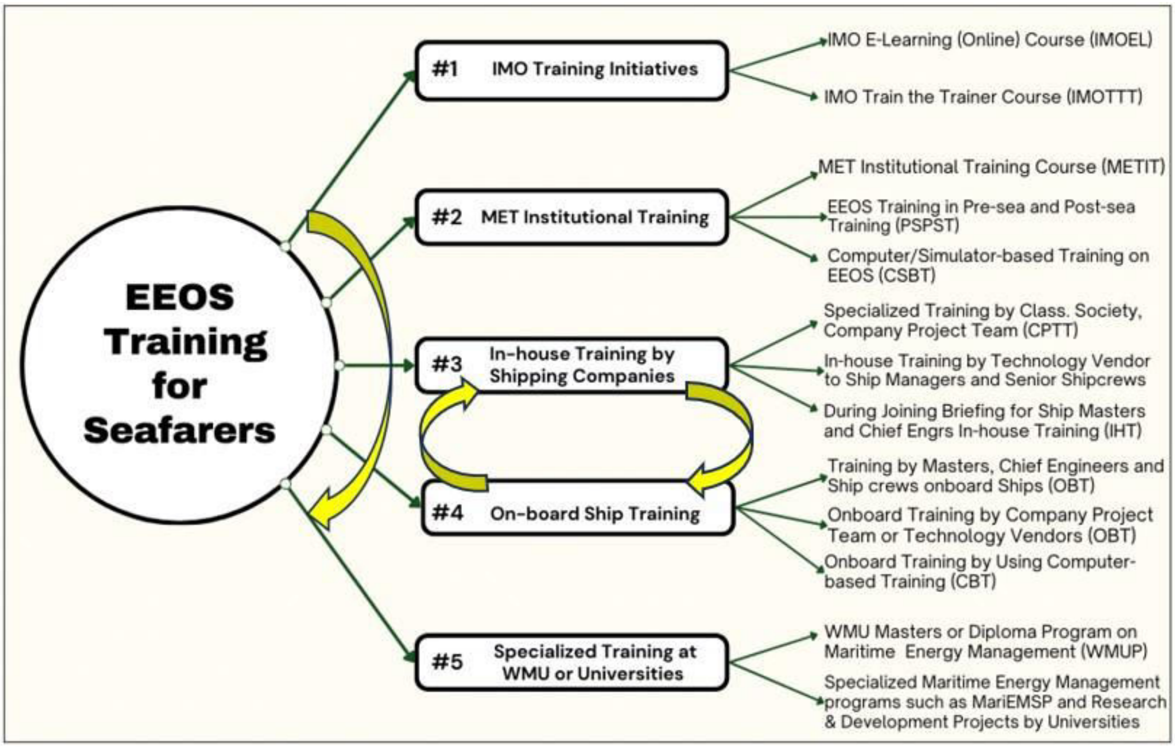


Figure 4. 20 - A Strategic Training Framework for Seafarers and Trainers in EEOS (Source: Paper 6)

We recommend a mandatory training program from the IMO Training Initiatives (IMOEL or IMOTTT) or MET Institutional Training (METIT or CSBT) for active seafarers who work onboard. For comprehensive skill development among seafarers, MET institutes should integrate CSBT into traditional methods. To ensure effective training delivery, trainers and instructors at MET Institutes must attend the IMOTTT program or workshops organized by member state administrations or the IMO. Moreover, for enhanced training output during OBT, it is advisable for masters, chief engineers, and technical managers to also participate in the IMOTTT program or workshop. Additionally, the continuity of IHT and OBT is emphasized for ship crew members directly involved in implementing SEEMP onboard ships, fostering ongoing professional development and adherence to industry standards.

Assessment and Feedback of EEOS Education and Training Programs:

Figure 4.21 illustrates the recommendations for the assessment and feedback procedures of seafarers' education and training programs on EEOS. Assessing participants' competence in EEOS training programs, such as IMO Training Initiatives (IMOEL and IMOTTT) and MET Institutional Training Programs (METIT, PSPST, and CSBT), is essential. This assessment, based on KUP, is conducted through IMO's web-based assessment system (In the case of IMOEL) or Maritime Administrations of Member States.

Successful participants receive a Proficiency Certificate in EEOS. Additionally, feedback from Participant Maritime Stakeholders on EE practices during ship operations is crucial. This feedback, directed to IMO's web-based system (IMOEL) or maritime administrations, facilitates improvements in EE measures and implementation procedures.

Regular upgrades to MET institution training programs are necessary to meet evolving industry demands, informed by feedback from seafarers. Trainers for shipping company in-house (IHT & CPTT) and onboard ship training (OBT) activities must attend IMOTTT courses and hold Train-the-Trainer (TTT) certificates to ensure proficiency in theoretical and practical knowledge.

After completing onboard job contracts, deck officers, engineer officers, Masters, and Chief Engineers are encouraged to provide feedback regularly to enhance EE practices during ship operations. Higher education and research on maritime energy management, whether at WMU or other universities, is vital for developing innovative technologies, retrofits, low-carbon or zero-carbon fuels, EE operational measures, operating procedures, and software tools. Conducting qualitative and quantitative surveys to gather input from industry stakeholders is crucial for policy formulation. Providing regular feedback to IMO MEPC, publishing articles in peer-reviewed journals, and sharing with scientists' arenas at international conferences and the maritime industry are essential for advancing EEOS towards achieving the net-zero emissions target by 2050. Finally, all feedback received must undergo a thorough examination by IMO to enhance standards, devise policies, and regularly establish guidelines for updating EEOS training programs.

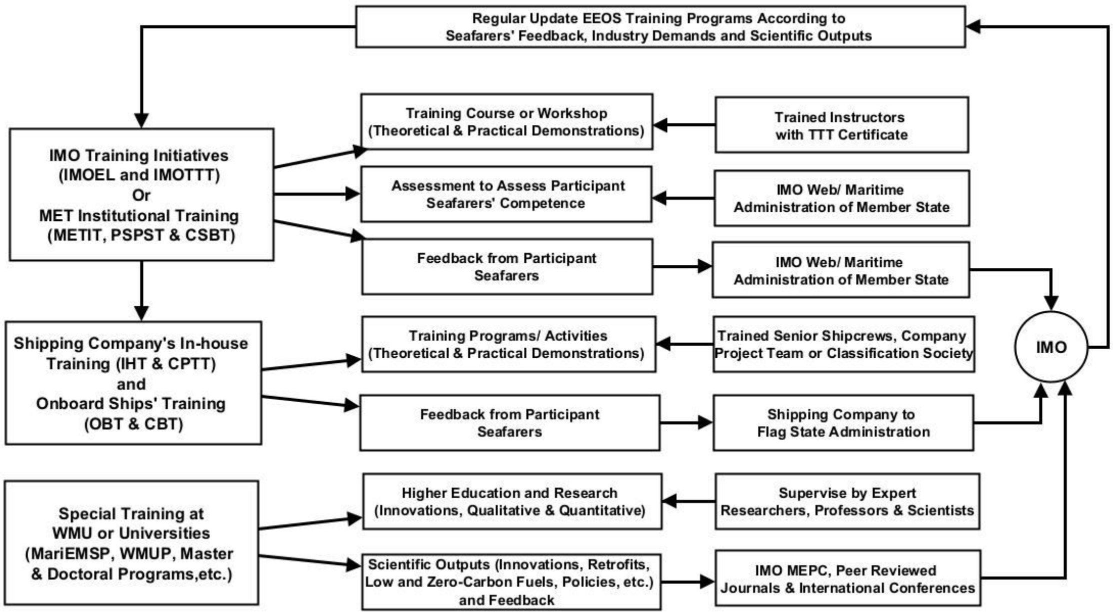


Figure 4. 21 - Training, Assessment, Feedback and Updating Cycle of EEOS Education and Training Programs (Source: Paper 6)

4.5.6 Concluding Remarks

The importance of effective training programs in advancing EEOS towards the goal of obtaining net-zero emissions by 2050 is emphasized in this study. Although IMO and shipping company training proved effective, institutional and specialized training had limitations. Recognizing sample biases, the proposed training framework advocates for a collaborative approach incorporating various training modalities to strengthen seafarers in meeting carbon reduction goals. These findings will assist regulatory bodies, policymakers, shipping companies, and industry stakeholders in promoting sustainable maritime practices and steering toward a greener future.

5

CONCLUSION

This chapter consolidates the main findings and accomplishments, addressing the research questions posed. The study underscores the significance of seafarers' awareness, knowledge, motivation, and access to effective training programs in fostering EEOS. Future research opportunities are identified to explore these aspects further and bridge existing gaps in understanding. Moreover, the study concludes with a recommendation for a strategic training framework aimed at facilitating successful energy-efficient ship operations that align with the IMO's net-zero emissions target.

5.1 Conclusion

The study offered valuable perspectives on seafarers' engagement, obstacles, strategies, and perspectives regarding EE initiatives within the maritime sector. It underscores the critical role seafarers play in the successful implementation of SEEMP on board vessels, despite the challenges they face and the need to adapt to new work norms associated with SEEMP implementation, in addition to dealing with entrenched barriers in traditional work culture. The results demonstrate that seafarers actively participate in EE measures while the vessel is in operation, delegating specific responsibilities and functions to crew members by their respective roles. The master and deck crew oversee navigation, cargo handling, and port-related procedures, while chief engineers and engine crews concentrate mainly on power generation and propulsion engines. Secondly, over the past decade, it has become evident that EEOS has changed seafarers' working cultures, with the adoption of various EE practices, including meticulous record-keeping of fuel consumption and adherence to planned maintenance systems for ship's machinery to ensure optimal performance, as well as frequent preparation for PSC inspections. Thirdly, while financial incentives and formal recognition have been identified as effective motivations, there is still concern about the reliance on such incentives despite the successful adoption of EE operational measures onboard ships.

Furthermore, technological advancements and the shift towards digitalization in the maritime industry were highlighted as crucial for achieving net-zero emission targets by 2050. Seafarers must transition into digital operators, necessitating continuous education and training to update their knowledge and skills in digital technologies, IT, IoT, and AI. Additionally, the research underscored the criticality of addressing the knowledge gap and arguing for environmentally sound practices through targeted training initiatives, especially considering variations in knowledge levels across gender, experience, and hierarchical positions within the maritime sector. Based on the findings, a recommended strategic training framework has been proposed for seafarers according to their roles and responsibilities. This framework should encompass a variety of training programs, including simulator and computer-based training, onboard training, and specialized training by project teams or retrofit vendors. It should also prioritize the use of effective training methods and tools to ensure comprehensive education and skill development among seafarers.

In conclusion, a strategic training framework customized to seafarers' particular requirements and obligations is necessary for the effective execution of the SEEMP and the achievement of EE objectives during ship operations. The maritime industry can effectively prepare seafarers to confront the obstacles of a decarbonized future and contribute to achieving the net-zero emissions target by 2050 by allocating resources towards ongoing education and training.

5.2 Contributions to Effective Training of Employees for Energy-Efficient Operation of Industries

Well-structured training programs strongly impact employee performance, substantially enhancing organizational effectiveness. Training based on scientific principles and designed with a systematic approach improves individual skills and builds teamwork, increasing overall workplace productivity. A Training Needs Analysis (TNA) is essential before training, as it defines the knowledge, skills, and attitudes required for each role, aligning training with organizational goals and increasing employee engagement (Baddeley & Longman, 1978; Salas et al., 2012). During training, incorporating practical examples, active participation, and feedback fosters a positive learning environment, enhancing skill retention and application. After training, post-training support through supervisor encouragement, refresher sessions, and reinforcement activities like goal setting help employees retain and effectively apply their new skills in the workplace.

5.2.1 For Seafarers in the Maritime Industry

The results obtained from this research make substantial contributions to the maritime sector in various critical domains, providing valuable insights into the challenges faced by seafarers, their adoption of EE practices, awareness of environmental impacts, and the effectiveness of training programs. Here is a comprehensive discussion of the contributions:

In paper 2, our study highlights the crucial involvement of crew members, especially ship's masters, deck officers, and engineer officers, including chief engineers, in implementing diverse EE measures during vessel operations. Seafarers actively participate in EE practices, with duties divided between deck crew and engine crew, focusing on navigation, cargo work, and power generation. Coordinated efforts among personnel are emphasized to enhance the vessel's energy efficiency and achieve emission reduction targets set by shipping companies, underscoring the collaborative nature essential for the successful implementation of EE measures. Due to increased workload, additional paperwork, frequent PSC inspections, and maintenance work, seafarers face challenges in implementing EE measures onboard. Addressing these challenges requires improvements in working conditions, training, financial incentives, and integration of new technologies, among other factors.

Our study in paper 3 reveals that seafarers have adopted numerous EE practices, including thorough reports on fuel consumption, vessel movement and cargo carrying data, vessel preparedness for frequent inspections, and enhanced maintenance work, demonstrating their dedication to sustainable operations. Formal Recognition and providing incentives for these efforts can also promote the implementation of EE practices across the maritime sector.

Paper 4 reveals variations in knowledge and awareness levels among seafarers concerning the environmental impacts of EE and LC vessel operations based on demographic characteristics. It draws attention to differences in awareness and knowledge levels by demographic characteristics, including job position, age, years of experience, and gender. To effectively address these knowledge gaps and promote sustainable behaviors, it is imperative to implement tailored strategies and continual training programs.

Our study in Paper 5 indicates that although various training initiatives exist, not all are equally effective for ashore technical managers or onboard crew members. Half of seafarers strongly endorse the effectiveness of CSBT in promoting EEOS. Training initiatives by the EE project team, in-house training for senior crew members by technical managers, and onboard training by the master and chief engineer are effective activities provided by shipping companies. Seafarers advocate enhanced ship-shore collaboration and corporate motivations to boost awareness and foster positive attitudes towards green shipping and environmental sustainability.

Finally, to minimize carbon intensity and support the industry transition to net-zero emissions, seafarers need to be equipped with the skills and knowledge indicated in the proposed strategic training framework to enhance their competence in the EEOS as described in Section 4.5.4, according to our study of Paper 6. The strategic training framework for seafarers on energy-efficient ship operations encompasses several vital stages. Initially, seafarers undergo foundational IMO Introductory Training, which involves engaging in the IMOEL course on EEOS. Trainers are encouraged to participate in IMOTTT programs to enhance their expertise. Formal institutional training follows, focusing on deck officers and engineers through METIT and integrating CSBT. IHT sessions conducted at company offices involve collaboration with relevant entities and utilizing simulators. The OBT sessions, supervised by experienced personnel, incorporate CBT or gamification and modern software for continuous skill development. The optional opportunities for advanced education include postgraduate programs at the WMU or participation in EU-funded MariEMS programs, providing research avenues in maritime energy management studies.

Overall, the study provides valuable research outputs into the role of seafarers in implementing EE measures, the challenges they face, and the effectiveness of training programs. Policymakers, shipping companies, and industry stakeholders can leverage these findings to develop comprehensive strategies that support sustainable maritime practices and facilitate the industry's transition toward a greener future.

5.2.2 For Employees in General Industries

In order to design the training program, the Job Task Analysis (JTA) is also important, defining specific skills required for each role and ensuring that training content meets performance standards (Salas et al., 2012). Tailoring programs to address the needs of individuals and teams, particularly in collaborative environments, increases training effectiveness (Dewan et al., 2024). Scholars argue that effective training improves productivity, leadership skills, cost-efficiency, and employee retention (Kessy & Temu, 2010; Khan et al., 2011). Leadership development programs benefit from mentorship and coaching, as well as aligning training with organizational culture and personal growth goals. The following strategic training framework with essential stages is recommended for employees to enhance energy-efficient operations in their industries, contributing to carbon emission reduction:

Firstly, it is essential to identify knowledge gaps across various roles and experience levels by leveraging demographic insights that align training initiatives with organizational objectives. Secondly, conducting a Training Needs Analysis (TNA) and JTA is crucial for defining role-specific skills and ensuring that the training content is relevant and performance-focused, enhancing employee engagement. Thirdly, foundational training should provide employees with baseline knowledge regarding environmental impact and EE through introductory online modules or courses, raising awareness among all staff. Fourthly, formal institutional training should be offered to develop specialized skills through technical, role-specific training utilizing simulators and computer-based Training (SCBT) modules. Fifthly, in-house workshops and collaborative projects can reinforce these skills, explicitly tailored to the organization's roles. Sixthly, on-the-job training allows employees to apply their skills in real-world settings under the guidance of supervisors, with continuous feedback aimed at improving performance. Seventhly, specialized programs and research initiatives should facilitate advanced training opportunities to promote ongoing development. Finally, regular performance evaluation is vital, including monitoring training effectiveness through feedback and refresher sessions to ensure that skills are maintained and applied effectively over the long term.

In Figure 5.1, the above-mentioned training recommendations are mapped to explain the strategic training framework for the industry employees for energy-efficient industry operations.

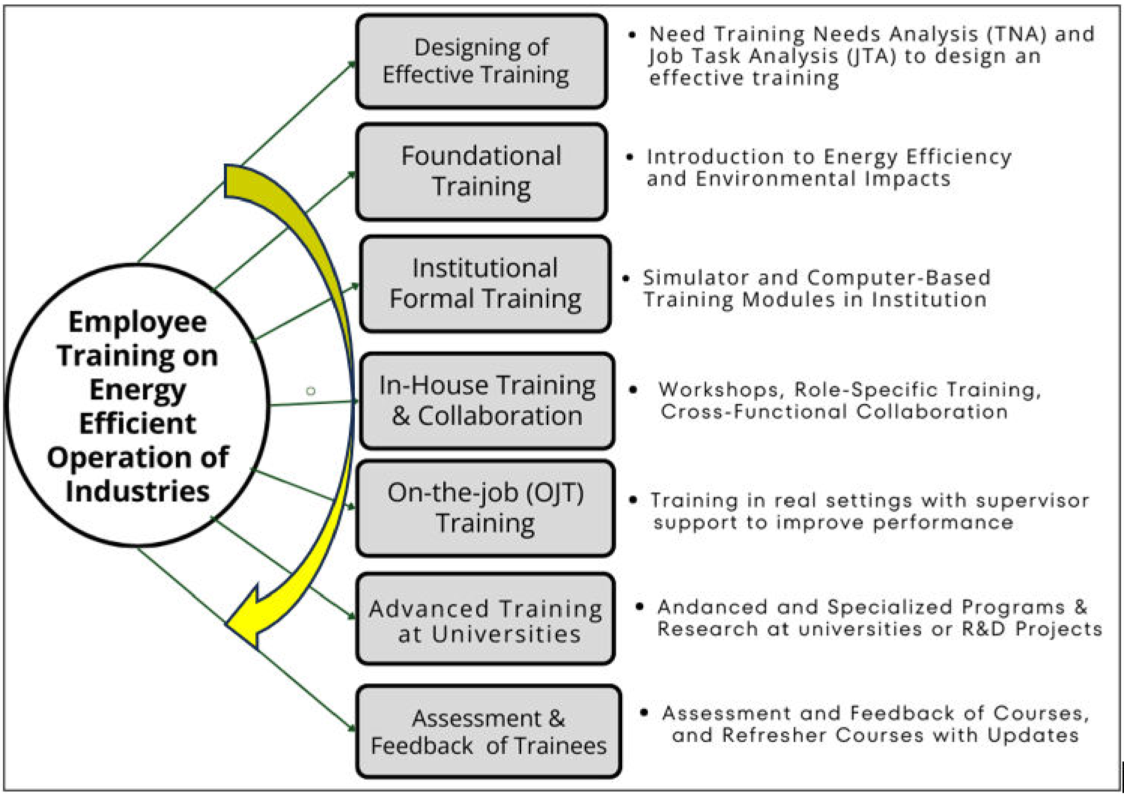


Figure 5. 1 - A Strategic Training Framework EE Operation of Industry for Employees

5.3 Limitations of the Study

While we attempted to collect data from seafarers worldwide for our studies from Paper 2 to Paper 6, a general limitation of this study is the unequal distribution of survey participants among countries. While sufficient data was obtained from seafarers occupying senior positions both aboard ships and in shore-based offices, the representation of seafarers in junior positions was not as balanced. Additionally, despite some participation from female seafarers, the disparity in numbers between male and female respondents poses challenges for meaningful gender-based comparisons. This discrepancy is attributed mainly to the underrepresentation of women in the shipping industry.

A bias towards seafarers primarily participating in EEOS training from shipping companies and IMO E-Learning courses is another limitation of Paper 6. Seafarers commonly use these avenues due to their accessibility and corporate endorsement. However, the study only received a few responses from those who attended EEOS courses conducted by maritime training institutes or specialized programs offered by institutions like the WMU or the EU-funded MariEMS program. The research limitations are Illustrated in Figure 5.2.

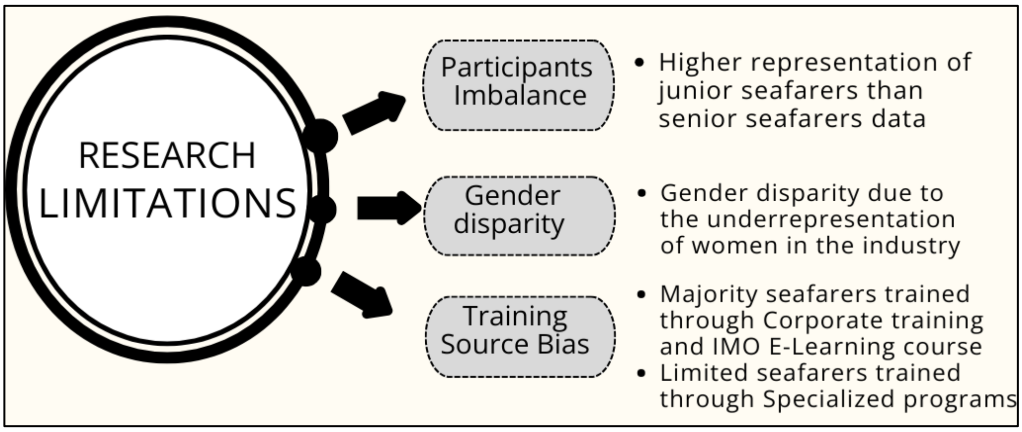


Figure 5. 2 - Limitations of the Study

5.4 Future Research Recommendations

Based on the findings of this study, several areas emerge as potential avenues for future research. Here are detailed recommendations for each area:

To advance knowledge and understanding of adopting EE practices in the maritime sector, subsequent investigations must prioritize several critical domains. Firstly, it is crucial to explore the SEEMP and consider seafarers' challenges during its implementation. Research should aim to identify effective training frameworks that incorporate innovative technologies to reduce seafarers' workload and simplify SEEMP adoption, as suggested in our paper 2. Effective training and education initiatives are imperative to support the transition to a decarbonized future and achieve net-zero emissions by 2050, which is in line with the updated IMO GHG Strategy. Researchers should prioritize developing focused training efforts to address knowledge gaps and foster sustainable practices across all individuals, regardless of gender, experience, or hierarchical position, as emphasized in paper 4. It is also essential to explore how seafarers can contribute to achieving the zero-emission target by 2050 through embracing cutting-edge technologies, low-carbon fuels, and zero-carbon green hydrogen fuels. Training programs should be tailored to ensure seafarers are proficient in operating new technologies required for EE measures, such as green hydrogen fuel-operated engines and carbon capture technologies.

Furthermore, achieving IMO's ambitious net-zero emissions target by 2050 in the shipping industry requires both technological innovation and skilled seafarers. Monitoring seafarer training by the IMO is inadequate, resulting in a slowdown in progress. Future research should focus on a comprehensive assessment mechanism, evaluating the long-term impact of training programs on SEEMP implementation and EE performance onboard ships, as suggested in paper 6. Enhancing training for seafarers and ship managers requires the exploration of advanced tools like immersive simulators and innovative methods such as gamification and immersive technologies, including augmented reality (AR), virtual reality (VR), and mixed reality (MR), which can significantly boost training efficacy. Concurrently, research should prioritize understanding seafarers' perspectives across diverse educational platforms to ensure well-rounded training in EEOS. As recommended in Paper 4, social media offers a valuable opportunity to serve as a continuous learning tool, fostering awareness of emerging technologies while disseminating updated knowledge on innovations and technical advancements for emission mitigation in the shipping industry. Moreover, Paper 1 highlights the need to evaluate the effectiveness of diverse training methods and tools to optimize learning outcomes. A follow-up study is recommended to assess the practical application and impact of the strategic training framework proposed in Section 4.5.5 of this study for enhancing seafarers' competence in EEOS.

Exploring the integration of Industry 5.0 technologies to reduce seafarers' workloads and improve data reporting and recording accuracy is crucial, as suggested in paper 3. Research in this direction can reshape maritime operations, providing seafarers with the support they need while driving the industry towards enhanced efficiency and environmental responsibility. By addressing these research gaps, future studies can contribute significantly to promoting sustainable practices and achieving environmental objectives set forth by regulatory bodies like the IMO. Furthermore, there is a need for further exploration into all the factors that influence the attitudes and behaviors of seafarers about enhancing EE and reducing GHG emissions, according to our study of papers 2 and 3. Additionally, as suggested in paper 5, collecting feedback from seafarers and analyzing it as linguistic data can help identify specific areas of concern and inform the development of policies and practices that better support seafarers' needs and interests. Recommendations for future research are illustrated in Figure 5.3.

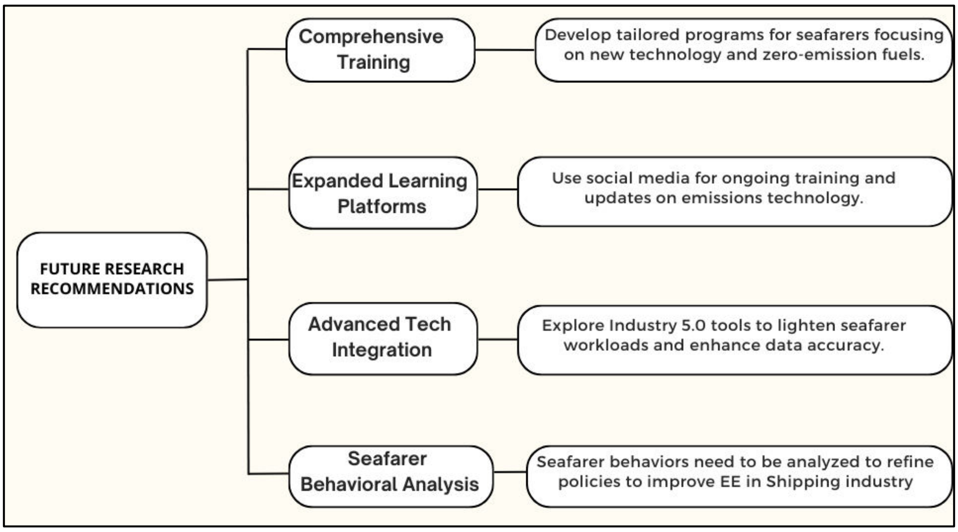


Figure 5. 3 - Recommendations for the Future Research

In conclusion, by addressing these research gaps, future studies can contribute to developing comprehensive training frameworks incorporating innovative technologies and targeted interventions to promote sustainable practices and achieve the ambitious environmental goals the IMO and other regulatory bodies set forth. Collaborative efforts among industry stakeholders, policymakers, and researchers are essential for realizing these objectives and fostering a sustainable maritime future.

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A

An Appendix

In Appendix A, we have included our published papers, which have been discussed in Chapter 2: Literature Review and Chapter 4: Summary of Published Papers.

A.1 Paper 1: An overview of seafarers' engagement and training on energy efficient operation of ships.

Paper Reference Details:

Dewan, M. H., & Godina, R. (2024). An overview of seafarers' engagement and training on energy efficient operation of ships. Marine Policy, 160, 105980.
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An overview of seafarers' engagement and training on energy efficient operation of ships

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ABSTRACT

As the shipping industry contributes significantly to anthropogenic CO_2 emissions, it is imperative to take urgent steps to reduce its impact on the environment. This study delves into the pivotal role of seafarers in achieving energy-efficient ship operations, which is crucial for mitigating climate change. In the study, 58 articles spanning a decade are analyzed, and key influencers are identified, including knowledge, awareness, education, rewards, social factors, technology, and barriers to participation. As digital tools are integrated into seafarers' roles in ship operations, comprehensive training initiatives will be necessary. The study underscores the urgent need for tailored seafarers' training programs, integrating interactive tools, and addressing gaps in knowledge and motivation. Moreover, it highlights the transformative impact of digital tools, necessitating the reevaluation of energy-efficient ship practices. Collaborative efforts between stakeholders, especially ship owners, ship managers, and crewmembers, must emphasize financial incentives and regulatory frameworks. Future research should evaluate diverse training methods and seafarers' perspectives, bridging knowledge gaps in energy-efficient ship operations after a decade of IMO regulations. This study equips policymakers, training institutions, and industry stakeholders with insights to enhance seafarers' engagement, thereby fostering energy efficiency and environmentally conscious maritime practices. These efforts are instrumental in promoting energy-efficient ship operations and addressing environmental challenges within the shipping industry.

1. Introduction

Over 90% of goods are transported worldwide by the global shipping industry in a cost-effective, safe, reliable, and energy-efficient way [20]. In 2018, maritime transports emitted 1056 million tons of CO_2, representing 2.89% of total anthropogenic emissions [39]. Several measures have been introduced by the International Maritime Organization (IMO) to address these emissions, including the Energy Efficiency Design Index (EEDI) and Ship Energy Efficiency Management Plan (SEEMP), which took effect on January 1, 2013 [15,53,55]. The SEEMP helps shipping companies track ships and fleet efficiency over time using the Energy Efficiency Operational Indicator (EEOI) [51]. A mandatory IMO Data Collection System (DCS) has been introduced within SEEMP Part II for shipping companies to collect and report ship fuel consumption data [56] since January 2019. The IMO has outlined its Initial GHG Strategy to decrease the carbon intensity of international shipping by 40% by 2030 and 70% by 2050, compared to 2008 [59]. Carbon intensity is expected to be reduced by 30% by 2025 under phase 3 of the EEDI. As part of the IMO's short-term measures, the EEXI and annual operational Carbon Intensity Indicator (CII) were adopted in 2021 to reduce carbon intensity by 40% by 2030 [63]. Starting in 2023, ships with more than 5000 GT are required to have a verified SEEMP Part III on board to demonstrate how they intend to meet their CII targets [62]. Furthermore, with a net-zero or nearly net-zero emissions target by 2050, the revised IMO GHG Strategy emphasizes the importance of technological innovation and low-emission solutions for international shipping [64]. Meeting IMO's ambitious net-zero emission target by 2050 requires securing a significant share of global carbon-neutral fuels, posing

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challenges amid competition from other sectors. The DNV's Energy Transition Outlook 2023 [32] report advocates for energy efficiency (EE) measures in digital systems, and explores alternative technologies like carbon capture, nuclear propulsion, and liquefied hydrogen for sustainable shipping.

The crew's responsibilities include navigation, cargo handling, maintenance of technical systems, ship security, and marine environment protection [81]. The IMO has developed and implemented various policies and regulations related to seafarers' training and education. These regulations require seafarers to have the knowledge, skills, and competencies to perform their duties safely and efficiently. In addition, the industry has developed various training programs and initiatives to enhance the skills and competencies of seafarers and promote best practices in the workplace onboard [24]. However, effective implementation and compliance with these regulations and initiatives are vital in ensuring the safety, security, and energy-efficient ship operations, as well as the protection of the marine environment. As ship sizes have increased, business has become more globalized, and technology has developed for communication, navigation, and automation, the maritime industry has experienced substantial economic and technological growth [79,119]. This has led to a more complex and demanding work environment for seafarers, with increased pressure to improve efficiency, reduce costs, and comply with regulations and environmental standards. Additionally, researchers have shown that insufficient guidance from land-based organizations can pose challenges to crewmembers trying to operate ships efficiently [101,116]. It is constantly stressful for seafarers when regulatory bodies' demands still need to be met with regard to energy efficiency related data or documentation [2]. Moreover, crew fatigue, safety, and welfare have become increasingly significant challenges for the industry, particularly as long-term deployments and changing employment patterns have increased [108].

This study aims to get an overview of seafarers' training and engagement in energy-efficient ship operations by reviewing existing journal articles. We present a summary of research findings related to innovations and developments in energy efficiency operational measures, seafarers' engagement, and training on energy-efficient ship operations through implementing various operational measures and their effectiveness as a means of increasing crew awareness and knowledge. Furthermore, this review study strives to identify gaps in the current research pertaining to seafarers' training and engagement in energy-efficient ship operations. This review study is structured as follows: Section 2 describes the methodology, which includes the research questions, search approach, criteria for selection, and data extraction procedures. Section 3 provides an overview of the selected articles, while Section 4 briefly describes energy-efficient operational measures for ships. Section 5 highlights the importance of ship crews' engagement in implementing energy efficiency measures. Section 6 discusses education and training on maritime energy efficiency, Section 7 highlights the factors influencing seafarers' engagement in energy-efficient ship operations, and Section 8 identifies research gaps and provides recommendations for future research. Finally, Section 9 concludes the study, summarizing the essential findings and contributions.

2. Methodology

This review paper employs a systematic methodology based on the PRISMA method [82,90]. This methodology involves designing Research Questions (RQs), selecting relevant databases, and devising appropriate keywords to search for related research articles. Inclusion and exclusion criteria and snowballing were used to screen identified records. Additionally, articles were manually screened, and their abstracts and titles were filtered before the full text and content of relevant articles were filtered. In the final selection, articles addressing the RQs were grouped and synthesized. Peer-reviewed scientific journal articles and conference papers describing relevant experimental or qualitative studies are included in this review. This study employs systematic methods to select high-quality studies that provide valuable insight and answer the RQs.

2.1. Formulation of research question

In this study, the following three Research Questions (RQs) were addressed during the research process:

RQ1. What innovative technologies, tools, software, and methods are available for ship crews to implement energy efficiency operational measures?

RQ2. What is the involvement of seafarers in implementing energy efficiency operational measures onboard ships?

RQ3. Which training initiatives are provided to seafarers to promote awareness and provide the required knowledge for successful energy-efficient ship operations?

2.2. Search strategy

An electronic academic search was conducted using Scopus and Web of Science between January 2014 and January 2023 using specific keywords. On 15 January 2023, we conducted a keyword search in two major interdisciplinary databases, Scopus and Web of Science, using the boolean search phrases listed in Table 1.

Table 1 presents the search strings utilized in the study. To obtain these search strings, the authors employed a systematic approach of generating an expanded set of strings based on relevant features associated with the search query, given the scope of the review on the engagement of ship crews for adoption of energy efficiency operational measures in shipping. To verify the search string, we conducted several test searches with other combinations of keywords (for example, "energy-efficient" and "energy," "efficiency" and "operation," and "ship" or "vessel" and seafarers or crew). The search was restricted to published articles that underwent the peer-review process and were included in reputable journals or conferences. During this review, only current energy-efficient operation of ships or energy-efficiency operational measures on ships or commercial vessels are considered (January 1, 2013 – January 15, 2023). Papers published in English were considered for this study and were of the following type: conference proceedings, journals, and book chapters.

In total, 172 references were retrieved from our searches. Our search criteria found scientific conference papers, book chapters, books and journal articles. An additional 26 articles were found through Google Scholar and citation searches, totalling 198 articles, including book chapters for the first screening. After conducting the initial screening, a total of 78 articles were identified, excluding any duplicates, online theses, and books that met the inclusion criteria for further analysis. In the second round of screening, all review articles and conference papers without full text were removed, resulting in 68 articles for the following assessment stage. The third round of screening involved carefully reading the titles and abstracts of the remaining 68 articles, and 62 articles were ultimately selected for the full text and data review. Subsequently, the full texts of all 62 articles were carefully read, and 59 articles were further selected for the complete content assessment. However, after careful consideration, 5 articles were of concern, and a second round of full-text reading was conducted. From this group, only 2

Table 1
Sources and strings used to conduct the search.

Database	Search in	String
Scopus	TITLE-ABS-KEY	TITLE-ABS-KEY ((Energy-Efficient) OR (Energy AND Efficien* AND Operation*)) AND ((Ship* OR Vessel*)) AND ((Seafarer* OR Crew*))
Web of Science	All Fields	Energy Efficien* ship* Operation* ship crew (All Fields)

articles were deemed satisfactory and added to the final list of articles. For this study, only articles published in peer-reviewed journals and conferences were selected. We also chose 2 articles out of 7 from the discarded articles for further reading and data extraction using the snowballing method. As a result, 58 articles were included in this review study.

This study utilized a Systematic Literature Review (SLR) using the PRISMA method [82,90]. The process of conducting the SLR was divided into four main phases, and the flowchart is shown in Fig. 1 described below:

1. The initial phase, referred to as "Identification," involves searching multiple databases for relevant information, setting essential criteria for inclusion, and removing duplicates. Additionally, 26 published articles were found through Google Scholar and citation searches based on the references of selected papers.
2. The second phase, "Screening," is a three-stage process that involves evaluating titles and abstracts in accordance with the predetermined inclusion criteria.
3. The third phase, "Eligibility," involves utilizing predetermined parameters and assessing the full text to determine if the article meets the inclusion criteria.
4. In the fourth phase, "Inclusion," full-text articles are selected, and papers are examined in their entirety. We categorize articles based on their focus on developing energy efficiency measures, developing innovative tools, software, or methods to help ship crews adopt energy efficiency operational measures onboard ships, involving crew members in the implementation of energy efficiency operational

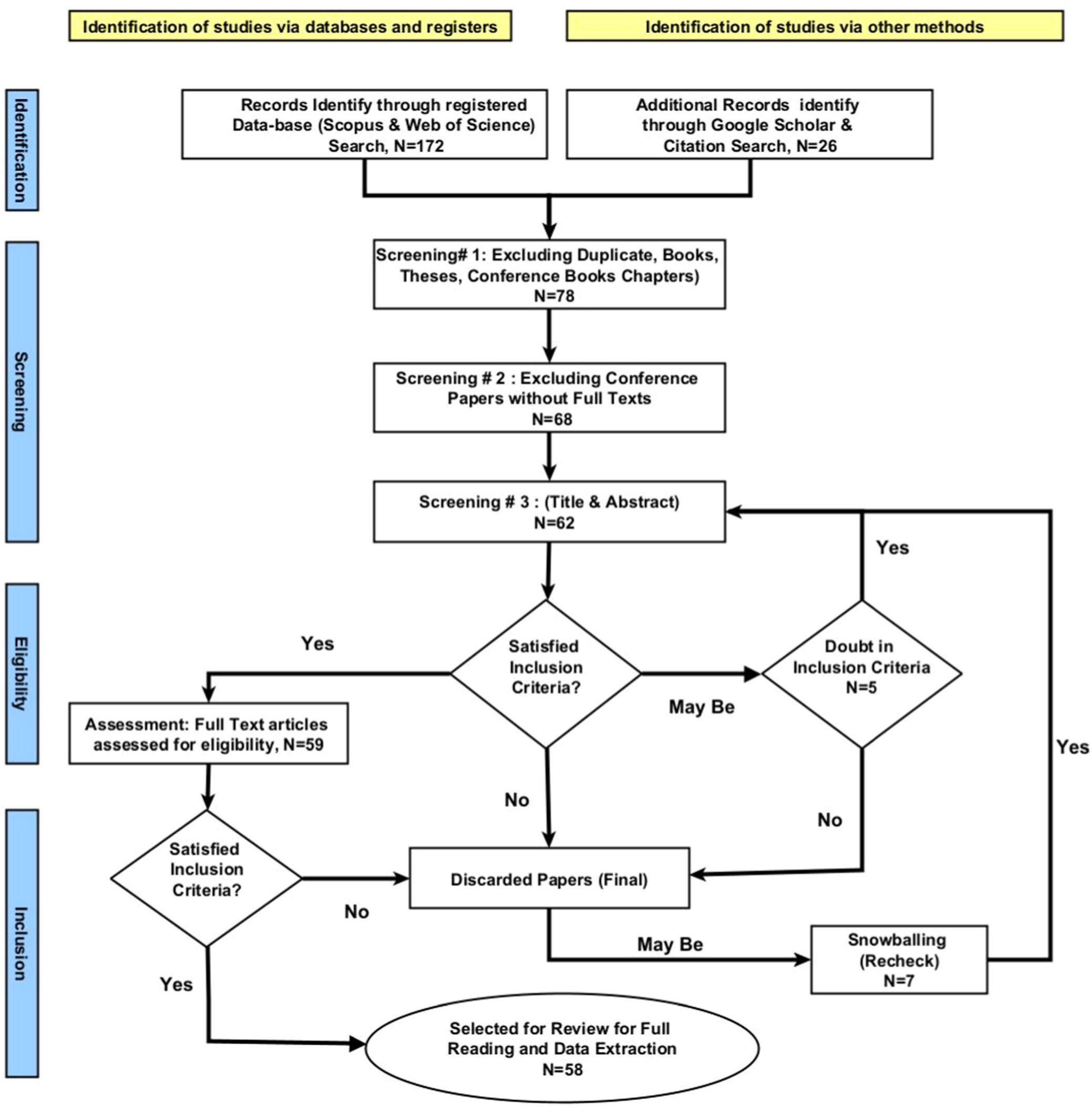

Fig. 1. The process flowchart for a systematic literature review (SLR).

measures, and providing training activities for raising awareness of energy efficiency measures and ensuring that they have the necessary knowledge. The snowballing method is utilized to locate additional publications from the discarded papers by thoroughly reviewing the title, abstract, and full text.Top of Form

The purpose of following the PRISMA method was to ensure a rigorous and transparent approach to the systematic review process and to minimize the risk of bias in the selection and analysis of literature. By adhering to this method, the study aimed to provide a comprehensive and reliable overview of the existing literature on the topic of interest.

Only research articles and conference papers about energy efficiency operational measures or energy-efficient ship operations in which ship crews or seafarers are involved in implementing measures, seafarers' training programs, or activities related to energy-efficient ship operations are considered for inclusion. In Table 2, we present a summary of our study's results, including the index and accuracy rates. The index rate represents the proportion of papers that met our inclusion criteria compared to the total number of papers in the database. Similarly, the accuracy rate represents the proportion of relevant items retrieved by the search strategy compared to the total number of items included in the study. The study utilized Scopus and the Web of Science to gather relevant papers, and Scopus demonstrated the best search accuracy rate (0.299) among the two databases. As per the report, the Scopus search method is more reliable and accurate than the other sources.

2.3. Selection criteria

Numerous papers are available for studying maritime energy efficiency, green shipping, and decarbonization in the shipping industry. These peer-reviewed articles examine experimental, case studies, and qualitative research, delving into the latest developments in operational measures for energy efficiency. They focus on aiding ship crews in more efficient ship operations and explore the involvement of crewmembers and ship managers, along with seafarer training programs, in achieving energy-efficient ship operations. This review study aims to answer questions regarding the impact of energy-efficient ship operation on seafarers' regular work on board ships, the comfort level of ship crews in implementing energy efficiency measures, and the effectiveness of seafarer training programs for energy-efficient ship operation after a decade of maritime energy efficiency regulations enforced by IMO.

The review study involved a rigorous screening process consisting of six stages to select articles that met specific criteria. To be included in the review, the articles had to meet the following requirements: (1) availability of information to answer any of the research questions, (2) written in English, (3) focus on the maritime sector and investigating energy-efficient ships operations or energy efficiency operational measures involving ship crews, (4) presenting relevant experimental, case studies, or qualitative studies in the fields of maritime energy efficiency, green shipping, or decarbonization of shipping, (5) presenting new information not previously reported or analyzed by the same authors, and (6) peer-reviewed and published journal articles and conference papers between January 1, 2013, and January 15, 2023. These stringent criteria ensured that the final selection of articles provided valuable and up-to-date insights into the maritime sector's energy efficiency and green shipping practices, contributing to the advancement of the field.

Following the initial screening process that excluded duplicates, books, published theses, and conference book chapters, 78 articles were assessed. Subsequently, only 58 articles satisfied all six criteria established for inclusion. Therefore, a final list of 58 articles was selected for inclusion in the study.

2.4. Data collection and extraction

During the research process, information extraction and data collection played an important role, enabling a comprehensive analysis of the subject matter. An extensive set of inclusion and exclusion criteria was applied to ensure the gathered data was relevant to the three research questions. This review study focused on gathering information about the maritime sector, emphasizing the engagement of seafarers in the implementation of energy-efficient operational measures onboard ships. Attendees of research surveys were limited to seafarers, focusing on energy efficiency operational standards. Research methods, objectives, and challenges were also considered during the analysis process. Using this approach, 58 peer-reviewed articles met all inclusion criteria, ensuring a comprehensive study.

3. Materials and methods

Numerous studies have been conducted in the last decade in the maritime industry focusing on innovative green technologies, decarbonization practices, energy-efficient ship operations, and seafarers' education and training to enhance their awareness and knowledge of energy efficiency regulations and measures. A wide variety of methodologies have been used, including experimental research on innovative technologies, case studies, quantitative surveys, and qualitative surveys. The primary objective of this article is to use an overview of energy-efficient ship operations and an overview of the progress made in energy efficiency operational measures and training programs that assist ship crews and managers in adopting more energy-efficient practices. An assessment of the level of comfort that ship crews have with energy efficiency measures has been conducted using case studies, qualitative questionnaires, and interviews with ship crews to determine the effectiveness of training programs for enhancing knowledge and awareness of implementing such measures on board ships. The findings and results are presented in Table 3 and Table 4.

4. Energy-Efficient Ship Operations

It is essential to remember that a ship's optimal energy-efficient operation is determined by various factors such as its type, cargo, routes, and others. SEEMP will allow vessels to operate in an energy-efficient manner, which includes a number of measures developed to reduce fuel consumption and GHG emissions. According to Annex VI, Chapter 4 of the International Convention on the Prevention of Pollution from Ships (MARPOL), all ships must have a SEEMP (IMO, 2011). Since January 1, 2013, SEEMP has been mandatory for new and existing ships to reduce GHG and energy consumption (IMO, 2012). It recommends quantifying goals in four phases: planning, action, measurement, and improvement after self-evaluation [51,62,94]. SEEMP consists of three parts: Part I examines ways to reduce carbon intensity and improve energy efficiency (IMO, 2013), and Part II deals with measuring and reporting used fuel data (IMO, 2016a). Vessels are required to specify how they plan to achieve their CII targets in Part III [62].

Table 2
The presentation of the systematic review results conducted to determine the accuracy rate of the search sources.

Database	Found	Accepted	Discard	Duplicate	Accepted	Discard	Index Rate	Accuracy Rate
Scopus	137	54	83	0	41	13	0.707	0.299
Web of Science	35	3	18	14	2	1	0.034	0.057
Google Scholar & Citations	26	21	3	2	15	6	0.259	0.577
Total	198	78	104	16	58	20	1.000	0.293

Table 3
List of selected articles related to energy efficiency measures, scope and methodology.

Sl. No.	Articles and Sources	Scope of the Study	Energy Efficiency Measures Studied	Methodology Utilized in the Study
01	Duan et al.[36]	Design and development of a sensor-based software system for determining the best practices in energy efficiency for ship managers and crew members.	Innovative software/tools to enhance energy efficiency management.	An expert survey in the maritime industry in China
02	Sørensen et al. [109]	The best practices for reducing fuel consumption for working vessels with a decision support system	Reduce fuel usage by power optimization	Case study and innovative software
03	Poulsen et al.[99]	Execution of virtual arrival and explanation of why shipping will not reduce emissions.	Virtual arrival operation energy efficiency and commercial operation influence.	Qualitative research by conducting interviews with ship managers and ship crews
04	Christodoulou & Cullinane[25]	The decarbonization of short-sea shipping through voluntary initiatives and reactions to environmental challenges.	Cold ironing, usage of low-carbon fuel, electrification, larger ship's construction and crew awareness and training	Case study approach to real-life cases and the semi-structural interview
05	Wang et al.[118]	Speed optimization approach by boosting sailing duration and main engine low-load operating range	Speed Optimization operational EE measures by boosting sailing duration with the low-load operation of the propulsion engine	Case study approach
06	Hüffmeier & Johanson[48]	Energy efficiency in shipping involves technical solutions, incentive schemes, and data collecting and analysis.	Energy efficiency technical solutions, incentive schemes, and data collecting	Review, Interview, and data collection
07	Viktorelius[114]	Developing an energy monitoring system for the crew of a shipping company	The use of an energy monitoring system by the ship crew	Collection of data from ships and case study
08	Baldi et al.[10]	Identifying key inefficiencies and assessing waste flows and processing to determine waste energy recovery potential in Chemical Tankers	Waste heat recovery energy efficiency operational measures in chemical tankers	Case study and ships' data collection
09	Hansen et al.[46]	A Study on how the SEEMP can maximize crew efficiency and support energy efficient ship operations at the operational level.	Effective implementation of SEEMP measures	Interview of the crewmembers
10	Poulsen & Sampson[96]	Problems of using virtual arrival measures to reduce GHG emissions in shipping	Virtual arrival EE operational measures	A qualitative study using interviews with key stakeholders
11	Viktorelius & Lundh[115]	How shipping stakeholders practice and understand energy efficiency, and how organizational and cultural factors affect it.	Implementation of various EE Operational measures.	A qualitative study using semi-structured interviews with key stakeholders.
12	Nguyen[84]	A methodical and systematic approach to low carbon emission solutions for maritime.	Multi-criteria decision-making can assist decision-makers in making optimal decisions for the adoption of EE onboard ships.	By reviewing relevant literature, a multi-aspect framework has been developed.
13	Dewan et al.[30]	Identifying the shipping industry's key barriers to execute energy efficiency operational measures.	Operational measures within SEEMP that improve energy efficiency.	A mixed-mode survey of shipping industry professionals, including ship owners, managers, and operators
14	Zaccone et al. [121]	The challenge of optimizing ship routes to minimize fuel consumption and CO_2 emissions while accounting for real-time weather conditions	Optimization of ship routes using real-time weather data	A case study of the optimization tool being used to plan ship routes between two ports
15	Lützen et al.[77]	Design a framework to evaluate and improve the energy efficiency of working vessels, considering their operational features.	Provides a systematic approach to evaluating and improving the energy efficiency of working vessels	Based on a review of existing literature and analysis of the specific operational characteristics of these vessels
16	Zhang et al.[123]	Identifying key factors that can be targeted to improve energy efficiency in Arctic navigation	The factors that affect energy efficiency in Arctic navigation include environmental conditions, vessel design and operation, and crew competency.	The interpretative structural modelling (ISM) method to analyze the relationships between the various factors
17	Beşikçi et al. [18]	Employ a fuzzy analytic hierarchy process (AHP) to analyze and prioritize energy efficiency measures for ship operations to find the most effective energy efficiency measures in ships.	Energy efficiency measures for ship operations, including route optimization, speed reduction, hull and propeller cleaning, and engine maintenance	Used fuzzy AHP to evaluate and prioritize different energy efficiency measures, then weighed the criteria and graded the options using expert views.
18	Johnson & Andersson[69]	Various barriers to industrial energy efficiency adoption and execution to find solutions.	Barriers to energy efficiency include factors such as market conditions, regulation, technology, and organizational culture.	Using semi-structured interviews to Conduct qualitative research
19	Brynolf et al.[22]	Reducing the environmental impact of shipping through improving energy efficiency and reducing fuel usage	Energy efficiency strategies include improving engine design, speed optimization, optimizing voyage planning, and implementing energy-efficient technologies.	Case studies, data analysis, and modelling
20	Poulsen & Johnson[95]	The factors that affect the decisions and outcomes of energy consumption monitoring systems in shipping	Energy consumption monitoring systems as an EE operational measure in shipping companies	A qualitative study that used semi-structured interviews with shipping company employees and energy consultants
21	A. Ölçer & Ballini [86]	A multi-criteria decision analysis (MCDA) framework for evaluating trade-off solutions in Maritime transport.	Energy efficiency measures for ships, such as using cleaner fuels, optimizing routes, and reducing vessel speed	Both qualitative and quantitative methods in a mixed-methods approach
22	Poulsen & Sornn-friese[98]	Worked on common themes and patterns related to the impact of ship management models on energy energy-efficient operation of ships	Two types of energy efficiency measures: technical and operational	A qualitative case study using data collected from interviews with 10 shipping companies
23	Schøyen & Bråthen[107]	Improve the energy efficiency in the field of transportation and logistics, specifically short sea container shipping.	The energy efficiency of short sea container shipping, such as optimizing vessel speed,	A case study of a short sea container shipping route in Norway to analyze the potential for energy savings

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Table 3 (*continued*)

Sl. No.	Articles and Sources	Scope of the Study	Energy Efficiency Measures Studied	Methodology Utilized in the Study
			improving vessel design, and using alternative fuels	
24	Armstrong & Banks[6]	An integrated approach to energy-efficient ship operations, including business focus areas and technical, operational, and commercial stakeholders' roles.	Various measures to improve energy efficiency in shipping	Case studies and data analysis
25	Lu et al.[76]	A semi-empirical model for estimating ship operational performance to optimize energy efficiency, which helps ship crew to make decision	Optimization of ship operational performance for energy efficient operation of ships by using a semi-empirical tool	Data analysis and modeling
26	Johnson & Styhre [72]	Short-sea shipping's potential for energy efficiency gains through reduced time in port	Optimized time in port as an energy efficiency operational measure	Case studies and data analysis
27	Johnson et al.[70]	Short-sea shipping energy efficiency barriers.	Measures to improve short-sea shipping's energy efficiency	Case studies and interviews with shipping companies
28	Johnson et al., [71]	Evaluate the potential emissions reductions of the SEEMP compared to ISO 50001 and the ISM Code.	The effectiveness of SEEMP in reducing CO_2 emissions from a ship's operation	A comparative analysis of SEEMP, ISO 50001, and the ISM Code using a framework
29	Vijapur et al.[112]	Develop a model that can help to make decisions on vessel routing, speed, and other factors that can affect energy efficiency.	Various ship's operational efficiency parameters, such as vessel speed, engine power, and weather conditions that, can affect fuel consumption	Ship's data from the Automatic Identification System (AIS) and the vessel's sensors for testing the model and its accuracy
30	Jafarzadeh & Utne [66]	Identifying barriers and gaps to adopting energy efficiency in shipping and developing a framework for bridging the energy efficiency gap in shipping	Energy-efficient technologies and practices, as well as crew incentives	A conceptual framework to analyze the factors that contribute to the energy efficiency gap in shipping by reviewing existing literature and case studies to support their arguments
31	Papanikolaou et al.[93]	The development of a comprehensive framework for energy-efficient and safe ship operation to enhance energy efficiency and safety in the maritime sector	Various measures, such as improving ship design, optimizing ship operation and maintenance, and developing decision-support systems for ship operators	Case studies to support their arguments and provide insights based on existing articles
32	Insel et al.[65]	A decision support system (DSS) to optimize ship propulsion system settings in real-time for energy-efficient ship propulsion	An energy-efficient ship propulsion system is optimized in real-time based on voyage conditions, trim, draft, propeller pitch, and RPM.	Simulation-based experiments to evaluate the performance of the prototype DSS under various operating conditions
33	Ballou[11]	Ship energy efficiency management, emphasizing the need for a holistic strategy to maximize ship energy efficiency	Various EE operational measures, such as hull design, propulsion systems, onboard equipment, and operations, to optimize energy efficiency	A systematic approach that considers all aspects of ship energy efficiency management
34	Rehmatulla & Smith[104]	Focuses on the barriers to energy efficiency in the shipping industry.	Barriers that prevent the implementation of energy efficiency operation measures onboard ships	A triangulated principal-agent problem investigation that includes stakeholder interviews, literature reviews, and case studies
35	Xing et al. [120]	Technological review to identify potential alternative marine fuels that reduce sulphur dioxide emissions, nitrogen oxide emissions, and CO_2 emissions simultaneously	Energy efficiency measures to reduce CO2 emissions from ships using alternative or low-carbon fuels	A qualitative ranking was conducted using existing articles and multidimensional evaluation frameworks.
36	von Knorring [116]	Analyses maritime companies' energy efficiency practices and the challenges they encounter in executing energy audits	Energy auditing involves measuring energy consumption, analyzing energy consumption patterns, and identifying areas for improvement.	Case studies and best practices to provide an overview of the barriers and opportunities for energy audits in the shipping industry based on reviewing the literature
37	Bännstrand et al. [13]	Energy efficiency optimization as part of the SEEMP	Optimizing ship energy efficiency with the SEEMP	A qualitative survey of various shipping companies and analyzed the collected data to evaluate the effectiveness of the SEEMP.
38	Waliszyn et al. [117]	Ship energy efficiency management plan (SEEMP) measures and their implementation for seafaring model ships	Energy efficiency measures involved in the SEEMP include efficient engines, optimized ship design, and onboard monitoring systems.	An overview and description of the Ship Efficiency Management Plan and its components from existing literature
39	Kitada et al.[73]	Reviewed innovative research on the management of maritime energy.	Researched energy efficiency improvements in the shipping industry at the frontiers of science	Review of recent maritime energy management research
40	Bassam et al. [14]	Evaluating voyage execution, slow steaming, and hybrid electric power and propulsion concepts using fuel cells as EEDI and SEEMP measures to improve the ship's propulsion system efficiency.	Voyage execution, slow steaming, and hybrid electric power and propulsion concepts using fuel cells as SEEMP measures	Case studies and ship voyage simulation
41	Rehmatulla et al. [103]	Assessment of over thirty technologies to improve energy efficiency and reduce CO2 emissions	Various energy efficiency technologies and measures that reduce CO2 emissions	A survey of shipowners and operators on a cross-sectional basis
42	Balcombe et al. [7]	A comprehensive assessment of various decarbonization options, including liquefied natural gas (LNG), biofuels, hydrogen, nuclear, carbon capture and storage (CCS), as well as efficiency measures focusing on the technological and available policy options.	Various energy efficiency measures, including biofuels, liquefied natural gas (LNG), hydrogen, nuclear, carbon capture and storage	A review study on the assessment of various decarbonization options, specially low-carbon fuels.
43	Ghaforian Masodzadeh et al. [42]	Identifying various barriers and their solutions for successful decarbonization in maritime industry	Various operational and technical EE measures for decarbonization in shipping industry	A review study on various barriers and their solutions for maritime decarbonization

Table 4
List of selected articles related to seafarers' training on energy efficiency, scope and methodology.

Sl. No.	Articles and Sources	Scope of the Study	Energy Efficiency Measures Studied	Methodology Utilized in the Study
01	de Melo et al.[26]	Designing a training management system for effective emissions control and enhancement of energy efficiency in ships	Management of emissions and ship energy efficiency	Reports and proposal of the training program
02	Beşikçi et al.[19]	Assessing awareness and understanding of ship energy efficiency measures from the perception of seafarers	Awareness and knowledge of energy efficiency measures	Qualitative survey
03	Jensen et al.[68]	Training ship crew in energy-efficient operations using bridge simulators.	Awareness and knowledge of energy efficiency operational measures	Assessment of proficiency of ship crews by using bridge simulators
04	Dewan & Godina[27]	Identifying the effectiveness of seafarers' training programs and activities that can enhance their ability to implement operational measures in ships.	Operational energy efficiency measures implemented by crewmembers onboard ships and ship managers ashore	Mixed mode survey among seafarers
05	Kitada & Ölçer[75]	The role of human factors in achieving energy efficiency in shipping and examines the challenges and opportunities for improvement.	Explores the human factors that can influence energy efficiency in shipping	A conceptual review paper
06	Banks et al. [12]	Energy efficiency knowledge and motivation among seafarers, along with challenges and opportunities for seafarers to promote energy efficiency.	Energy efficiency knowledge and awareness among seafarers	The survey included questions and follow-up interview
07	Oliveira et al.[88]	Designing a simulator-based training tool, "Tomorrow's On-Board Learning System" (TOOLS), to enhance seafarers' skills and knowledge	E-learning tools to improve the skills and knowledge of seafarers for better energy-efficient operation of ships	Used E-learning modules and interactive simulator training and surveyed to gather feedback from seafarers who used the system.
08	Baldauf et al.[8]	Training requirements for energy-efficient ship operations and challenges associated with them	Training and education of seafarers in promoting the energy-efficient ship operations	The critical data, findings, and recommendations of previous literature
09	Ölçer et al. [87]	Development of a postgraduate marine energy management program at WMU and emphasizes the demand for special education and training to promote energy efficiency in the Maritime sector.	Postgraduate program on topics such as energy efficiency, renewable energy, and environmental management to promote energy efficiency in the shipping industry	A survey of WMU alums to assess the program's effectiveness in preparing students for careers in the shipping industry.
10	Viktorelius [113]	The role of ship crew in accomplishing energy efficiency objectives and the value of human factors, communication, and teamwork in enhancing ship performance.	The importance of engaging and motivating crew members to improve energy efficiency	Case studies and best practices by reviewing previous articles for improving crew engagement and motivation
11	Dewan & Godina[28]	Involvement of ship managers ashore and crewmembers aboard ships in implementing various energy efficiency operations.	Various cost-effective energy efficiency operational measures are mostly included in SEEMP.	Mixed mode survey among seafarers who work ashore in offices and onboard ships
12	Kitada & Ölçer[74]	Issues with people and Technology management for Energy-Efficient Shipping and Corporate Social Responsibility	Energy efficiency measures such as optimizing vessel design, fuel-efficient operations, and energy management systems	A conceptual study that analyzes the challenges and opportunities in implementing CSR
13	Jensen et al.[67]	Develop an educational program to train maritime students and professionals in the principles of energy-efficient ship handling.	Several energy efficiency measures can be applied to ship handling, including optimized route planning, reduced speed, and improved engine performance.	A combination of theoretical instruction and practical exercises, such as simulation exercises and on-board training
14	Ziarati et al.[124]	Development of an online delivery platform for a maritime energy management system that delivers maritime energy management tools and resources	Some energy efficiency measures include monitoring fuel consumption, optimizing voyages, and analyzing performance.	Case studies of a shipping company are used to check the effectiveness of the course.
15	Rasmussen et al.[102]	The role of knowledge, communication, and situational awareness in promoting energy efficiency in the maritime sector	Some measures to improve energy efficiency, including efficient technologies, optimized ship design, and	A qualitative analysis of data collected from interviews with crew members

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Table 4 (*continued*)

Sl. No.	Articles and Sources	Scope of the Study	Energy Efficiency Measures Studied	Methodology Utilized in the Study
			adopting sustainable practices	

The DNV's Energy Transition Outlook 2023 shows that six technologies are getting greater attention in the shipping industry, which necessitates a thorough understanding of all the options available to it [32]. In addition to solid oxide fuel cells, liquefied hydrogen, air-assisted propulsion, air lubrication systems, shipboard carbon capture technology, and nuclear propulsion are among them. Using alternative or low-carbon fuels, energy efficiency operational measures, and innovative technologies, including retrofits, innovative tools, and software, ships can operate more energy efficiently and consume less fuel. Installing energy-efficient technology, such as air lubrication systems, modern propulsion systems, and waste heat recovery systems, can effectively mitigate ship fuel consumption and GHG emissions through retrofitting [103]. Using energy-efficient tools and software, such as voyage optimization systems and trim optimization software, can also significantly lead to fuel savings [31]. The use of low-carbon fuels such as LNG, biofuels, and hydrogen can substantially reduce carbon emissions, with the help of LNG lowering emissions by up to 23% compared to traditional bunker fuels [7,120]. Ship owners and ship charterers can play a vital role in reducing GHG emissions from ships by introducing these alternative low-carbon fuels. The energy efficient operation of vessels can be mapped as presented in Fig. 2:

4.1. Development of energy efficiency operational measures

To reduce CO2 and other GHG emissions, all ships must comply with energy efficiency regulations and have the SEEMP onboard ships. Using the SEEMP, ships, and fleets can raise their energy efficiency over time and apply techniques for increasing performance while reducing energy usage and fuel consumption. Numerous technological innovations and operational measures for energy efficiency and carbon reduction have been identified by researchers [10,17,36,76,89,105,112,114,121]. A number of energy-saving technologies, such as hull air lubrication, novel hull forms and ship structures and waste heat recovery systems, efficient lighting, and renewable energy technologies, are installed on newly built ships [45]. A potential reduction of 10% in CO2 emissions can be achieved by considering logistical factors, berthing schedules, and contractual restrictions [23]. During voyages, keeping the engine load constant and minimizing the main engine's output power can reduce fuel consumption [40]. AIS data can optimize vessel speed, ensuring fuel efficiency on every voyage [101]. Researchers Bassam et al. [14] reveal that time savings of up to 4% and earlier arrival are the results of consistent speed mode and careful voyage planning. Fuel-efficient voyages can be further enhanced by utilizing weather routing, which considers wind and wave conditions, vessel and cargo characteristics [125]. Optimizing the trim and draft of the ship is essential for achieving optimal performance [105]. As a result of regular hull cleaning, including propeller polishing and cleaning, microorganisms are less likely to attach to the propeller, reducing friction and fuel consumption [15,83,107].

Ensuring optimized performance of the ship's propulsion engine, a ship can operate energy efficiently and reduce GHG emissions. A significant amount of fuel can be saved by making engine adjustments, such as increasing cylinder pressure and fine-tuning combustion pressure [5,9]. Reducing fuel consumption by minimizing ship resistance by steaming slowly, reducing fuel valves for injection, and cutting off additional turbochargers [41,107]. Additional opportunities for fuel savings can be found by producing steam from exhaust gas boilers and optimizing power usage at ports [9]. A number of energy-saving practices can be implemented at ports, such as turning off non-essential consumers, fans, and pumps, as well as optimizing the use of power by ship operators, which can result in a reduction in operating costs and fuel consumption [43]. Giannoutsos & Manias [44] suggest implementing Variable Frequency Drive (VFD) tools in the engine room to optimize cooling systems and ventilation fans. Optimal scheduling and sequencing of vessel arrivals and departures help to reduce waiting and idle times, resulting in fuel savings and emissions reductions [3]. Poulsen & Sampson [97] reveal that optimizing port calls reduces fuel consumption and GHG emissions. In order to ensure energy-efficient ship operations through wide adoption of various technological and operational measures, shipping companies must promote energy-saving practices and provide training to their ship crews [12,15,55].

4.2. Implementation of energy efficiency operational measures onboard ships

SEEMP provides guidance for enhancing ship energy efficiency by implementing operational measures such as improving voyage planning, weather routing, optimizing speed, reducing power consumption, optimizing ship handling, maximizing power management, and optimizing cargo operations [13,15]. According to numerous studies, energy efficiency measures can significantly decrease fuel consumption and GHG emissions in the shipping industry. A survey conducted by Duan et al. [36] found that energy efficiency measures significantly reduce fuel consumption and GHG emissions. Several technical and operational measures have been proposed to improve energy efficiency onboard ships and lower GHG emissions. Researchers Lu et al. [76] presented a ship operational performance prediction model for voyage optimization toward energy-efficient shipping. They have proposed a semi-empirical model for estimating ship operational performance to optimize energy efficiency, which helps ship crews in making decisions. A decision support system has also been designed to help ship operators make energy-efficient ship propulsion decisions by the study group by Insel et al. [65]. These measures include modular decision support systems for working vessels, combined strategies to reduce GHG emissions and improve energy efficiency, voyage decision-making, and voluntary

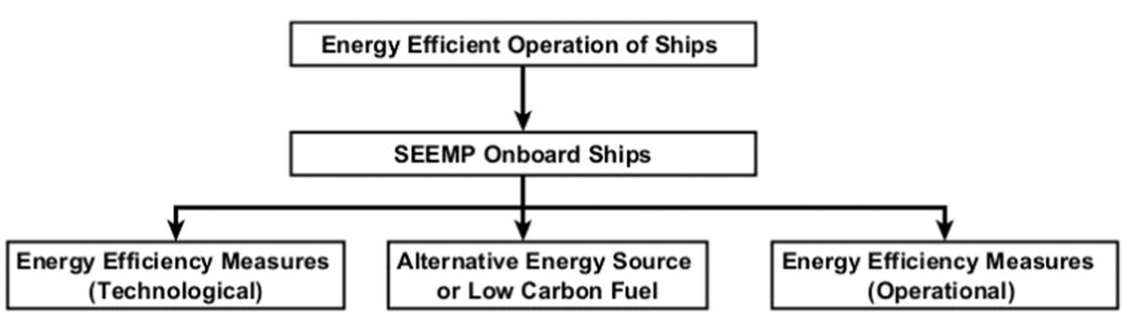

Fig. 2. Energy efficient operation of ships and SEEMP measures.

initiatives [25,89,99,109,112,118]. According to the study group Schøyen & Bråthen, [107], voyage management plans, slow steaming, and optimal trim are crucial measures to monitor energy efficiency in short-sea container shipping. Johnson & Styhre [72] identified that reducing time spent in port would increase energy efficiency in short-sea shipping.

An integrated approach to improving energy efficiency in ships that includes energy-efficient design, operational optimization, and technological innovations was proposed by Armstrong & Banks [6]. Surinov & Shemonayev [110] reveals the option of dual-fuel ships instead of oil-fuelled ships to minimize carbon emissions and increase energy efficiency. In their study, Papanikolaou et al. [93] introduced the Energy Efficient "Safe Ship Operation (SHOPERA)" project, which aims to develop innovative solutions to improve energy efficiency and safety in ships. As an added benefit, de Melo et al. [26] discussed the concept of achieving zero ship emissions in the context of "Project Greenship." Using energy-monitoring technology, Viktorelius [114] shows how the shipping industry reduces GHG emissions and improves energy efficiency. Furthermore, using Internet of Things (IoT) and big data analytics in conjunction with computer-controlled intelligent navigation allows ships to continuously monitor and adapt to changing conditions, ensuring optimal performance [80]. Ships can manage variables like weather conditions, navigation routes, and speed in an effective manner with this approach, which is aligned with the SEEMP introduced by the IMO [4]. Ships can achieve maximum energy efficiency by actively adjusting operations based on real-time data, resulting in significant fuel savings and a reduction in environmental impact. Researchers Tan et al. [111] investigated how computer-controlled intelligent navigation systems could optimize ships' routes and speeds to enhance energy efficiency and save fuel.

It is important to note that while technical factors play an important role in achieving energy efficiency in shipping, human factors, such as the awareness, knowledge, and motivation of ship crew, also play a significant role in determining the effectiveness of energy efficiency measures. By using activity theory, the human element can be considered in the context of achieving energy efficiency in seaborne transportation [113]. Seafarers' awareness and knowledge of low-carbon energy-efficient operations are essential in promoting the adoption of energy efficiency measures [12,30]. Numerous studies have urged the shipping industry to implement energy efficiency measures to lower fuel consumption and GHG emissions. Technical and human factors contribute to this reduction in fuel consumption and GHG emissions. Ship operators must implement regulatory initiatives, implement effective training programs for ship crews, and implement decision support systems to promote energy efficiency.

5. Engagement of ship crews for implementation of energy efficiency operational measures

5.1. Ship management system and roles of crewmembers onboard ships

The Ship management system includes operations, maintenance, safety, and regulatory compliance. It starts with the ship owner, who may manage the ship directly by ownership management by hiring experienced ship managers. Ship managers ensures compliance with international laws and regulations, that the ship is seaworthy, and that the ship is always capable of transporting cargo in a cost-effective, safe, and reliable manner [91]. The ship owner must provide the facilities and resources for safe and effective operation of ships. This includes training the crew, complying with regulations, and maintaining the ship's systems. When a third-party ship management company is employed, they oversee all aspects of ship operations on a daily basis, including crew manning, training, and appointing ship and shore staff, sourcing supplies for the ship, advising on possible registration options, trade, maintenance options and so forth [21]. Shipowners with only a few vessels to manage could not afford the costs of specialized services, which third-party ship management companies can provide by spreading them over a more extensive fleet [92]. A cargo owner and charterer can work directly with a shipowner or commercial manager or by using a shipbroker as an intermediary [85]. Charter party agreements require discussions regarding freight rate, cargo type, loading and discharge ports, as well as vessel specifications as part of the negotiation process.

Seafaring is a unique profession with distinct working conditions, and over 1.6 million seafarers are employed in merchant shipping [50]. Seafarers are vital in the shipping industry for ensuring ships' safe and efficient operation. They transport goods from one port to another and ensure that global trade runs smoothly. Safety management, maintenance procedures, and emergency procedures are all included in the Safety Management System (SMS) manual. Additionally, the International Safety Management (ISM) Code outlines the roles and responsibilities of various stakeholders, including the crew, in ensuring ships' safe and efficient operation and specifies the minimum safety and pollution prevention requirements for ships [49,58,91]. Ashore and onboard personnel are crucial in ensuring that vessels are operated safely, efficiently, and environmentally responsible. The technical manager, also called a technical superintendent or marine superintendent, oversees the technical and navigational operations of ships under their supervision. In addition to providing technical support and guidance to the masters and chief engineers of the vessels, they ensure that all regulations and standards are followed [91]. The organizational structure of a ship typically consists of two primary departments, namely, the Deck Department and the Engine Department. The Engine Department, under the supervision of the chief engineer, is tasked with the efficient operation and maintenance of the propulsion engine and auxiliary machinery. In contrast, the Deck Department, headed by the chief officer, is responsible for cargo operations, deck maintenance, and safe navigation. The master is the highest-ranking officer onboard and is responsible for the overall operation and administration of the ship. The chief officer is the second in command and assumes the responsibilities of the master in their absence. The SMS manual of the shipping company outlines the responsibilities and authority of the master and other personnel to ensure the efficient and safe operation of the ship. A general ship management system chart has been presented in Fig. 3 as below:

5.2. The Engagement of Ship Crews for Adoption of Energy Efficiency Measures

Several cost-effective energy-saving measures have been highlighted for SEEMP in studies by [37,47,52], as well as recent studies by [13,34]. As part of these efforts, voyage planning, speed optimization, weather routing, trim, and ballast optimization, hull and propeller performance monitoring, propulsion and auxiliary engines performance monitoring, just-in-time arrival or virtual arrival, optimization of port operations, optimization of steam usage, slow steaming, waste heat recovery, autopilot adjustments, optimization of power usage, improved ship handling, enhanced fleet management, and crew training and awareness are among them. Crew members are directly involved in these measures since they are implemented during ship operations (IMO, 2012). The seafarers contribute directly to the implementation of energy efficiency measures and the performance of various operational tasks that contribute to reducing emissions and fuel consumption. A study by Dewan & Godina [28,29] indicates that the vessel's master and deck crewmembers are directly involved with energy efficiency measures for navigation and port operations, such as optimizing speed, voyage execution, weather routing, optimizing trim and ballast, just-in-time arrivals, and optimizing hull efficiency. Similarly, the chief engineer and engine crews onboard ships monitor propulsion, power generation, and management operations for energy efficiency. This process includes monitoring propulsion and auxiliary engines' performance, optimization of the ship's power, waste heat recovery, slow steaming, and propeller and hull monitoring. Masters and chief engineers of the fleet are

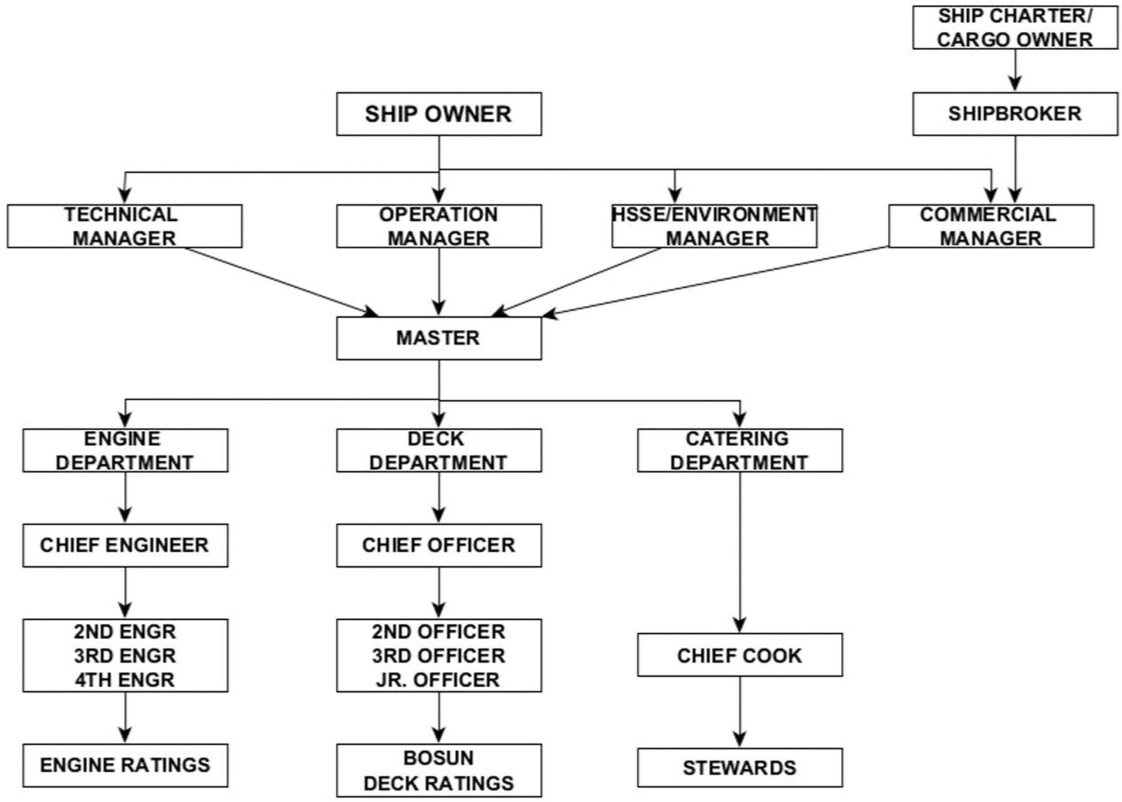

Fig. 3. A general ship management chart.

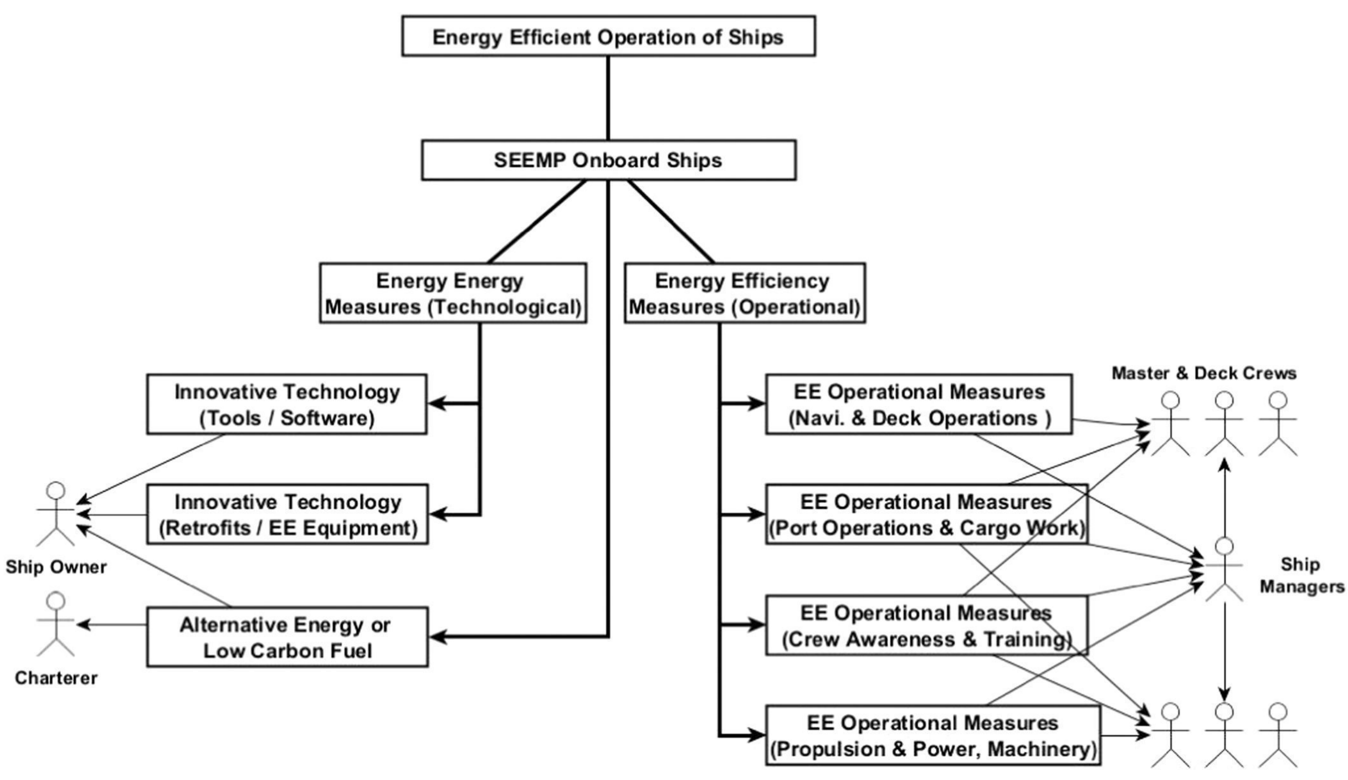

Fig. 4. The engagement of ship owners, ship managers, and crewmembers in the implementation of energy efficiency operational measures.

under the supervision of the shore technical managers, who oversee navigation, port management, propulsion, power generation, and power management. Using intelligent energy efficiency tools or software driven by data [122], SEEMP measures can be monitored and improved remotely by technical managers from shore offices. In addition, the Vessel Performance Monitoring Analysis System (VPMAS) has developed by Mak et al. [78], and Voyage Performance Onboard Analyzer (VPOA) by Lu et al. [76] to monitor vessel performance remotely from ashore offices. To achieve sustainable and greener shipping practices, seafarers' active involvement, adherence to procedures, and continuous improvement efforts are vital to the success of the SEEMP [74,77]. However, by summarizing the studies of researchers Balcombe et al. [7]; Dewan & Godina [28,29]; DNV [31]; Rehmatulla et al. [103]; Xing et al. [120] in Sections 4 and 5 focusing on the engagement of ship owners, managers, and crewmembers, the energy efficiency operational measures onboard ships can be mapped as presented in Fig. 4.

Ship crew members must report rough ship data during voyages, including main engine power and fuel oil consumption. In the event of non-compliance with energy efficiency-related EU MRV or IMO DCS regulations, monetary penalties and other consequences exist [2]. Additionally, ship data must be recorded monthly, at the beginning and end of each voyage, and every day between noon and noon (IMO, 2016a). This includes the following parameters: propulsion engine RPM (revolutions per minute), specific fuel oil consumption (SFOC) of the propulsion engine, engine power in kilowatts (KW), distance covered in nautical miles (NM), hours underway (H), fuel oil type, caloric value (CV), fuel data collection method, and EEDI.

6. Education and training on maritime energy efficiency in maritime industry

6.1. IMO capacity building initiatives on maritime energy efficiency for stakeholders

According to MEPC.213(63) Resolution, it is crucial to increase awareness and provide necessary training to the staff onshore and aboard for the successful execution of the SEEMP (IMO, 2013). The SEEMP guideline already emphasizes the importance of raising awareness and providing training to implement energy efficiency operational measures effectively. However, there is no clear definition of what "necessary training" means. Many crew members report needing to be introduced to the SEEMP or trained in its use despite being involved in developing and reviewing goals to some extent [46,113]. Researchers and classification societies claim that the success of these efforts depends on the ability of ship crews to learn new practices, skills, and knowledge [12,19,35,74].

To implement SEEMP measures onboard ships successfully, the IMO offers a range of training courses and workshops for government officials and other stakeholders from its Member States, covering maritime energy efficiency regulations, technical and operational energy efficiency measures, and the implementation of energy efficient measures for ships. As part of IMO's capacity-building initiatives, member states offer training courses to stakeholders to increase energy efficiency in the maritime industry [87]. As a result of the IMO's capacity-building initiatives and training framework, the shipping industry reduces its GHG emissions and promotes sustainable practices. Several global collaboration programs have been launched by the IMO over the last decade to improve energy efficiency and reduce GHG emissions from shipping in member states or party countries. In addition to these initiatives, Global Maritime Energy Efficiency Partnerships (GloMEEP), Global Industrial Alliance (GIA) to facilitate low-carbon shipping, Global Maritime Technology Cooperation Centers Network (GMN), and GreenVoyage2050 are also involved [38,60,61]. Initiated in 2015 in conjunction with the Global Environment Facility (GEF) and the United Nations Development Program (UNDP), the GloMEEP initiative encourages the adoption and implementation of energy-efficient solutions for shipping. Established in 2017, the GIA aims to identify and overcome obstacles to energy-efficient technology adoption and operational procedures in the maritime industry. As part of the GMN, five Maritime Technological Cooperation Centers (MTCCs) have been established across Africa, Asia, the Caribbean, South America, and the Pacific with the assistance of the European Union (EU). In addition to promoting low-carbon technology and operations and setting up voluntary pilot data collection and reporting systems, nations can develop energy-efficient maritime policies and measures. The GreenVoyage2050 project was launched in 2019 and aims to demonstrate and test technical solutions for reducing GHG emissions and improving knowledge and information sharing for maritime administrations in member states to support IMO's goal of reducing greenhouse gas emissions. Through these projects, all maritime sector stakeholders will receive energy efficiency training, sustainable practices will be promoted in developing nations, and green shipping will be encouraged. In May 2021, the GIA, a partnership under the IMO-Norway GreenVoyage2050 Project, launched a free, self-paced e-learning course, "An Introduction to Energy Efficient Ship Operation," for seafarers and other stakeholders [60].

6.2. Seafarer's training activities on maritime education and training (MET) domain

Energy efficiency enhancements and fuel-saving programs can only be successful with the understanding, motivation, cooperation, and participation of the crew [17]. The shipping industry's ambitious goals can only be achieved by crews understanding energy-efficient and low-emission operations. Even though they actively participated in setting and revising the SEEMP, many crew members claim they were never trained for the adoption of the SEEMP [75,110]. To facilitate the implementation of SEEMP measures onboard ships, ship crews need to be educated and trained. Ship captains and crew members report that shipping companies provide adequate training onboard ships, but not all training activities are effective [27]. Insufficient crew engagement in the SEEMP process and insufficient training, however, can reduce the effectiveness of SEEMP in ensuring ship safety and minimizing shipping operations' environmental impact [46]. The crew must be included in the SEEMP process and provided with sufficient and effective training in order to overcome these obstacles. They must have the skills and information necessary to make informed decisions and contribute to the SEEMP's goals. Several studies have explored education and training activities for seafarers or ship crews on maritime energy efficiency, including a project called 'GreenShip' [26], which aims to develop sustainable solutions for shipping by exploring alternative fuels, improving energy efficiency, and reducing emissions. The awareness and knowledge of seafarers of ship energy efficiency measures have been examined [46,118], along with energy-efficient operational training using ship bridge simulators [68], computer-based training using gamification tools on energy efficiency measures [88] and education design for energy-efficient ship handling [67]. Baldauf et al. [8] emphasized the training requirements and challenges of energy-efficient ship operation. The development of online delivery platforms for maritime energy management systems has also been explored [124], as well as the development of a holistic maritime energy management program at the postgraduate level [73]; [87]. Overall, these studies highlight the importance of education and training in promoting sustainable solutions and reducing emissions in the maritime industry.

Seafarers must be trained in energy-efficient operations, but more than formal education and training programs are required. With the IMO's revised GHG Strategy aiming for net-zero emissions by 2050, the maritime industry needs to provide training programs to ensure a safe transition to a decarbonized future. DNV Maritime Forecast estimates that 1.8 million seafarers will require additional training by 2050 based on decarbonization [33]. Increasingly, the maritime industry now requires higher-skilled seafarers with expertise in information technology, digitalization, and technical and organizational skills. Many crew members claimed that formal education, training, or environmental awareness-raising information campaigns could not teach people how to operate the ship energy-efficiently [113]. Most crew members learn best by interacting with the ship, testing strategies, and seeing how the energy system reacts to varied operating methods. Various training programs are accessible to mariners, including computer-based, simulator-based, aboard, in-house, and specialized training initiatives [12,60,68,88]. IMO's "Train the Trainer" course aims to train providers and their teaching staff to improve, update, and enhance existing Energy Efficient Ship Operation courses [16]. This training package is also designed to train the administrators to support the IMO capacity-building initiatives primarily focused on developing countries [57]. By partnering with the WMU in 2012, the IMO developed a model course on the energy-efficient operation of ships, which promoted energy-efficient ship operations and set performance standards. Topics covered include GHG emissions, climate change, IMO regulations, activities, and operational and technical components integrated into a realistic training environment [8]. Besides, energy efficiency measures and regulations are taught in pre-sea and post-sea training curricula, including MARPOL Annex VI Chapter 4. It is possible to provide a deeper understanding of energy efficiency concepts and practices by integrating maritime energy efficiency training into pre-sea and post-sea training curricula [27].

Many shipping companies and classification societies have already developed ship operation courses and materials geared toward energy efficiency [12]. As part of the energy efficiency project team, qualified individuals with technical skills, knowledge, and experience are also required. The project team or retrofit vendor can train crew members on the new energy-efficient systems installed on the vessel [27]. They have also reported that seafarers use computer-based training (CBT) programs that use game-based e-learning tools during onboard training. These programs provide seafarers with authentic situations for them to make informed decisions. Recently, simulators and game-based e-learning software have been used to provide training on energy-efficient ship operations [68,88]. These training initiatives are designed to raise seafarers' awareness of and familiarity with energy-efficient ship operating and GHG emission reduction. Simulators offer students opportunities to practice energy-efficient, low-carbon ship operations in a safe environment [12]. The full-mission simulator combines human and technical aspects, and Jensen et al. [68] claim that by reducing energy use by 10% by raising awareness, technological equipment is added. According to the study of Dewan & Godina [27], onboard training activities, including computer-based and simulator-based training, are the most effective training programs for seafarers to ensure energy-efficient ship operations. Onboard training conducted by the master, chief engineer, or the ship manager ashore, in-house training during pre-joining briefings given by the technical managers, and special training conducted by retrofit vendors or project teams provide seafarers with the most effective training programs. Shipping companies make many efforts to train their seafarers, but not all efforts are fruitful. However, summarizing the studies discussed in Sections 6.1 and 6.2 focusing on maritime energy efficiency training

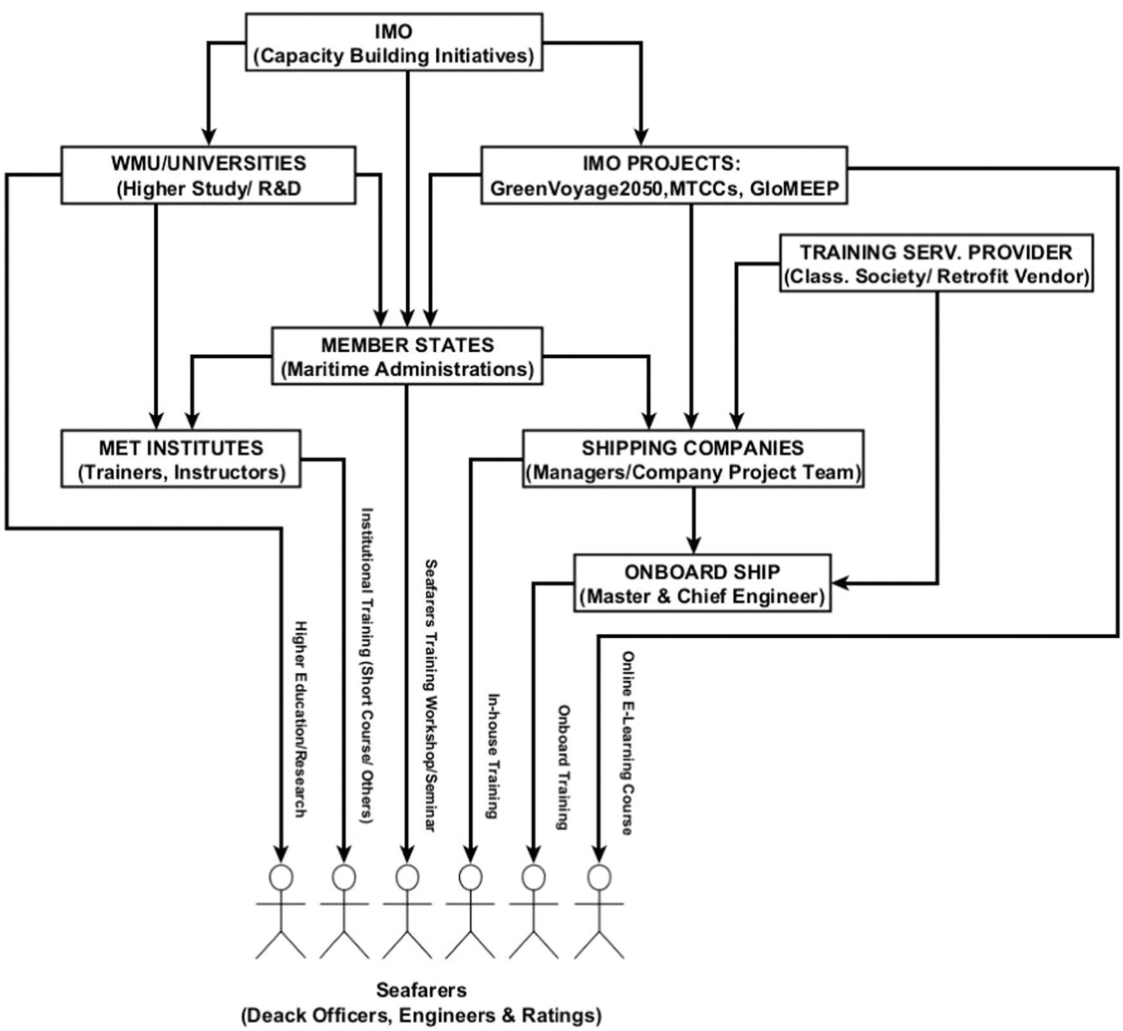

Fig. 5. Mapping of maritime energy efficiency training programs and activities.

programs and activities can be mapped as presented in Fig. 5.

7. Factors influencing seafarer's engagement in energy-efficient ship operations

Reviewing the selected papers in Tables 3 and 4, it has been determined that a number of factors influence seafarers' participation in energy-efficient ship operations. Banks et al. [12] reveal that seafarers' level of knowledge and attitudes toward low-carbon and energy-efficient practices can significantly affect their engagement. To operate ship energy efficiently, seafarers need to be knowledgeable about energy efficiency practices, procedures, technologies, and regulations [114]. For seafarers to gain the necessary skills to perform these tasks efficiently, onboard learning and decision support systems are crucial [8]. Seafarers' engagement in energy-efficient ship operations is positively associated with the adoption of energy monitoring technology and training on energy-efficient ship operational methods through ship bridge simulators [68,114]. In their study, Hansen et al. [46] found that communication skills and situational awareness influence seafarers' ability to participate in energy-efficient ship operations. The ship crew's lack of awareness and training and the resistance to change are some of the barriers to energy efficiency in the shipping industry [12]. Their attitudes and perceptions about energy efficiency significantly impact their engagement with energy-efficient ship operations [84]. In addition to human factors, social factors can affect seafarers' involvement in energy-efficient ship operations. Kitada & Ölçer [74] and Viktorelius [114] suggest that organizational culture, leadership, training, communications, and motivation must be considered.

New technologies, such as dual-fuel vessels, may provide seafarers with new opportunities and increase their involvement in energy-efficient ship operations [110]. With technological advancements, seafarers can monitor and optimize energy consumption on ships, allowing for more efficient operations. It has also been shown that seafarers' engagement in energy-efficient ship operations is also influenced by the availability and effectiveness of energy-saving technologies [10]. It may be possible to assist seafarers in making informed decisions regarding energy-efficient ship operations with the help of the innovative technology "Decision Support Systems (DSS)"[65]. A decision-making framework, on the other hand, can help evaluate trade-off solutions for cleaner seaborne transportation, thus increasing energy efficiency and increasing seafarers' participation in energy-efficient ship operations [86]. Researchers Viktorelius & Lundh [115] have demonstrated that organizational support and leadership play a significant role in seafarers' engagement in energy-efficient ship operations. In their study, Dewan & Godina [27] report that ship-shore cooperation can contribute to more effective training activities and increase motivation for seafarers to become more involved in energy-efficient ship operations. Audits of energy performance can provide useful information about ships' energy efficiency and identify areas for improvement [116]. Policies and regulations to reduce carbon emissions can encourage seafarers to engage in energy-efficient ship operations [7]. Private voluntary initiatives for decarbonizing short-sea shipping are key factors influencing the involvement of shipping companies and seafarers [25]. For shipping companies to promote energy-efficient practices, they must provide the necessary resources and support. When shippers and their agents have divergent interests, principal-agent problems can hinder the ship's energy efficiency [104]. Lu et al. [76] emphasize that the best incentive to encourage energy-efficient ship operations is a reward and recognition program for seafarers who achieve energy efficiency targets. However, seafarers' participation in energy-efficient ship operations can also be negatively affected by insufficient incentives, financial constraints, and inadequate infrastructure [30,66]. Barriers to energy-efficient ship operations can hinder the involvement of seafarers. It is difficult for seafarers to engage in energy-efficient ship operations within the short-sea shipping sector [69,70]. However, by summarizing all studies discussed in this section, the factors influencing seafarers' engagement in energy-efficient ship operations as presented in Fig. 6.

8. Recommendations for future research

8.1. Research gaps in operational energy efficiency measures adoption in shipping industry

Studies have focused on aspects such as voyage decisions, awareness of officers towards energy efficiency, and the implementation of energy monitoring technology. Some studies have examined private voluntary initiatives and the potential for decarbonization in short-sea shipping [25]. Over the last two decades, several studies have been conducted to develop innovative technologies, energy-efficient equipment and retrofits, improved energy efficiency methods, and sustainable energy sources or low-carbon fuels [103,120,31,36,5–7,99]. Moreover, research on the effectiveness of technical and operational measures, such as improving energy efficiency and reducing GHG emissions, still needs to be done. Finally, there is a need for studies to analyze the socio-economic factors that influence the adoption of energy efficiency practices in the shipping industry. Most studies noted that implementing energy-efficient measures could save fuel consumption and reduce GHG emissions. The researcher group Rony et al. [106] revealed the same. For example, studies highlighted the use of decision-making support systems [109], energy-efficient speed decisions [118], and technical and operational measures [89]. Furthermore, energy-monitoring technology [113] was explored to increase the adoption of energy-efficient practices. While these studies provide insights into the potential benefits of energy-efficient practices, there are limited research on adopting and implementing these practices. Johnson et al. [71] compared the SEEMP with ISO 50001 and the ISM code to assess the potential of the SEEMP to reduce CO_2 emissions which was a great initiative to study the potentiality of the SEEMP for GHG emissions control from the shipping industry.

Several studies have been conducted in the last decade to examine the drivers and obstacles to the implementation of energy efficiency measures [1,30,66,69,70,104], however, there are few studies

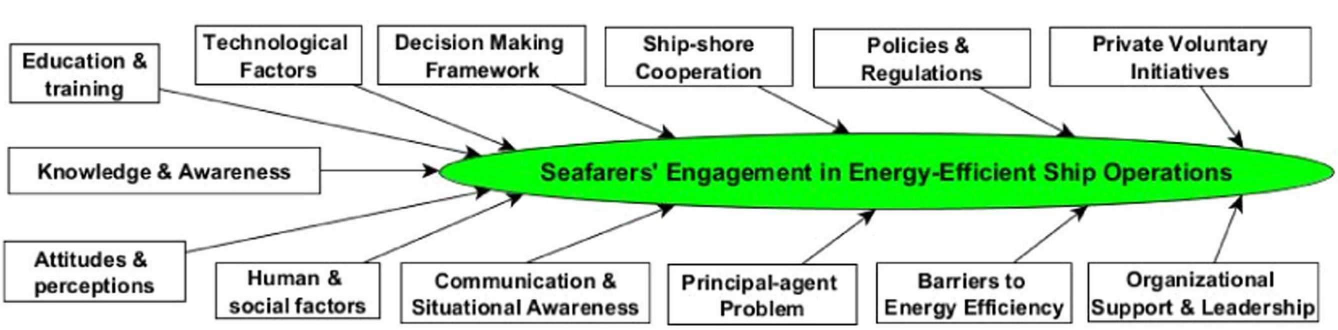

Fig. 6. Factors influencing seafarers' engagement in energy-efficient ship operations.

examining financial and regulatory incentives, as well as the role and influence of different stakeholders, including shipowners, operators, and ship crews. It is also important to note that there are still many research gaps in developing low-emission and net-zero emission ship technologies and examining their effectiveness. It has been highlighted in articles that very few studies have been conducted on the effects of energy efficiency practices on safety as well as on the impact of crew behavior and decision-making on ship energy efficiency, which was highlighted in articles [36,99,114]. Some research gaps still exist, such as the need for a standardized framework for energy-efficient ship operation, limited focus on the practical implementation of energy efficiency measures, and further investigation into the financial and economic aspects of energy-efficient shipping.

The integration of digital tools brings lots of changes in the maritime domain, blurring the boundaries of energy-efficient ship operations between ashore ship managers and aboard crewmembers [18,36,76,78,114,122]. In fact, innovations and digital tools are transforming the maritime sector, reshaping the roles and practices of seafarers. The transformation of seafarers into digital operators necessitates a comprehensive reassessment of energy-efficient ship practices. For achieving net-zero carbon emissions by 2050, digitalization provides insights, boosts operational efficiency, and facilitates the transition to alternative fuels. It will still take human judgment, expertise, and decision-making to ensure vessel effectiveness and safety, according to the recent DNV and Lloyd's List Intelligence safety report [32]. It is imperative for future research to give priority to study the significance of innovative digital technologies and tools in enhancing energy efficiency and promoting compliance with stringent environmental regulations. It is of utmost importance to conduct a study into the real-time efficacy of these tools in decision-making processes pertaining to energy efficiency [65,76,84,109]. It is essential to provide comprehensive training initiatives that focus on using innovations and digital technologies effectively onboard in order to support seafarers' evolving responsibilities. Incorporating this strategy supports the purpose of addressing research gaps in the utilization of innovative technologies and digital tools in the dynamic domain of maritime energy efficiency in the era of digitalization.

8.2. Research gaps in seafarers' education and training on maritime energy efficiency

Seafarers' awareness and knowledge of energy efficiency measures have been investigated in several studies [12,27,75], which reported a need for education and training improvements. In a study conducted by Beşikçi et al. [19], officers were found to lack knowledge of energy efficiency measures and were unaware of their benefits. In the study by Ghaforian Masodzadeh et al. [42], effective collaboration between IMO and various stakeholders was identified as crucial. Their research emphasized solutions like technical cooperation, capacity-building programs, guideline publications, data exchange, and periodic updates of MAC Curves. These solutions were found to address barriers related to training and awareness-raising, enabling stakeholders to adopt energy efficiency measures in the shipping industry. In contrast, Banks examined seafarers' awareness, motivation, and ideas regarding the low-carbon and energy-efficient operation of ships. In a recent study, Dewan & Godina [27] revealed that shipowners provide seafarers with energy-efficient training to operate ships efficiently. According to their study, the training and education of seafarers are critical components of promoting energy-efficient ship operations.

To integrate the knowledge of maritime energy efficiency regulations and measures into the MET's curriculum, a comprehensive training program on energy-efficient ship operations must be developed [67,68]. It has also been found that computer-based gamification tools and simulations can enhance crew training. The gamification-based "tomorrow's onboard learning system (TOOLS)" [88] and ship bridge simulators [68] are examples of innovative and interactive training tools. Through the EU-funded Maritime Energy Management System (MariEMS) program, maritime personnel can learn how to operate ships efficiently through simulation tools, online delivery platforms, and workshops [124]. Furthermore, Psaraftis & Kontovas [100] emphasize that energy efficiency should be incorporated into seafarers' training and education, as well as continued training to keep up with new regulations and innovations. Online delivery platforms, interpretative structural modelling [4], and postgraduate maritime energy management programs [73]; [87] have been suggested as additional methods. It is recommended for future research to address several research gaps in maritime energy efficiency education and training for seafarers. As part of the assessment [12,19], seafarers' knowledge, awareness, and motivation regarding ship energy efficiency should be evaluated.

Banks et al. [12] investigated 312 seafarers globally and concluded that only 6% consider themselves knowledgeable. Additionally, they have observed that seafarers in the marine sector need more skills, education, and motivation. Among them, 74% of respondents expressed interest in knowing more about what seafarers may do to help reduce CO_2 emissions from ships. To provide effective training, seafarers need to be trained more specifically in relation to their roles in implementing energy efficiency operational measures onboard ships [27]. According to this review study, seafarers' engagement and training on energy-efficient ship operations indicate that the maritime sector needs more effective training and education programs in order to improve energy efficiency in shipping, and these programs need to be tailored to the needs of seafarers. As most seafarers attend maritime energy efficiency training onboard ships conducted by the master, chief engineer, or technical manager, as well as in-house training by technical managers or environmental compliance managers of shipping companies [27], the ship's masters, chief engineers, and technical managers must receive adequate training. Onboard training is not highly effective as trainers, mostly ship masters and senior crews, need to be better versed in maritime energy efficiency regulations and measures, according to [12]. There is also a need for more research on the effectiveness of different training programs and tools, as well as the factors that influence seafarers' attitudes and behaviors toward enhancing energy efficiency and reducing GHG emissions.

9. Conclusions

Providing a thorough understanding of energy-efficient ship operations and identifying critical research gaps and recommendations for future research, this review study provides a comprehensive understanding of the factors influencing energy-efficient ship operations. Knowledge, education, attitudes, communication skills, technological advancements, financial incentives, and socioeconomic factors influence seafarers' engagement in energy-efficient ship operations. Notably, seafarers' education and training are identified as key drivers for enhancing energy efficiency during ship operations. The study underscores imperative avenues for future research: the continual assessment of training effectiveness, seamless integration of maritime energy efficiency into educational curricula, and a profound understanding of seafarers' motivations. The efficacy of different training programs and tools, as well as the factors that influence seafarers' attitudes and behaviors regarding energy efficiency, need to be evaluated further. The review study suggests that energy efficiency in the shipping industry can be improved through customized education and training programs according to roles and needs of the seafarers in implementing energy efficiency operational measures onboard ships. Moreover, following a decade of stringent enforcement of maritime energy efficiency regulations by the IMO, a thorough evaluation of the impact on ship crews, ship owners, and the entire shipping industry is imperative. Nonetheless, collaborative efforts among seafarers, ship owners, and regulators are not merely essential; they serve as the compass guiding us towards a greener, more energy-efficient maritime realm. This collaboration ensures the preservation of our environment while fostering operational excellence and shaping a sustainable future for the maritime industry.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data Availability

Data will be made available on request.

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A.2 Paper 2: Roles and challenges of seafarers for implementation of energy efficiency operational measures onboard ships

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Roles and challenges of seafarers for implementation of energy efficiency operational measures onboard ships

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ABSTRACT

As international shipping contributes to 2.89% of global carbon dioxide (CO_2) emissions, the International Maritime Organization (IMO) has set a target of reducing the carbon intensity by at least 40% by 2030 and 70% by 2050 compared to 2008. To achieve these goals, the IMO has developed guidelines and regulations for enhancing energy efficiency in ship design and operation, such as adopting various operational measures, low-carbon fuels, innovative technologies, and retrofits. A purposive sampling strategy was employed in this study to ensure a representative sample, engaging seafarers, ship managers, and technical and operations managers from 46 shipping companies worldwide. The study demonstrates that seafarers actively engage in various energy efficiency practices, with navigation, cargo works, deck operations, and port-related measures divided between the master and deck crews. Chief engineers and engine crews are involved in power generation, propulsion engines, and engine load management. Onshore technical managers oversee both groups to ensure the successful implementation of the Ship Energy Efficiency Management Plan (SEEMP). However, seafarers encounter challenges such as increased workload, additional paperwork, heightened inspections by regulatory bodies, enhanced planned maintenance, and increased technical difficulties in executing SEEMP onboard ships. Furthermore, the implementation of SEEMP has also affected the traditional work culture of crewmembers, who rarely receive recognition or incentives for their efforts. As part of its recommendations, the study emphasizes the need for improved working conditions, training, and incentives, as well as introducing new technologies to reduce workloads and ensure compliance with SEEMP.

1. Introduction

Global shipping is responsible for transporting over 90% of goods worldwide [19]. At the beginning of 2020, there were 98,140 commercial ships with a total capacity of 100 billion gross tonnage (GT) [91]. This substantial number of maritime transports emitted more than 1056 million tonnes of carbon dioxide (CO_2) despite contributing only 2.89% of total anthropogenic greenhouse gas (GHG) emissions [41]. As the maritime trade grows, CO_2 and other GHG emissions from the shipping industry are projected to increase between 50% and 250% by 2050 [89], making it imperative to improve fuel efficiency and reduce CO_2 emissions. The enormous amount of CO_2 and other GHG emissions have led to an increase in ocean temperatures, altered ocean circulations, decreased oxygen levels, a rise in sea level, and changes in marine biodiversity [22]. Furthermore, the melting of glaciers and arctic ice caused by GHG emissions increases global temperatures and flood risk in low-lying lands [81]. Researchers Buhaug et al. [26] reported that shipping companies can save 25–75% of fuel through energy efficient construction and operation of ships, helping to meet environmental and economic goals. As a United Nations (UN) organization, the International Maritime Organization (IMO) has adopted various regulations to reduce GHG emissions in the maritime industry. These include the Energy Efficiency Design Index (EEDI) and the Ship Energy Efficiency Management Plan (SEEMP) [51,53]. The SEEMP requires vessels over 400 GT to optimize energy efficiency through operational practices and technology upgrades. The IMO's Initial GHG Strategy 2018 aims to

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reduce international shipping's carbon intensity by at least 40% by 2030 and work towards a 70% reduction by 2050 compared to 2008 levels [57]. A number of short-term measures have been developed to reduce carbon intensity by 40% by 2030, including the Energy Efficiency Existing Ship Index (EEXI) and the Carbon Intensity Indicator (CII) [59, 60]. Ships above 5000 GT are required to report fuel consumption data through the IMO's Data Collection System (DCS), a requirement imposed in 2019 [55]. A verified SEEMP Part III is required for ships of the same size from 2023 to 2024, with the DCS Statement of Compliance indicating an environmental performance rating (A to E) [35]. Thus, SEEMP aims to optimize energy management, reduce GHG emissions, and address pertinent issues in the shipping industry [46].

Researchers Bloor et al. [20] argue that enforcing international regulations on ship's emissions poses a significant challenge due to the complexity of the industry, the limited availability of resources, and political will. In reality, improving operational energy efficiency in the shipping industry depends on crewmembers' active engagement, and the success of these initiatives depends on the training and development of their skills ([12,18,25,33]; DNV [37]). Banks et al. [12] found that seafarers' motivation and ideas are essential in promoting the low-carbon and energy-efficient operation of ships. Moreover, seafarers' cultural, professional, and economic differences also affect their attitudes toward environmental protection and daily compliance practices [1]. Insufficient engagement and training of ship crews can undermine the effectiveness of the SEEMP in ensuring ship safety and mitigating environmental impacts [46]. Poulsen et al. [78] emphasized the importance of decision-making processes and the involvement of all stakeholders in achieving energy efficiency in ship operations, including seafarers. Viktorelius [93] stressed the importance of communities of practice among seafarers in embracing energy-efficient ship operations, whereas Bazari & Longva [16] contend that the successful implementation of SEEMP relies on clearly assigning roles and responsibilities to stakeholders, particularly onboard crewmembers. The authors, Banks et al. [12]; Dewan et al. [34]; Kitada & Ölçer [65], emphasize the importance of the awareness and knowledge of seafarers who are directly involved with the implementation of energy efficiency measures. Rasmussen et al. [82] reveal that promoting knowledge, communication, and situational awareness among ship crews is crucial for enhancing energy efficiency and performance. Training and raising crew awareness significantly promote energy-efficient behavior and reduce GHG emissions [12]. Numerous studies have been undertaken over the last twenty years in order to identify barriers and develop cutting-edge technologies, energy-efficient instruments and retrofits, high-efficiency energy methods, and low-carbon fuels [7,8,34,40,62,64, 78,84]. These efforts have led to a significant improvement in ship energy efficiency worldwide, with operations becoming one-third more energy efficient since 2008 [41].

Seafaring is a tough, high-risk, and stressful profession, as it is subjected to specific physical, mental, and psychosocial stressors that set it apart from land-based jobs [88]. Seafarers face multiple challenges and risks onboard ships that significantly impact their mental health and well-being. There are many factors involved with these, including prolonged time away from family and home, isolation from social connections, long shift duties, irregular work hours, limited opportunities for shore leave, work-related stress, irregular sleep patterns, high job demands, and pressures, and exposure to physical risks such as engine noise and vibration, accidents, dealing with hazardous substances, transmissible diseases, limited onboard medical facilities, and the constant threat of piracy at sea [5,61,68,73]. Additionally, their isolation from the normal social life resulting from the unique onboard lifestyle and the short turnaround times of the ship, the small number of crewmembers, as well as the limited shore leave opportunities contribute to their challenges in the workplace [61,68]. Researchers have also shown that crewmembers operating ships in an energy-efficient manner face challenges because of imprecise instructions from ashore vessel managers and organizations [80,94]. When energy efficiency-related data or documentation does not meet the requirements of regulatory bodies, penalties and sanctions coexist, which puts seafarers under constant stress [2]. However, it is crucial to find out how comfortable the seafarers are with the energy-efficient operation of ships after a decade of enforcement of maritime energy efficiency regulations by the IMO.

The study provides valuable insights into the roles of seafarers in adopting energy efficiency operational measures to achieve the IMO's emission targets, as well as the challenges they encounter in implementing SEEMP onboard ships. While only focusing on certain salient parts of collected data, the article highlights key issues facing seafarers in enhancing energy efficiency in ship operations. Furthermore, the article contributes to the broader literature on seafarer health and well-being by addressing the challenges of implementing energy efficiency measures in the shipping industry. It sheds light on the challenges seafarers face in implementing SEEMP as they face increasing regulatory demands from the industry and international bodies. The paper is structured into six sections: Section 2 provides a literature review on details of SEEMP and the implementation of SEEMP onboard ships by ship crews. Section 3 focuses on the research approach and methodology adopted in this study. Section 4 presents the profiles of survey respondents. Section 5 discusses the results and findings of the study in detail. Section 6 presents the conclusions and future research recommendations.

2. Literature review

2.1. Energy conservation practices in shipping industry before implementing SEEMP

The shipping industry faced significant challenges during the 1970s, including low freight rates, surplus tankers and bulkers, and a dramatic rise in fuel prices [21]. The increased fuel costs accounted for over 50% of ship operating expenses, including capital and cargo handling costs, causing a deep recession in the maritime sector [27]. In response to the energy crisis, the US Navy initiated efforts to improve energy efficiency, focusing on reducing operating speeds and conducting research on waste recovery systems. A shipboard energy conservation program was introduced, encompassing hull cleaning, antifouling, hull painting, machinery system optimization, and crew training to emphasize individual contributions [17]. However, due to interdependencies and differences in costs and planning horizons, the maritime industry coordination meeting participants did not rank other identified fuel savings measures. They unanimously agreed that the most important key to a successful fuel savings program is developing the understanding, motivation, cooperation, and participation of the crew [17]. The participants of coordination meetings have employed effective techniques such as appointing a dedicated program manager for energy conservation, assuring the ship crew that new procedures are safe and legal, and using internal publicity based on performance to promote energy conservation. The low fuel prices of 1989, however, eliminated shipboard energy conservation. Energy conservation literature has not explicitly addressed the period between the 1990s and early 2000s when fuel prices were significantly lower than they are today (Poulsen & Sornn-Friese, 2015).

The NAVSEA incentivized Energy Conservation (ENCON) program was established in the early 1980s and focused on improving the operational energy efficiency of ships and the fleet [75]. The researcher, Shneerson [87], discussed the optimal ship speed and the benefits of minimizing idle time in port by arriving just in time for port operations. DeTOLLA [32] created MOSES, a computer model for analyzing shipboard energy consumption, aiding the design of more efficient vessels. Researcher Morisseau [71] examined various uses of sails for energy reduction in ships. Later, he explored the innovative concept of harnessing wind power through the Magnus effect, such as with Flettner rotors. From 1980 onwards, ship speed reduction or slow steaming became increasingly popular as a means of energy conservation. Ship speed alterations require plant tuning, and ship's engineers are used to make required adjustments. Slow steaming alone can save significant fuel up to 30% [17]. The program managers implemented other measures, such as hull cleaning, antifouling, hull painting, propeller polishing, machinery system optimization, waste heat recovery, and crew training for the shipboard energy conservation program. Therefore, crewmembers onboard ships were primarily responsible for tuning engines, monitoring performance, and maintaining the propulsion system, so they did not experience additional energy conservation work. As the crewmembers are directly involved in the ships' operations, motivating the crew significantly impacts the execution of additional strategies, like enhancing the efficiency of propulsion and power generation plants.

Previous studies have addressed several critical issues related to energy consumption and energy conservation practices in commercial and naval ships. Ship crew involvement in successful fuel savings programs has been highlighted as a vital component, emphasizing the importance of crew understanding, motivation, cooperation, and participation. The past experience of shipping companies has shown that crew motivation programs can improve energy conservation efforts, fuel-saving activities, assurances about safety, legality, and internal publicity based on performance.

2.2. Implementation of SEEMP regulations and measures onboard ships

In 1997, the Kyoto Protocol assigned the IMO responsibility for controlling greenhouse gases in international shipping [92]. After extensive deliberation, the Marine Environment Protection Committee (MEPC) of IMO enacted regulations (MEPC 40 to MEPC 62) to tackle ship emissions [15]. In 2011, Bazari & Longva [16] assessed energy efficiency measures in international shipping in the MEPC 63/INF.2 report. Since 2013, the SEEMP has been introduced as a mechanism for implementing energy-saving measures on commercial ships [53]. SEEMP recommends a four-phase approach: plan, execute, measure, and improve after self-evaluation [49,59,76]. The SEEMP includes three parts: Part I describes ways to improve energy efficiency and reduce carbon intensity [53], while Part II describes how to measure and report used fuel data [54]. In Part III, the vessel documents how it intends to meet its CII targets [60]. To obtain the first International Energy Efficiency Certificate (IEEC) under the International Convention for the Prevention of Pollution from Ships (MARPOL) Annex VI Chapter 4, all ships must have a SEEMP onboard ships [51].

Energy efficiency measures have been adopted in the maritime industry under the IMO's regulations over the past decade. To achieve energy efficiency and reduce fuel consumption, the maritime sector has implemented various energy efficiency measures, both operational and technical. Operational measures include alternative low-carbon fuels, energy efficiency operational measures, and the use of modern tools and software for optimization [9,35,83]. The marginal abatement cost (MAC) analysis is utilized to identify economically viable measures for reducing GHG emissions, enabling the selection of suitable strategies for implementing the SEEMP [39,47,50]. Eide et al. [39] demonstrate that integrating SEEMP and MAC analysis helps shipping companies to minimize their environmental impact, reduce costs, and comply with regulations. The MAC analysis reports by Eide et al. [39], Hoffmann et al. [47], and IMO [50], along with recent studies by Bännstrand et al. [13]; DNV GL [36] highlight several cost-effective energy efficiency measures for SEEMP, including voyage planning, weather routing, speed optimization, auto-pilot adjustments, power utilization optimization, improved ship handling, enhanced fleet management, optimized cargo operations, reduced steaming, waste heat recovery, retrofitting VFDs in pumps and fans, and crew awareness and training. As these cost-effective energy efficiency measures are implemented during ship operations, they require the direct involvement of crewmembers onboard ships [52].

The DNV GL Energy Management Study 2014 found that optimized voyage planning, hull cleaning, propeller polishing, slow steaming, weather routing, and propeller polishing were the most popular energy efficiency measures included in the SEEMP across 86 shipping companies (DNV [36]). The study also highlighted the importance of familiarization with energy management through crew awareness and training, incentive activities, and establishing dedicated roles for energy management. Some shipping companies also invested in energy-efficiency devices, propellers, and hull retrofits. Researchers Adland et al. [3] revealed that periodic hull cleaning has also proven effective in reducing fuel consumption, with potential savings of 3%. Regularly cleaning and polishing propellers help minimize microorganisms' attachment and friction, reducing fuel consumption [72]. Monitoring specific fuel oil consumption (SFOC) and engine load helps the ship's engineers to maintain the propeller's performance effectively. The lowest fuel costs per tonne mile can be achieved by maintaining a constant engine load during a voyage. A ship's fuel consumption can be reduced by minimizing its propulsion engine's output power [42]. The ship's engineers operate the propulsion engine at a slow speed by tuning and monitoring the engine's performance. With AIS data, master and deck officers can ensure the vessel's optimized speed during every voyage [80]. Additionally, careful voyage planning and maintaining a constant speed mode can result in time savings of up to 4% and earlier arrivals [14]. Maintaining optimal trim and draft is crucial for achieving optimal performance [85]. The deck officers maintain the vessel's trim and draft by optimizing ballast operations.

Implementing various operational measures mainly depends on the involvement of crewmembers onboard ships and technical managers ashore offices. Therefore, increasing regulatory requirements in shipping lead to significant challenges and pressures for seafarers in meeting energy efficiency, carbon capture, and GHG emission targets. In order to improve energy efficiency onboard ships, seafarers must engage in active energy-saving practices, perform additional tasks in addition to their traditional routine duties, record fuel consumption data in real-time, and comply with the stringent reporting and documentation requirements of the SEEMP and the Data Collection System (DCS) which are discussed in following sections.

2.3. Energy efficiency practices and onboard responsibilities of seafarers

Global trade depends on the safe and efficient operation of ships, and seafarers ensure the safe and efficient transportation of goods. The ship's master, chief officer, chief engineer, and other officers are responsible for various aspects of ship operations, including navigation, cargo stowage, machinery operation and maintenance, and power generation. Ashore technical managers provide technical support and guidance to the vessel's masters and chief engineers [74], ensuring the implementation of energy efficiency measures such as optimizing voyage execution, ship speed, cargo operations, and trim optimization [23]. An effective implementation, monitoring, and improvement of SEEMP measures can be achieved remotely from shore offices by utilizing the intelligent energy efficiency management system that is driven by data [96] and software such as Eco-Voyage, Vessel Performance Monitoring and Analysis System (VPMAS) [69], and the Voyage Performance Onboard Analyzer (VPOA) onboard ships [66]. Ashore technical managers manage some ships and support their masters and chief engineers with technical and operational issues from ashore offices [74].

Recent studies have emphasized the role played by the ship crew in improving energy efficiency and mitigating emissions [10,12,17,63,65,67,82]. Onboard ships, the master must have a complete and unwavering dedication to the SEEMP for its effective implementation. The chief officer is responsible for managing ballast, trim, cargo, and other ship operations, while the deck officers and ratings work in the deck department under his supervision. The chief engineer oversees the maintenance, operation, and optimal performance of propulsion plants, auxiliary engines, and other shipboard equipment and machinery. Taking charge of all shipboard machinery plant operations and maintenance alongside the chief engineer, the second engineer plays a vital role in the engine department. Additionally, the second engineer supervises all engineers and engine ratings assigned to the engine room.

Armstrong [7] revealed that engine adjustments, such as increasing cylinder pressure, have been shown to save fuel, with approximately 0.1–0.2 g/kWh of fuel saved by increasing the pressure by one bar. Fine-tuning the engine, particularly regarding combustion pressure, further reduces specific fuel consumption [11]. Besides, slow steaming of the propulsion engine significantly reduces fuel consumption by minimizing the ship's resistance [43]. The ship's chief engineer and engineer officers operate the propulsion engine and ensure better performance by tuning and monitoring to enhance energy efficiency and reduce fuel consumption. Weather routing during voyages is influenced by factors such as wind and wave conditions, vessel characteristics, and cargo characteristics [97]. The vessel's master and deck officers are responsible for the weather routine and navigational operations. During sea passage, steam production from exhaust gas boilers is another fuel-saving opportunity [16]. Regular dry cleaning of exhaust gas economizers and wet cleaning during port stays, vessel's engineers ensure improving the performance of the exhaust gas boiler [11]. At ports, crew members can implement energy-saving practices such as turning off non-essential consumers, fans, and pumps. At the same time, crewmembers can optimize power usage to reduce operating costs and save fuel [44]. Utilizing variable frequency drive (VFD) tools for optimizing cooling systems and ventilation fans in the ship's engine room further reduces energy usage [44,45]. Optimizing vessel arrivals and departures through effective scheduling and sequencing helps minimize waiting times and idle time, leading to fuel savings and emissions reductions [4]. The ship's master, operation managers ashore, and the port authority can ensure the just-in-time arrival of the ship. By providing appropriate facilities at the pilot boarding location, vessels can arrive at the optimum speed, leading to a reduction of 14% in buffer time and fuel consumption [58]. Fuel consumption can be reduced by 15–23% with Sea Traffic Management (STM) [6]. Similarly, optimizing port calls contributes to reduced fuel consumption and GHG emissions [77]. These operational measures have direct impacts on ship masters, deck officers, chief engineers, and engine officers on a daily basis which make them sometimes overworked with additional workloads for optimized uses of the ship's power and machinery, improving energy efficiency and hence reducing fuel usage.

Several studies highlight that seafarers' behavior, decision-making, and engagement play a vital role in the energy efficiency of a vessel [79,82]. Seafarers working onboard directly involve in implementing energy efficiency measures and carry out various operational tasks that contribute to fuel savings and emissions reductions. As a result of the increase in energy efficiency and fuel-saving concerns, their daily work culture has changed in recent years. The successful adoption of SEEMP relies on seafarers' active involvement, adherence to procedures, and continuous improvement efforts, making their experience a critical factor in achieving sustainable and greener shipping practices [65,67].

2.4. Energy efficiency documentation and reporting of ship's data by onboard seafarers

The IMO established the Data Collection System (DCS) in 2016 to monitor fuel consumption for ships over 5000 GT [54]. Flag state administrations collect the data, and crewmembers report the distance covered, fuel consumption, and hours under their power. The gathered fuel data is verified by a Recognised Organization (RO) and reported to the IMO's Global Integrated Shipping Information System (GISIS) database. Additionally, since 2015, ships over 5000 GT calling into European Union (EU) ports are required to monitor and report their CO_2 emissions under the EU Monitoring, Reporting, and Verification (MRV) regulation [38], with data verified by RO to European Maritime Safety Agency's (EMSA) THETIS-MRV database. Ship crews must report real-time ship data such as main engine power and specific fuel oil consumption during the voyage and at port arrival and departure. Financial penalties and other sanctions coexist when energy efficiency-related data or documentation does not comply with EU MRV or IMO DCS obligations [2]. Moreover, Shipboard data, such as reporting time, main engine revolution, power, main engine SFOC, distance covered, hours underway, fuel oil type, fuel energy value, fuel data correction method, and EEDI value, must be reported every noon to noon during a voyage, departure, and arrival at a port, and monthly reports [56].

To ensure adherence to emissions and fuel consumption regulations, technical managers based in ashore offices diligently review and monitor all reported data received from the ship. Ship managers do not always recognize or appreciate the effort made by their crew [70]. They pay particular attention to excessive or unusual fuel consumption and often seek explanations from the ship crew regarding such discrepancies. Furthermore, vessels are subject to inspections by the Port State Control (PSC) during port stays. These PSC inspections aim to verify the accuracy of the reported data and the accompanying documentation. If any deficiencies are found in meeting the regulations and maintaining proper documentation, a financial penalty may be imposed, and in severe cases, the vessel may be detained from regular operation [2]. In these circumstances, seafarers onboard ships often work under stress and overtime with increased workloads to comply with these regulations [24], avoid penalties, and participate in increased PSC inspections at the EU ports and IMO's member countries.

3. Research approach and methodology

3.1. Research approach

This research adopts an abductive research approach involving inductive and deductive reasoning [90]. According to [86], the process of inductive reasoning entails gathering and scrutinizing data to formulate hypotheses and theories. Conversely, the deductive reasoning approach involves refining and testing theories and hypotheses through empirical observation and analysis based on practical experiences gained from the industry. Through this approach, we can gain a more holistic understanding of the roles and challenges seafarers face when implementing energy efficiency measures onboard ships.

3.2. Research design

This study used a mixed-methods design, combining pilot and main online surveys. We used the mixed-mode survey for the pilot and main surveys, providing in-depth understanding and initial insights into the problem. As part of this study, quantitative and qualitative data were collected and analyzed using a mixed-methods approach [29].

3.2.1. Pilot survey

A pilot survey was conducted from June 18 to June 28, 2022, among 22 technical managers and ship crews employed by shipping companies in Bangladesh, Denmark, Hong Kong, Malaysia, Saudi Arabia (KSA), and Singapore. The survey included participants such as masters, chief engineers and environmental managers working onboard ships, as well as technical managers working onshore offices in shipping companies. The primary objective of this pilot survey was to justify participants' involvement in energy-efficient operational practices and to gather comprehensive support for the development of the main mixed-mode survey questionnaires. Various topics were covered in the survey, including active involvement in ship operation and management, direct engagement in implementing energy efficiency operational measures, and the challenges encountered by the participants during the execution of SEEMP measure onboard ships. The purpose of this pilot survey was to justify the involvement of participants in energy-efficient operational practices and get comprehensive support for developing the main mixed-mode survey questionnaires. Based on the data analysis report, the findings of the pilot survey indicate the operational energy efficiency measures chosen by participants for their ships as part of the SEEMP. Among the respondents, 57% adopted speed optimization, while 54% implemented main engine performance monitoring, crew awareness, and training. Additionally, 53% implemented auxiliary engine performance monitoring, 49% focused on the ship's power optimization, and 41% practiced hull efficiency monitoring. Other measures adopted by participants include voyage execution (40%), slow steaming (39%), weather routing (38%), propeller efficiency monitoring (35%), waste heat recovery (32%), trim and ballast optimization (28%), port operation optimization (25%), just-in-time (JIT)/virtual arrival (23%), and retrofits/VFD for pumps and fans (22%). These results provide insights into participants' preferences and implementation of operational energy efficiency measures onboard ships.

Following the pilot survey results, secondary data from the literature review in Sections 2.2 and 2.3 were validated, leading to the validation and adjustment of the online main survey questionnaires to ensure their reliability and alignment with the research objectives.

3.2.2. Main online survey

In order to ensure reliable and relevant data collection for analysis, comprehensive questionnaires were developed for the mixed-mode survey. The survey questionnaires were validated by academic and industrial experts following the method of "Content Validity Index (CVI)" according to Davis [30] and [31]. Online survey questionnaires were created using the Google Form, with single-answer and multiple-choice options and checkboxes for selecting individual and multiple responses. Following are the survey questionnaires (SQs) that respondents were asked to answer:

SQ1. What is your current position aboard a ship or ashore shipping company?

SQ2. What is your rank experience onboard ships or ashore shipping offices?

SQ3. What types of ships do you operate or manage?

SQ4. Which operational energy efficiency measures do you use to implement the SEEMP onboard ships from the list of measures provided?

SQ5. As an onboard seafarer or onshore ship manager, are you facing any challenges in implementing energy efficiency operational measures onboard ships?

SQ6. Please select the challenges you experience from the provided list when implementing the SEEMP.

SQ7. Has Energy Efficient Ship Operation impacted the traditional working culture of seafarers in recent years?

SQ8. Which rewards have you received for successfully implementing SEEMP onboard your ships to meet the pre-fix goal from the list of options provided?

The survey questionnaires were developed online using the Google Form and the survey link was distributed to seafarers and ship managers working in shipping companies in various countries through the email, social media, and various online platforms.

3.3. Sampling strategy

On January 1, 2013, the IMO implemented the SEEMP to require shipowners, ashore managers, and crewmembers to implement, monitor, and enhance energy efficiency measures in the ship's operation [13]. For the energy-efficient operation of ships, crewmembers get clear instructions and guidelines from ship managers, shore-based organizations, and energy-efficiency service providers [94]. Therefore, the research population includes ship operation and technical managers, environmental compliance managers working ashore, and seafarers onboard ships.

To ensure a representative sample, we employed a purposive sampling strategy to select participants who met specific criteria. Seafarers and ship managers from 46 shipping companies around the world were contacted. Seafaring professionals who work ships as masters, deck officers in navigation bridges and decks, and chief engineers, engineer officers in charge of engine room watch onboard ships, were given the survey link. Additionally, we sent the online survey link to the technical and operations managers ashore. The online Google Form survey link was distributed through various channels such as the email, Facebook and LinkedIn messengers, and WhatsApp group platforms.

We received 109 responses from active seafarers who work onboard ships or ashore managers who meet the research criteria. A total of 5 responses were removed after careful consideration because they had not been actively involved in vessel management and operation since January 2013. The final sample comprised 104 participants who provided reliable and relevant data for analysis.

3.4. Analysis of survey data

SPSS and Excel spreadsheet formulas and charts were used to analyze the data for the main mixed-mode survey. After receiving 104 survey responses, the data was saved in PDF format and downloaded in CSV format for further analysis using SPSS software and Excel spreadsheet formulas and charts. The charts provide the percentage (%) of respondents for each variable. The total number of responses for each chart is denoted by "N = Number of Participants" in the caption. In the case of respondents leaving a variable blank in one of the dependent rating questions, the complete survey response was considered invalid and excluded from the analysis.

4. Profiles of survey respondents

The survey conducted among seafarers aimed to gather their profiles by asking them the main survey questions (SQ1-SQ3). A total of 104 seafarers completed the online survey, comprising 35 Chief Engineers, 23 Ship Masters, 23 Ship Managers, 5 Second Engineers, 2 Chief Officers, 6 Second Officers, and 10 Third Engineers completed the online survey (Fig. 1(a). The survey findings indicate that most responses came from Chief Engineers, who are typically responsible for overseeing SEEMP-related tasks such as reporting, documentation, and crew awareness and training in most ships. It is shown in Fig. 1(b) that the respondents were either employed onboard vessels or by shipping companies based ashore in 24 different countries around the globe.

As illustrated in Fig. 2(a), a majority of respondents indicated that they were actively involved in the operation and supervision of various types of ships. According to Fig. 2(b), 22% of the respondents were technical managers based ashore, 30% of the respondents were masters and deck crew members, and 48% of the respondents were engine crew members. Fig. 2(c) illustrates how many years of experience respondents in the current positions of technical managers, masters, chief engineers, deck officers, and engineer officers have in their current jobs.

5. Results and discussion

5.1. Execution of energy efficiency operational measures onboard ships

The study conducted by [39] reveals that energy efficiency operational measures are the most economically beneficial for the shipping industry. Hence, for this study, we identified 15 energy efficiency operational measures from the secondary data from the literature review, validated by the pilot survey, that are cost-effective and easily adoptable by shipping companies. These operational measures are termed "Low-Hanging-Fruits (LHF)" and are a part of the SEEMP of most shipping companies. While energy efficiency measures are usually associated with environmental concerns, they are often driven by fuel prices and charter rates [78]. To encourage honest responses, we added an "Others" checkbox to the online survey form where respondents could select which of the 15 energy efficiency measures were operationally adopted to their ships as part of SEEMP (SQ4). The measures included in the survey were based on the most popular ship energy efficiency operational measures, which include weather routing, voyage

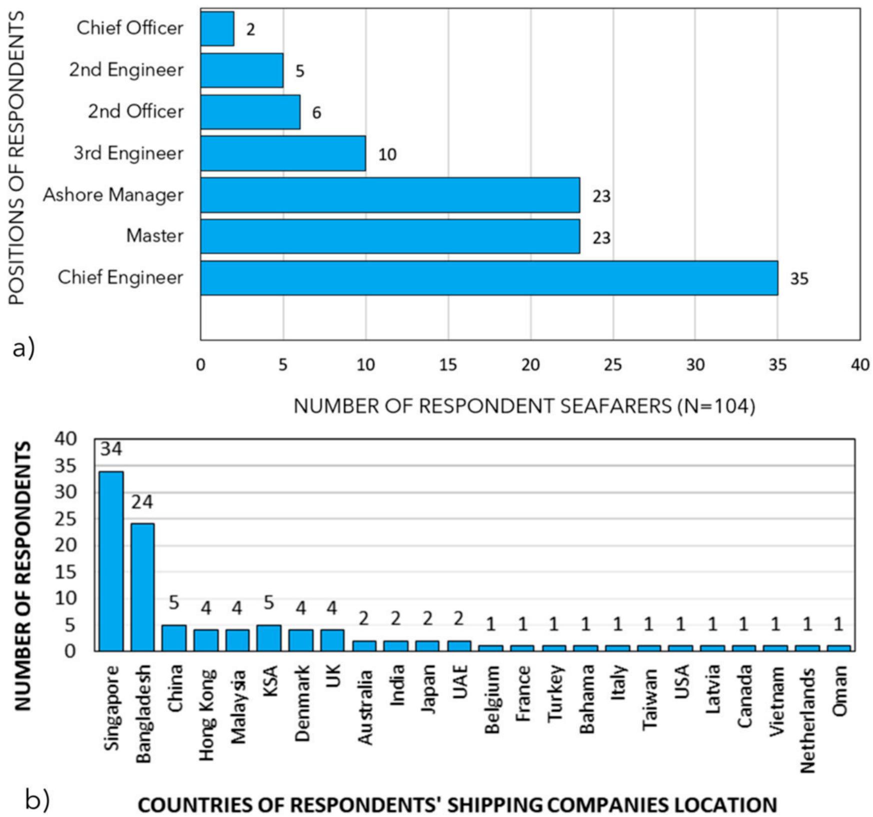

Fig. 1. (a) Respondent Seafarers and (b) Location of Respondents' Companies.

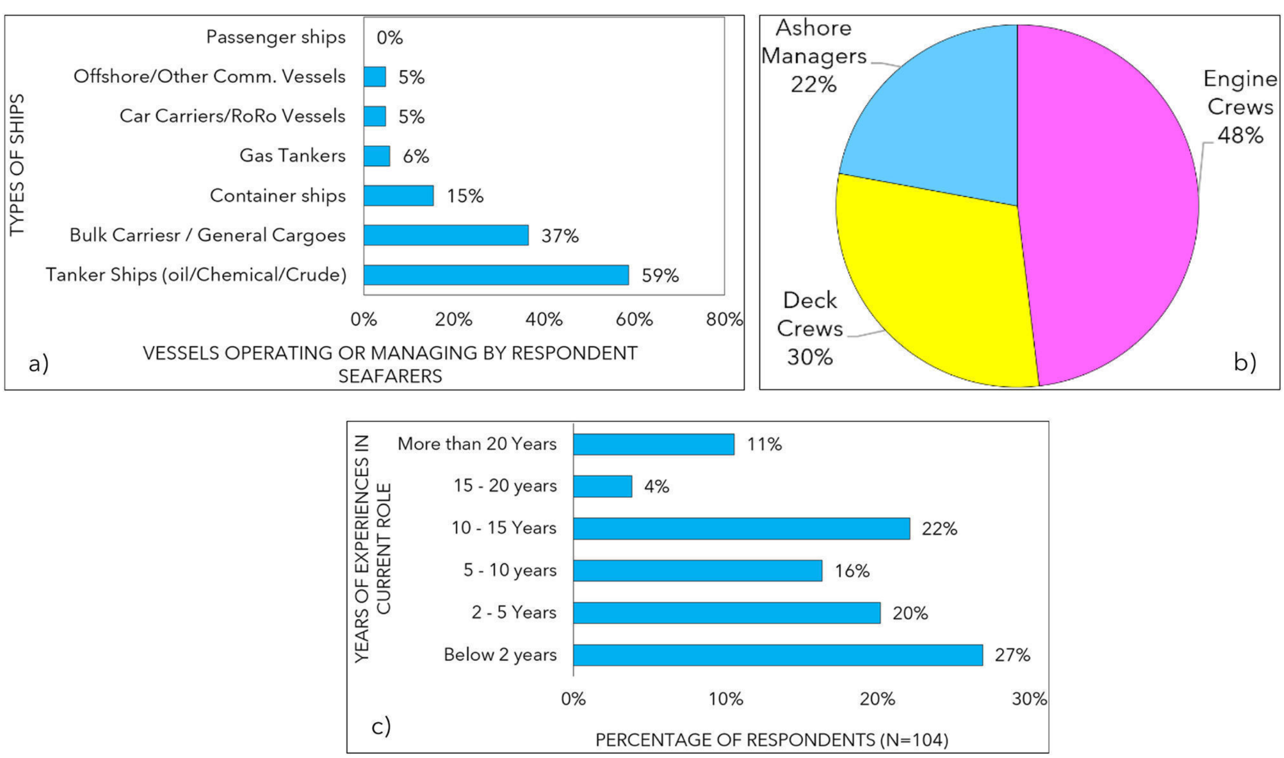

Fig. 2. (a) Types of ships; (b) Respondent Seafarers' Workplace; (c) Years of Experience of Respondents Seafarers in their Current Role.

execution, just-in-time arrival, propeller, and hull efficiency monitoring, main engine performance monitoring, slow steaming/speed reduction, trim and ballast optimization, auxiliary engine performance monitoring, VFD for pumps and fans, waste heat recovery, awareness and crew training, and ship's power optimization ([13,34]; DNV [36]).

5.1.1. Execution of energy efficiency operational measures by onboard ship crews

The survey found significant differences among crew members in their involvement in operational energy efficiency measures onboard ships. The master and deck crewmembers are directly involved in implementing various measures, as seen in Fig. 3(a). These measures include voyage execution, awareness and training of ship crews, speed optimization, weather routing, trim and ballast optimization, and just-in-time arrival measures. The figure illustrates that the ship's chief engineers and engine crews are directly involved in monitoring auxiliary engines, main engines, the ship's power, waste heat recovery, slow steaming, speed optimization, propeller performance monitoring, and awareness and training of ship crews operational measures. These findings suggest that the involvement of crew members in energy efficiency operational measures is highly dependent on their respective roles and responsibilities on the ship. Operational energy efficiency measures for navigation, deck, and ports are implemented by the ship's master and deck crews. Chief engineer and engine crews are involved in propulsion and power-generating machinery operations and management-related energy efficiency measures onboard ships.

5.1.2. Execution of energy efficiency operational measures by ashore ship managers

The survey results reveal that ashore managers, particularly technical and marine superintendents, were essential in implementing several energy efficiency operational measures onboard ships. In Fig. 3(c), ashore managers supervise masters and chief engineers in implementing energy efficiency measures such as optimizing speed, monitoring hull efficiency, awareness and training of ship crews, optimizing ship power, monitoring engine performance, executing voyages, routing for the weather, and slow steaming.

5.1.3. Summary of execution of energy efficiency measures onboard ships

Seafarers are actively engaged in executing energy efficiency measures during ship operations, and the master and deck crews mainly administer the navigation, cargo, deck, and port-related measures. On the other hand, the chief engineer and engine crews monitor power generation, propulsion engines, and engine load management measures onboard ships. A further observation is that, according to Fig. 4, ashore ship managers are also involved in a wide range of environmental initiatives both directly and indirectly through their involvement in implementing these energy efficiency measures both onboard ships and within the fleet of a shipping company.

5.2. Seafarers' challenges for executing SEEMP measures onboard ships

The survey examined the challenges encountered in implementing SEEMP measures onboard ships for seafarers working ashore and aboard ships. The findings revealed that among both groups, 39% experienced challenges, 33% experienced sometimes, and 28% did not experience any challenges. Fig. 5(b) provides a breakdown of the challenges faced, including increased paperwork, increased workload, more inspections by the PSC or 3rd party, increased planned maintenance works, technical difficulties, changing of traditional work culture, attending lots of training in ships or at home, increased working hours, and the need to work beyond regular hours. Both onboard crewmembers and ashore ship managers encountered these challenges. However, 23% of the respondents did not provide any comments on the challenges faced in implementing SEEMP onboard ships.

5.3. Impact on seafarers' working culture for adoption of SEEMP aboard ships

The survey inquired about the influence of SEEMP adoption on the traditional working culture of seafarers aboard ships. The findings, depicted in Fig. 6(a), reveal that a majority of seafarers (75%) agree or strongly agree that energy-efficient ship operation has influenced their traditional working culture in recent years. A small proportion (15%) responded neutrally, while a minority (10%) disagreed with this statement. Seafarers are now more mindful of saving fuel by practicing power management, avoiding running machinery unnecessarily, carrying out proper operation and maintenance of the machinery, monitoring propulsion engine performance, optimizing voyage and weather routing, and getting continuous feedback and suggestions from ashore technical managers through innovative online software and tools.

5.4. Rewards received by seafarers for effective implementation of SEEMP onboard ships

In recent years, the IMO has significantly improved the financial and environmental performance of the shipping industry by implementing energy efficiency regulations and measures. However, a survey of seafarers explored the recognition and rewards they received for effectively implementing SEEMP onboard ships. As shown in Fig. 6(b), among the respondents, 79% of seafarers at sea and ship managers ashore did not receive any rewards or appreciation despite successfully implementing SEEMP onboard ships and meeting targets. Only 8% received financial incentives, 6% received annual bonuses, and 4% received formal recognition or trophies. These results suggest seafarers need to be sufficiently rewarded or appreciated for their efforts despite the significant benefits for implementation of energy efficiency measures onboard ships.

6. Conclusions and future research recommendations

Seafarers play a crucial role in the shipping industry and are key stakeholders in implementing energy efficiency measures aboard ships. However, despite their vital contribution, seafarers face significant challenges due to increasing regulatory demands, minimum safe manning requirements, and strict cargo transportation requirements. As a result of these challenges, energy efficiency operational measures aboard ships can be difficult to implement because of excessive workload and difficulties maintaining the work-rest balance of crewmembers. The findings of this study demonstrate that seafarers actively engage in various energy efficiency practices during ship operations, with responsibilities divided between the master and deck crews for navigation, cargo work, deck operations, and port-related operational measures. In contrast, chief engineer and engine crews focus on power generation, propulsion engines, and engine load management-related energy efficiency measures onboard ships.

This study also reveals that seafarers face challenges such as increased workload, additional paperwork, more inspection by PSC or third parties, increased planned maintenance works, increased technical difficulties, and changing traditional work culture to execute SEEMP onboard ships. These challenges can hinder the effective implementation of energy efficiency measures, particularly due to the burden of additional work and the struggle to maintain adequate work-rest hours. It is crucial to acknowledge that seafarers experiencing these challenges and stresses in implementing energy efficiency regulations and measures, combined with increasing regulatory demands from the industry and regulatory bodies, may experience negative impacts on their mental health and well-being. Moreover, continuous stress at the workplace, overload due to a minimum number of crewmembers, long working hours, disruption of sleep patterns, and compromised safety standards are among the leading causes of fatigue among seafarers [5,28,48,73,95]. Fatigue is a major cause of maritime accidents, affecting both seafarers' well-being and the environment [73].

Our study also reveals that financial incentives, bonuses, and formal recognition are powerful drivers for seafarers to adopt energy efficiency measures onboard ships. It is concerning that despite their successful implementation of the SEEMP and meeting company goals, numerous seafarers do not receive any rewards or appreciation. Seafarers' rightful

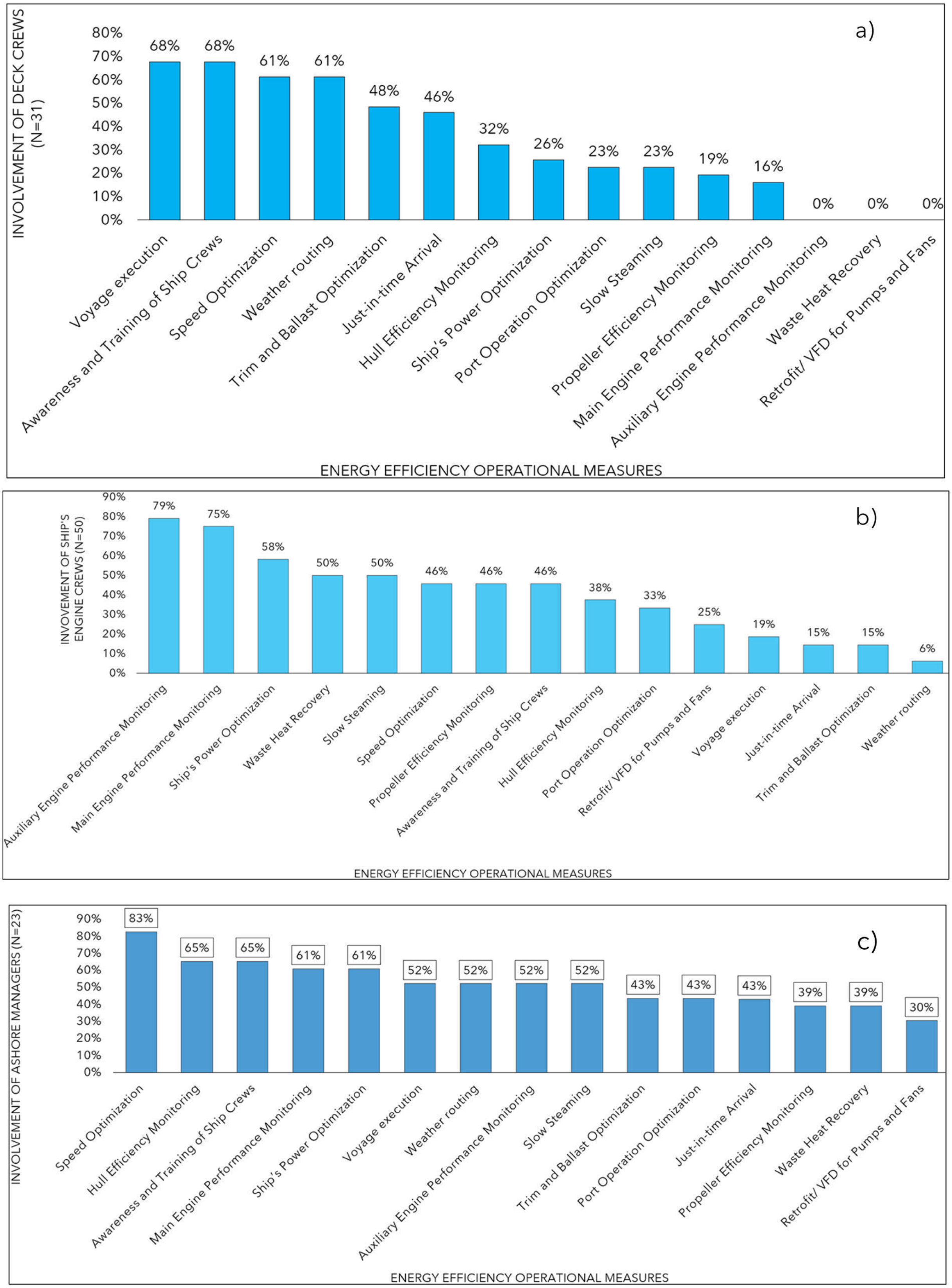

Fig. 3. (a) Execution of EE Measures by Ship's Master & Deck Crews; (b) Execution of EE Measures by Ship's Chief Engr & Engine Crews; (c) Involvement of Ashore Ship Managers.

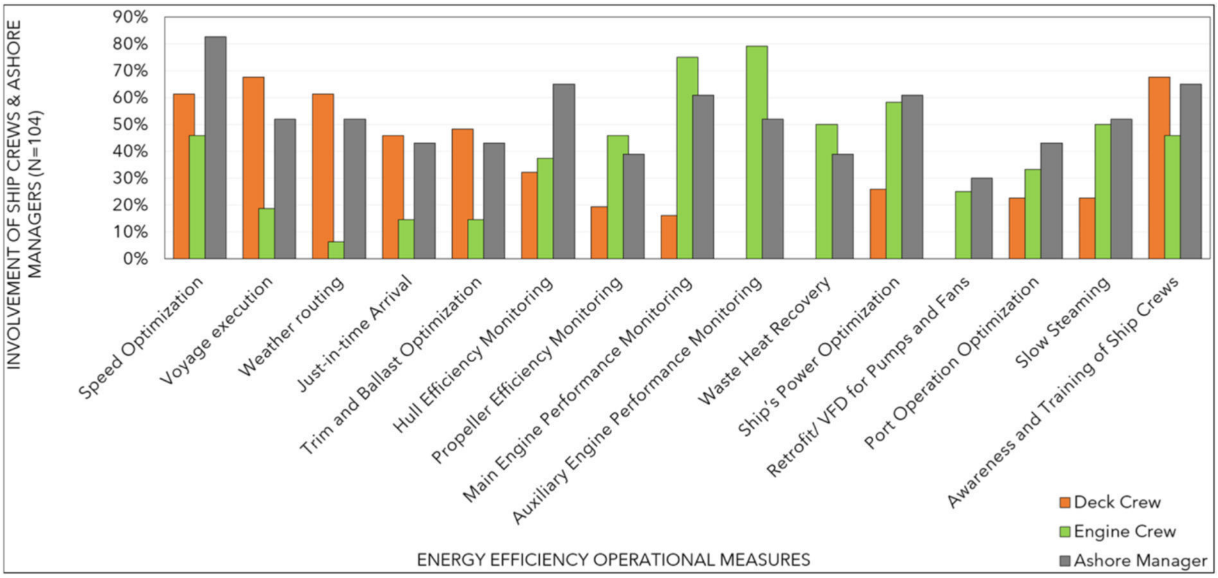

Fig. 4. Involvement of Ship Crews and Ashore Managers (N = 104).

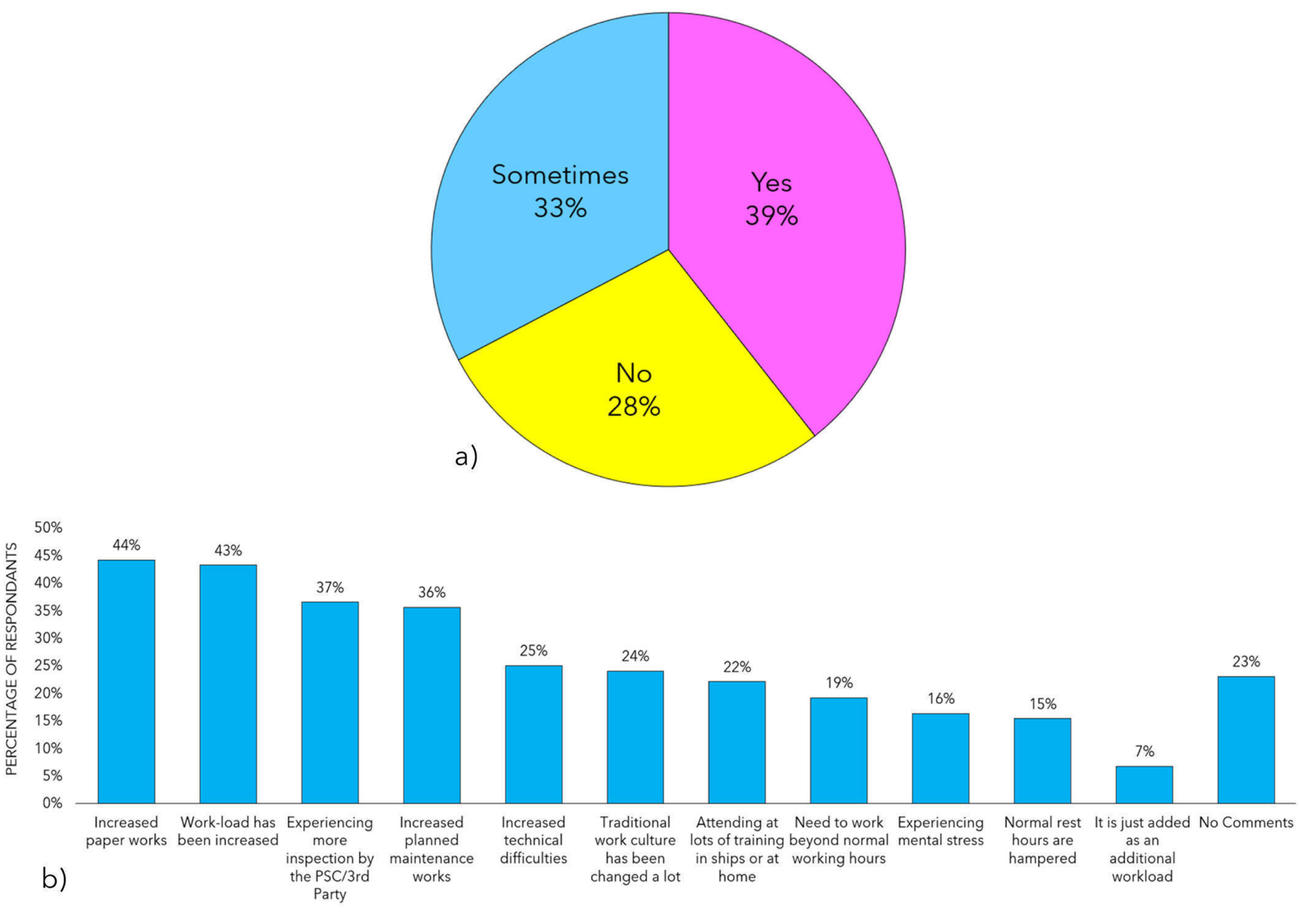

Fig. 5. (a) Percentage of respondents Facing Challenges (N = 104); (b) Challenges Experiencing by Seafarers onboard Ships and Ashore Ship Managers(N = 104).

recognition and the closing of this disparity will not only foster a more sustainable maritime industry but also cultivate a highly motivated workforce.

Based on the findings of this study, several areas could benefit from further research. First, it is vital to investigate the effectiveness of various incentives, such as financial incentives, bonuses, and formal recognition, in motivating seafarers to adopt energy efficiency measures onboard ships. This could be done through a longitudinal study

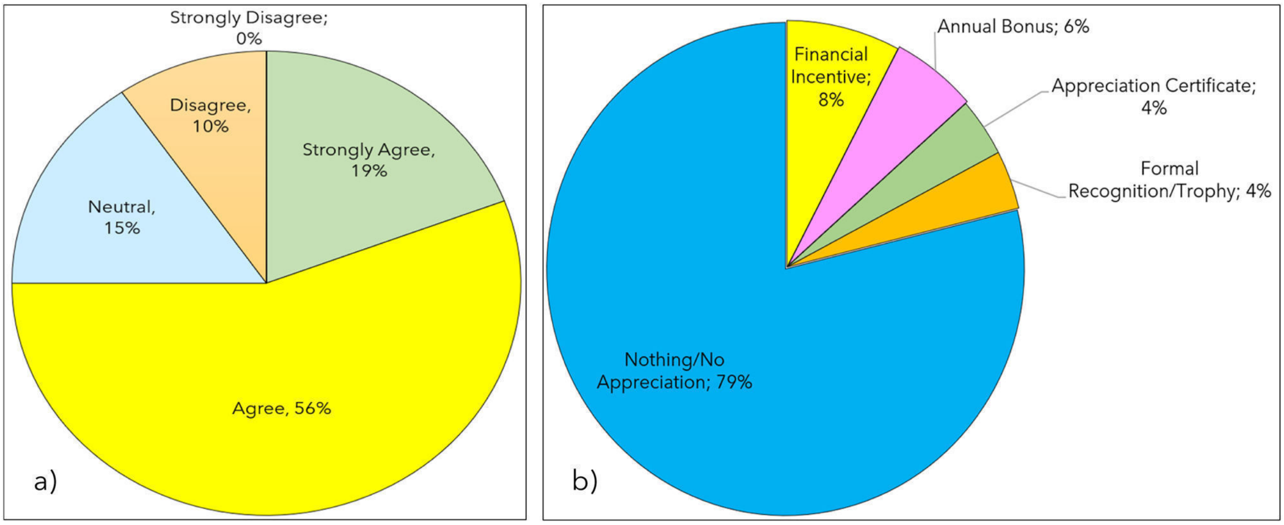

Fig. 6. (a) Impact on seafarers' traditional working culture (N = 104); (b) Rewards Received by Seafarers for effective implementation of SEEMP Onboard Ships (N = 104).

examining incentives' impact on seafarers' attitudes, behaviors, and outcomes over time. Second, future research should explore the challenges faced by seafarers when implementing the SEEMP onboard ships and introduce effective training frameworks or new technologies to reduce their workload and paperwork, simplify the process, and reporting system. Finally, it is important to collect feedback from seafarers and analyze it as linguistic data. As a result of this feedback, specific areas of concern can be identified, and better policies and practices can be developed to support the needs and interests of seafarers. Further research is necessary to ensure seafarers are adequately supported and motivated to adopt energy efficiency measures, leading to safe and efficient shipping operations. By addressing these research gaps, the maritime industry can continue its journey towards efficient work operations and contribute to global efforts in combating climate change.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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A.3 Paper 3: Sailing Towards Sustainability: How Seafarers Embrace New Work Cultures for Energy Efficient Ship Operations in Maritime Industry

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Sailing Towards Sustainability: How Seafarers Embrace New Work Cultures for Energy Efficient Ship Operations in Maritime Industry

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Abstract

It is imperative to take proactive measures in light of the escalating concerns about greenhouse gas (GHG) emissions of international shipping. The GHG study conducted by the International Maritime Organization (IMO) indicates that the sector accounted for 2.2% and 2.89 % of emissions in 2012 and 2018, respectively. As a result, IMO has endorsed strategies to reduce ship-induced emissions to 50% by 2050 and net zero emissions by 2100. For reducing carbon emissions, regulations such as the Energy Efficiency Design Index (EEDI) and Ship Energy Efficiency Management Plan (SEEMP) were implemented a decade ago. We collected data from 104 seafarers in 24 countries using purposive sampling, exploring how the energy-efficient operation of ships transforms their work cultures onboard ships. The majority of seafarers in our study agreed that energy-efficient ship operation has changed seafarers' working cultures over the last decade. Seafarers have adopted a variety of energy efficiency (EE) practices, including meticulous record-keeping of fuel consumption and adherence to Planned Maintenance Systems. As well as preparing for Port State Control (PSC) inspections, they follow energy-saving measures prescribed by the SEEMP. In addition to engine maintenance, energy-saving practices, accurate reporting and recording of EE-related data, and efficient power usage, they provide just-in-time arrival, crew training, energy-efficient lighting, environmental awareness, and slow steaming to minimize fuel consumption. The majority of seafarers implemented SEEMP successfully and met the company's objectives, but they did not receive any form of recognition or financial incentives. Although SEEMP can help shipping companies gain financial benefits and preserve the environment, seafarers do not receive tangible rewards or appreciation for implementing it. Only one-fourth of seafarers were rewarded with incentives, bonuses, formal recognition, or trophies. This study holds significant implications for policymakers, offering insight into seafarers' adaptation to energy-efficient ship operations and advocating for integrating Industry 4.0 technologies for EE regulations compliance by reducing seafarers' workloads and improving data accuracy.

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1. Introduction

International shipping is projected to contribute around 2.2% [1] and 2.89% [2] to greenhouse gas (GHG) emissions in 2012 and 2018, according to the Third and Fourth GHG Studies 2014 and 2018 of the International Maritime Organization (IMO), respectively. Anthropomorphic carbon dioxide (CO_2) and other GHG emissions foster seawater acidification, rising sea temperatures, and deoxygenation. Global warming and related environmental issues have become a global challenge. Recent studies suggest a 3°-5°C increase in global average temperature by 2100, in line with the Paris Agreement's goal of keeping temperatures below 2°C over pre-industrialization levels [3].

The control of emissions from the shipping sector has drawn constant attention worldwide over the last decade [4]. These considerations have resulted in regulatory and financial constraints that have compelled the shipping sector to improve its energy use and environmental effects. A resolution establishing a new strategy for lowering emissions caused by ships was approved and passed by the IMO. The GHG emissions from the maritime sector are expected to decrease by 50% by 2050 compared to 2008 levels [5]. Regulations for minimizing maritime-related air pollution and GHG emissions have been added to Annex VI Chapter 4 of the International Convention for the Prevention of Pollution from Ships (MARPOL) [6]. Chapter 4 establishes energy efficiency (EE) requirements to be applied in the design and construction of new ships and in the operation of all existing old and new ships used for commercial purposes to achieve compliance with CO_2 emission obligations. Two sets of rules, the Energy Efficiency Design Index (EEDI) and Ship Energy Efficiency Management Plan (SEEMP), aimed at reducing commercial ships' carbon output, went into effect on January 1, 2013 [7].

A three-step strategy to reduce the quantity of GHG emissions from commercial ships was developed by the European Commission (EC) in 2013: First, CO_2 emissions from big boats operating in European Union (EU) ports must be Monitored, Reported, and Verified (MRV) [8]. Next, the GHG reduction targets for the marine transport sector must be set. Finally, market-based policies must be complementary measures over the medium to long term. As of January 1, 2018, ships with a gross tonnage (GT) of more than 5,000 that call at EU ports must comply with this rule, enacted on April 29, 2015. Collect and exchange CO_2 emission data. The EU estimates that the MRV system will reduce CO_2 emissions by 2% [9].

The IMO has accepted the Energy Efficiency Existing Ship Index (EEXI) [10] and the Carbon Intensity Indicator (CII) as new methods to reach this goal [11]. The technological equipment or retrofit requirement to reduce carbon intensity is based on the new EEXI. In contrast, the ship's operational requirement is presented as new operational CII and CII ratings [12]. These revisions to MARPOL Annex VI Chapter 4 were approved at the 76th Marine Environment Protection Committee (MEPC) Meeting in June 2021 and went into force in January 2023 [13]. Every existing vessel must have a technical file for EEXI before January 2023. To ensure compliance with the yearly operational CII requirement, recording and comparing the actual CII accomplished will be necessary. Furthermore, in the updated MEPC 80 strategy, ambitious targets are set for international shipping. With new regulations expected to take effect around mid-2027, the goal is to achieve net-zero emissions by 2050 and a 20% reduction in emissions by 2030, a 70% reduction by 2040 compared to 2008 levels [14]. The final objective is to reach zero GHG emissions by 2100 [15].

The Annual Efficiency Ratio (AER) measures the carbon intensity metric based on the Poseidon Principles [16]. This measure is very similar to the "Energy Efficiency Operating Indicator (EEOI)"; however, it estimates cargo carried based on the design deadweight (DWT) capacity of the vessel rather than the actual cargo carried and the assumption that the vessel is constantly transporting cargo. AER is now IMO-mandated, but EEOI reporting is still voluntary. The operational carbon intensity of a vessel traveling ballast or loaded is the yearly DWT distance divided by the total annual CO_2 emissions [11]. Calculating carbon intensity involves dividing annual CO_2 emissions by tonne-nautical miles. It does not always provide exact readings of a ship's EE since it combines nautical, commercial, meteorological, and sea conditions into a statistic. These factors affect the AER, the EEOI, and the efficiency and effectiveness of SEEMP aboard ships [11].

From 2008 to 2018, the energy efficiency of international ship operations increased by one-third [2]. By implementing EE operational and design features, several maritime companies throughout the globe have experienced significant economic and environmental advantages by reducing their fuel use on every voyage. Over the last two decades, numerous research investigations have been carried out with the aim of developing novel technological advancements, energy-conserving instruments, and modifications, identifying obstacles and gaps related to EE, economically viable approaches for enhancing energy efficiency, as well as environmentally-friendly alternative or low-carbon fuels with reduced carbon emissions [17–27].

The effective implementation of EE measures onboard ships by both ashore ship managers and onboard crewmembers is crucial, considering their direct involvement in cargo transportation between ports. The significance of these measures is underscored by the fleet's average Marginal Abetment Cost (MAC) for various reduction measures in 2030, where operational EE measures are identified as the most economically viable options[28]. To successfully implement the SEEMP onboard ships, seafarers play a crucial role in the execution of various operational EE measures over time [29,30]. As a result of executing SEEMP onboard ships, seafarers are faced with increased workloads, additional documentation requirements, frequent inspections by port state controls or external entities, more maintenance works, and a surge in technical complexities, as well as changes in traditional working cultures [29]. These challenges may prevent the effective implementation of EE measures due to the increased workload and difficulty maintaining adequate work-rest hours.

Industry 4.0 changes in management philosophy and technology help change labor organization. For example, lean management is integrating with Industry 4.0 to integrate digital manufacturing technologies with advanced lean management technologies. As a result of this convergence, cutting-edge artificial intelligence (AI) is integrated seamlessly with human expertise to enhance efficiency [31]. Industry 4.0 can help the maritime sector reduce seafarers' workloads while improving data documentation, a crucial part of complying with EE regulations. The implementation of these technologies optimizes operational procedures, reduces human error risk, and refines decision-making processes by using technologies such as automation, AI, and the Internet of Things (IoT). With such advancements, the maritime industry is moving towards a sustainable future marked by cohesion and sustainability, underscored by the judicious use of Industry 4.0 to ease seafarers' challenges and ensure EE compliance. Because industry 4.0 smart devices exchange information constantly about inventory issues and order fluctuations. A cyber-physical production system (CPPS) is an integrated network of machinery, properties, technology, products, and people. During ship operation, this integration allows real-time defect detection and increases operational efficiency [32]. Moreover, energy management systems have recently been developed that systematically monitor energy consumption and the drop in facility performance due to aging and malfunctioning equipment [33]. Therefore, this innovative technology can reduce the machinery maintenance works of the crewmembers onboard ships, ensure better performance, and improve EE ship operations.

Operational EE practices have changed seafarers' traditional working cultures, as reported by Dewan and Godina [29], but specifics about these new working cultures have not been explored in previous studies. The purpose of this study is to examine seafarers' newly adopted working cultures, which are crucial to the successful implementation of SEEMP onboard ships and in reducing CO_2 emissions, and therefore, bridge this research gap. Furthermore, the study investigates the influence of incentives in motivating seafarers to adopt new EE practices and cultures onboard ships. By shedding light on both aspects, this research aims to contribute significantly to advancing sustainable and EE practices within the maritime sector.

In section 2 of this paper, there is a comprehensive literature review of SEEMP development and implementation onboard ships by seafarers, while in section 3, the method of this study is described. A description of the participants' profiles is provided in section 4, and a discussion of the research findings and results follows in section 5. At the conclusion of Section 6, recommendations are presented for future research endeavors based on the study results. By shedding light on the evolving working cultures of seafarers and their motivation for EE practices, this paper aims to contribute significantly to the advancement of sustainable shipping practices and knowledge in the maritime industry.

2. State-of-the-Art Literature Review

2.1. Energy-Efficient Operation of Ships

US Navy officials initiated EE measures in the 1970s due to the fuel crisis. The shipboard energy conservation initiative highlighted individual contributions by introducing initiatives such as machinery optimization, waste heat recovery, hull maintenance, and crew training [34]. Although other fuel-saving measures were not prioritized by industry participants due to cost differences and planning horizons, they unanimously stressed the importance of crew understanding, motivation, cooperation, and participation. The NAVSEA launched the Energy Conservation (ENCON) program, which incentivized ships and the fleet to improve operational efficiency in the 1980s [35]. In further development, to reduce GHG emissions and comply with the MARPOL convention, a ship must implement the SEEMP during its operational stage. From January 1, 2013, all new and existing ships must comply with the SEEMP, which involves planning, executing, monitoring, and self-evaluation [36]. In addition, to provide a comprehensive approach for enhancing the EE of ships and fleets over time, the SEEMP also provides prospective techniques for increasing performance, improving efficiency, and reducing fuel consumption. Several studies have shown that EE operational measures substantially reduce fuel consumption and GHG emissions [32–34]. In many shipping companies, an environmental management system based on ISO 14001 is in place. It describes how to choose the most appropriate measures for each ship, how to set measurement targets for critical parameters, and how to control and get feedback to improve it further [40]. Thus, a more comprehensive management system must include monitoring environmental efficiency in operations.

According to the recent resolution MEPC.346(78) adopted on 10 June 2022, the SEEMP has three parts [41]. Part I of SEEMP provides methods for monitoring the efficiency of ships as well as improving their energy efficiency [42]. Ships subject to the IMO DCS must develop SEEMP Part II data collection plans, and the administration must approve them [43]. The SEEMP Part III explains how the data required by MARPOL Annex VI should be gathered and how the ship should report that information to its administration or other authorized organizations. It also provides the method to determine whether the ship has achieved the required annual operational CII mandated by MARPOL Annex VI, the subsequent three-year operational CII, and an implementation strategy for achieving the required annual operational CII [44]. It is possible to rate the operational CII on a scale of A, B, C, D, or E, which stands for "A: Major Superior," "B: Minor Superior," "C: Moderate," "D: Minor Inferior," or "E: Inferior." The actual performance must be documented in the SEEMP. The corrective action strategy must describe how the ship will achieve a C or higher index if it has received a D rating for three consecutive years or an E rating for a year. Administrations, port authorities, and other stakeholders should reward ships with an A or B rating appropriately [45]. All cargo ships, RoPax, and passenger ships above 5,000 GT that engage in international trade must comply with the CII regulations [41]. Monitoring a ship's EE and setting a quantitative goal are essential. It is recommended that a quantitative goal be defined for a ship before using a quantitative performance indicator tool developed by the IMO, such as AER, EEOI, or CII.

2.2. Improving Ship's Energy Efficiency by Implementing Operational Measures Onboard Ships

A Ship must adopt the SEEMP while in operation to increase its EE and reduce GHG emissions. The SEEMP provides a thorough approach for raising the ship's and the fleet's EE over time and prospective techniques for increasing performance while reducing energy usage and saving fuels [43]. Aside from overseeing maritime energy management, the SEEMP provides guidance on implementing best practices tailored to each vessel. These practices encompass enhanced voyage planning, efficient weather routing, optimized speed, reduced power consumption, efficient ship handling, enhanced fleet management, and optimized cargo operations. Various operational measures aimed at bolstering EE and curbing carbon emissions can be employed on ships. However, determining the most suitable measures for a particular vessel relies heavily on factors such as its type, cargo, route, and other relevant considerations, which need to be identified initially. To offer a comprehensive overview of the recommended actions for a specific ship, these measures should be compiled as a cohesive package and integrated into the SEEMP for implementation onboard the vessel [7].

Maritime operations have adopted various operational and technical measures to improve EE and reduce fuel consumption. Alternative low-carbon fuels, EE measures, modern tools and retrofits for optimization, are examples of operational tactics [33,34,38,40]. The study of Irena et al. [47] reveals the cost-effectiveness of prioritizing operational and technical EE measures over alternative fuels. Eide et al. [28] highlighted that marginal abetment cost (MAC) analysis was particularly beneficial for shipping companies, as it guided the selection of implementation strategies for SEEMP [28,42,43]. This study highlighted specific cost-effective operational measures, often referred to as "Low

Hanging Fruits," commonly integrated into SEEMP by shipping companies. Trim and ballast optimization, slow steaming, monitoring performance of the hull and propellers, and monitoring performance of the main and auxiliary engines. Several practical operational EE measures have been adopted widely and have proven to be economically feasible, including voyage planning, speed optimization or constant speed, weather routing, optimized power utilization, efficient ship handling, efficient fleet management, and streamlining cargo operations, adaptive autopilot, and virtual or just-in-time arrival [31,39,44,45]. The DNV GL Energy Management Study of 2014 reveals that 91% of companies engage in hull cleaning and coating, 88% undertake propeller cleaning and polishing, 86% optimize both auxiliary and main engines, and 83% retrofit energy-efficient devices within engine room pumps and blowers [52]. The crewmembers implement these widely used “Low Hanging Fruits” operational EE measures during ship operations to improve EE and reduce GHG emissions.

2.3. Roles of Onboard Seafarers and Ashore Technical Managers for Implementing Operational EE Measures

Seafarers are crucial to the smooth flow of global trade because they ensure that vessels are operated safely and efficiently. Several studies have pointed out that EE operating practices aboard ships require collaborative efforts between onshore technical management, the master of the ship, and the crew [7,30,45]. Ashore technical managers and onboard crewmembers operate and manage ships according to shipping companies' Safety Management Systems (SMS) manual and the International Safety Management (ISM) Code of IMO [53]. Consequently, they are directly involved in executing EE operational measures aboard vessels. The onshore Technical Managers supervise the masters and chief engineers for vessel navigation and technical operations [54]. They manage some vessels and provide technical and operational support to the masters and chief Engineers of each vessel. Besides, environment compliance managers are accountable for implementing all IMO-enforced environmental regulations and standards and adequately coordinating with the ship's masters and chief engineers in some shipping companies.

For the SEEMP to be successfully implemented on board the ship, the master of the vessel must demonstrate unwavering dedication and a comprehensive understanding of its principles. The role of the chief officer, who serves as the second-in-command, involves managing cargo, trim, ballast, deck and hull maintenance, and other ship operations. Working directly under the chief officer's supervision are the deck officers and ratings assigned to the deck department. In addition, the chief engineer oversees the entire engine department and ensures that the propulsion and auxiliary engines are maintained, operated, and optimized. In addition to working closely with the chief engineer, second engineers ensure proper maintenance and operation of the entire onboard machinery plant. Furthermore, they supervise engineers and ratings in the engine room. A significant development in recent times is the adoption of advanced software or tools utilizing satellite technology, which provides real-time data on ship and machinery operations and weather conditions to onshore ship management offices. These cutting-edge technologies enable technical managers onshore to analyze and assess the ship's operational data from their office, offer relevant feedback to the ship's master and crew, and guide the vessel’s safety, security, and optimizing energy-efficient ship operations [30,49,50].

2.4. Seafarers' Energy Efficiency Practices During Ship Operations

During ship operations, seafarers are essential in implementing EE operational measures, which decrease emissions and fuel consumption. In addition to optimizing speed and executing voyages, masters and deck crews also optimize trim and ballast, efficient cargo operations, and enhance hull efficiency, according to Dewan & Godina [29,30]. Similarly, the chief engineer and engine crews onboard ensure EE by closely monitoring propulsion, power generation, power management, and machinery operations. This process includes monitoring propulsion and auxiliary engines, energy optimization, waste heat recovery, slow steaming practices, and meticulous monitoring of propellers and hulls. Onshore technical managers supervise the fleet's masters and chief engineers, who oversee navigation, port management, propulsion, power generation, and power management. With the help of intelligent EE tools and data-driven software [55], technical managers from shore offices can remotely monitor and enhance SEEMP measures. Additionally, Mak et al. [57] and Lu et al. [54] developed the Vessel Performance Monitoring Analysis System (VPMAS) and Voyage Performance Onboard Analyzer (VPOA), respectively. Both of these analyses facilitate remote monitoring of the performance of vessels and vessels at sea, regardless of their location.

By regulating the main engine's output power [58] and ensuring the Automatic Identification System (AIS) data is used to maintain the vessel's optimal speed [59], seafarers contribute to optimizing a ship's fuel consumption. The use of precise voyage planning and constant speed modes has resulted in savings of up to 4% and earlier arrivals [60]. By analyzing factors such as vessel characteristics, cargo properties, wind, and wave conditions, weather routing techniques can further increase EE of the vessel [61]. The arrival and departure of vessels can be optimized through scheduling and sequencing, reducing waiting time and idle time, and reducing fuel consumption and carbon emissions [62]. A ship's master, operations manager on shore, and port authority can work together to ensure a just-in-time arrival. In order to maintain the Estimated Time of Arrival (ETA) at the destination port at optimal speeds, vessels need suitable facilities at pilot boarding locations, which reduces buffer time and fuel consumption by 14% [63]. It has been shown that implementing Sea Traffic Management (STM) can reduce fuel consumption by 15–23% [64]. A vessel's trim and draft must be optimized for optimal propeller performance [65], and fuel consumption (SFOC) and engine load must be monitored to ensure optimum main engine performance. The researcher Armstrong [24] believes that adjusting engine pressure, such as increasing cylinder pressure, can reduce fuel consumption by 0.1-0.2 g/kWh. It is also possible to reduce fuel consumption further by tuning the engine properly, especially regarding combustion pressure. Engineers onboard ships also optimize boiler performance by wet cleaning during port stays and regularly drying exhaust gas economizers during dry cleaning to minimize fuel consumption [66]. They also reduce energy use at ports by turning off exhaust and supply fans as well as pumps. In addition, ship operators can reduce operating costs and save fuel by optimizing power usage when necessary [67]. Besides, the cyber-physical production systems (CPPS) of Industry 4.0 keep track of inventory and order fluctuations. They integrate machinery, properties, technology, products, and people. During ship construction and operational stages, this integration detects defects in real-time and improves EE in ships [32]. Additionally, reporting and recording cargo-transport-work and fuel consumption data has become an increasingly critical practice for ship crews, as described in the next section.

2.5. Reporting and Recording of Ship's Energy Efficiency Data by Seafarers

During the 70th session of the IMO's MEPC in October 2016, the Data Collection System (DCS) was adopted, effective on March 1, 2018, for vessels with 5000 GT or above [68]. Data collected and reported by crew members about distance covered, fuel consumption, and operating hours by flag state administrations. The IMO's Global Integrated Shipping Information System (GISIS) receives verified fuel consumption data from a Recognized Organization (RO) [68]. Furthermore, beginning in July 2015 ships over 5000 GT calling into EU ports will have to abide by the MRV regulations and report voyage-based data, conduct RO verification, and submit aggregated data every year to the EMSA-run Thematic Marine Environment Monitoring System (THETIS-MRV) [69]. Ship crew members are responsible for reporting various data points such as distance traveled, time spent at sea, fuel consumption in port and at sea, and cargo transported. As part of a voyage, various ship data must be reported regularly, including the time, propulsion engine revolution and power, the number of hours underway, the distance covered at sea, the type of fuel, the calorific value of the fuel, the correction method of the fuel, and the EEDI value. Data must be reported daily between noon and noon, upon departure from and arrival at ports, and every month [70].

Innovative software, Excel spreadsheets, or specified forms are required to ensure accurate data transmission to comply with IMO DCS and EU MRV reporting obligations. If these obligations are not met, financial penalties and sanctions will be imposed on ship crews calling at EU ports or affiliated IMO countries, increasing stress and the need for port state control (PSC) inspections [71]. As reported by Dewan and Godina [29,30], seafarers are responsible for the adoption of various EE measures during ship operations, along with their core responsibilities for transporting cargo safely and efficiently from port to port. The growing regulatory requirements from the flag state, national, and international bodies lead ship's crewmembers to heavier workloads, increased documentation, frequent port inspections, and technical intricacies. Due to these factors, ship crews are often under considerable stress when visiting EU ports or countries affiliated with the IMO due to heightened work pressure from shipping companies and the increased frequency of port state control (PSC) inspections. As well as constantly stressing out at work, overloading due to a minimum number of crew members, long hours at work, and commodifying safety standards, seafarers often experience fatigue due to their work conditions [72–75]. Utilizing Industry 4.0 technologies such as automation, AI, and IoT, maritime regulatory compliance can be improved by capturing and reporting real-time data, reducing seafarers' workloads, and minimizing human errors. Because the lean management and Industry 4.0 are resulting in advanced artificial intelligence working collaboratively with humans to improve efficiency [31].

3. Methodology

Over a decade ago, in 2013, the IMO implemented EE rules in MARPOL Annex VI in an effort to reduce CO_2 emissions in the shipping industry [7]. In order to succeed in implementing operational initiatives and achieving the overall goal of improving EE in the maritime industry, the ability of seafarers to acquire new skills, knowledge, and practices is crucial [28]. A recent study by Dewan and Godina [29] highlights that EE ship operational practices have led seafarers to adopt new work cultures onboard ships. However, a comprehensive understanding of these adaptations is vital for policymakers to plan and implement SEEMP successfully onboard ships.

Specifically, this study examines the roles and responsibilities of active seafarers, including shipmasters, chief engineers, deck officers, engineers, and managers, from the perspective of the adoption of SEEMP onboard ships. As part of an abductive methodology [76], we combine inductive and deductive reasoning to formulate and refine hypotheses [77]. We combine qualitative and quantitative data collection and analysis through an online mixed-methods design. This mixed-mode survey aims to examine EE practices carried out by seafarers during ship operations, identify the working cultures followed by the seafarers to implement EE measures during ship operations and examine what influences them to adapt to these new work cultures. Moreover, we conducted a pilot study before conducting the main mixed-mode survey in order to validate the secondary data and test the hypotheses behind this study.

3.1. Pilot Survey

As part of our evaluation of the participation of onboard crew members and ashore technical managers in implementing EE operational measures onboard ships, we interviewed 22 experienced maritime professionals. Technical Managers, ships' masters, and chief engineers from various countries participated in this pilot study. As experienced masters and chief engineers, all the interviewees hold high-ranking positions within the maritime industry. With extensive experience managing and operating a diverse range of vessels, they have gained familiarity with EE operational measures by serving as masters or chief engineers on international voyages for at least five years. We posed the following three questions to the interviewees between June 18 and June 28, 2022:

1. Are you directly engaged in implementing SEEMP measures on board ships?
2. What specific EE measures have been integrated into ship operations as part of the SEEMP?
3. In your view, have seafarers adapted novel work cultures to enhance ship energy efficiency? If yes, please tell us about new working cultures adapted by seafarers.

The secondary data, derived from a literature review described in Section 2, was validated following the pilot survey results. The principal mixed-mode survey questionnaires and research hypotheses were systematically examined, verified, and refined as needed. This meticulous procedure was undertaken to verify both their reliability and congruence with the overarching research goals.

3.2. Collection of Survey Data

Ashore ship managers, as well as various third-party EE service providers, provide clear operational instructions and guidelines to onboard crew members to achieve EE ship operations. We selected participants based on specific criteria to ensure a representative sample. From 42 shipping companies worldwide, we contacted vessel operations managers, ashore technical managers, masters onboard vessels, environmental managers, and ship crews. Many of the respondents were ashore technical and operation managers with extensive experience, many of whom had served as masters or chief engineers in the past. In managing and operating the vessels, chief officers, masters, second engineers, and chief engineers play a crucial role. In addition to navigation and cargo handling, they are responsible for maintaining and operating machinery, supervising crews, and monitoring equipment.

The questionnaire link was distributed to active seafarers, including chief engineers, masters, second engineers, and chief officers, as well as ashore ship managers, including marine and technical superintendents, ship operation managers, and environmental compliance officers. In addition, maritime educators, trainers, freelancers, and classification society surveyors with experience as shipmasters and chief engineers were included in the study. Considering that seafarers may not always be available at work or home, the survey link was emailed to them to ensure access. To distribute the Google Form survey link directly to seafarers' mobile devices, we used WhatsApp group chats and Facebook Messenger after receiving consent. In some cases, seafarers or ship managers were reminded by phone to encourage participation in the survey. Due to the slow response rate from respondent seafarers, the online survey was conducted for three months from July 2022 to September 2022. We received 109 responses from seafarers, with each participant allowed to provide only one response since Google Form's settings limited the number of responses per participant to one. A total of 5 respondents were excluded from the study after careful review. These individuals have not been actively involved in vessel management or operation since January 2013. Finally, a total of 104 responses were securely saved in the Comma-separated values (CSV) and pdf format to analyze the data.

3.3. Analysis of Survey Data

The study excluded participants who left any aspect of the dependent rating questions unanswered as incomplete responses. Moreover, we did not consider individuals no longer involved in the operation or management of vessels since January 2013. Retrieving the CSV data format from the online Google form, we have carefully arranged the survey data into an Excel spreadsheet for an in-depth examination in Section 3.3 of the report. An exhaustive evaluation was performed once a substantial volume of data had been collected using SPSS Version 16 and Excel spreadsheet functions. The captions for each chart include the label "N = Number of Participants," indicating how many valid responses were considered. These graphical representations illustrate participants' proportional breakdowns (%) adeptly.

4. Profiles of the Respondents of the Survey

The survey to capture the profiles of participating maritime professionals included a series of inquiries. There are 104 responses in the gathered dataset, which includes ship managers, environmental compliance managers, vessel operation managers, marine/technical superintendents and vessel's masters, chief engineers, chief officers, second engineers, third engineers, and second officers as presented in Figure 1(a). According to Figure 1(b), these individuals are employed on board ships and within onshore shipping companies, representing a diverse global presence across 24 countries, including Bangladesh, Singapore, Hong Kong, China, Saudi Arabia, and more.

The nature of the participants' work is revealed in Figure 2(a), which demonstrates their active involvement in overseeing and operating various vessel types, including general cargo ships, bulk or carrier tanker ships, gas carriers, container ships, and Ro-Ro vessels. A very few (5%) works in offshore or other commercial vessels. As shown in Figure 2(b), 22% of respondents hold ashore managerial positions, 30% serve as master and deck crew members, and 48% serve as engine crew members. Additionally, Figure 2(c) provides an overview of the years of experience held by ship managers, masters, and chief engineers in their current positions.

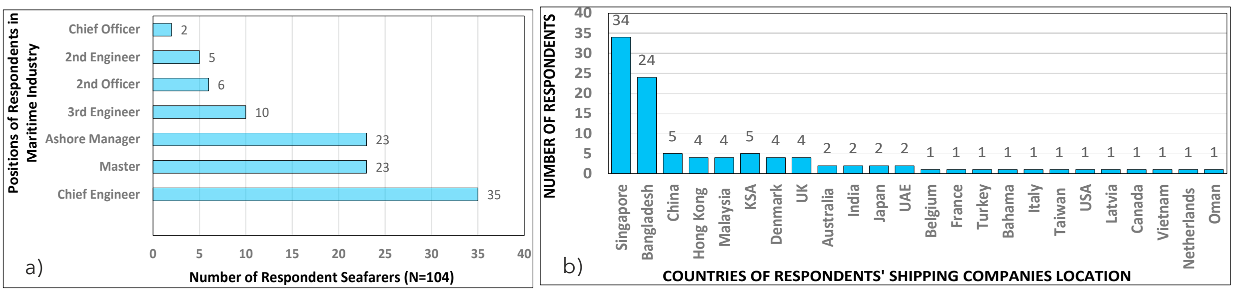

Fig. 1. (a): Respondents (Seafarers); and (b): Countries of Respondents' Companies

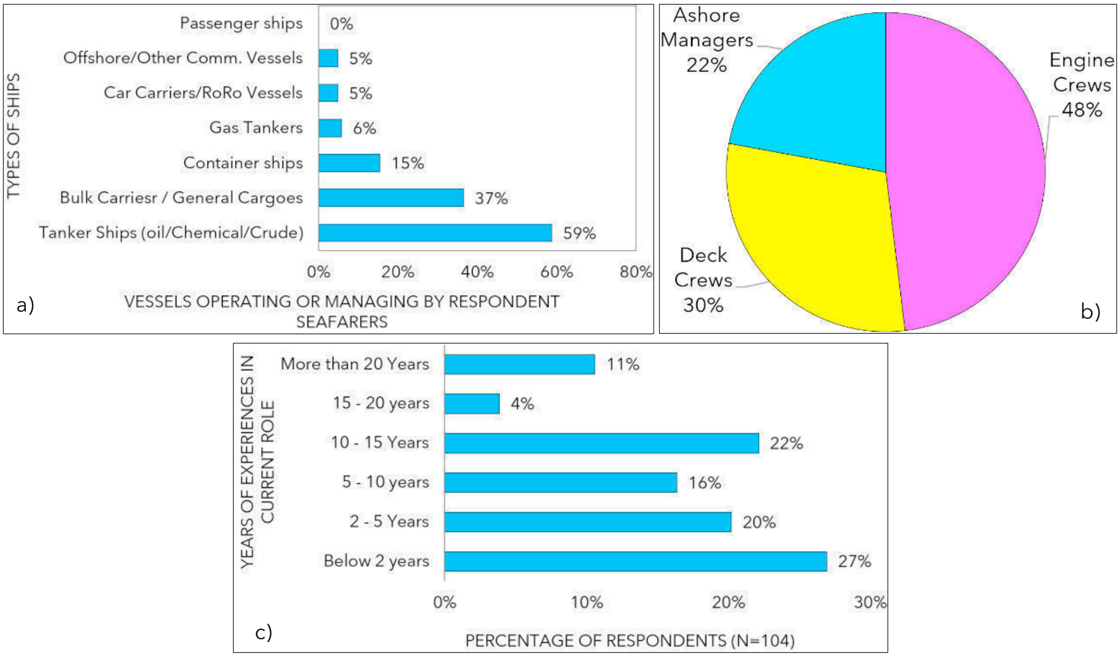

Fig. 2. (a): Ship Types Respondents Work; (b): Workplace of Respondent Seafarers; and (c): Respondent Seafarers' Years of Experience

5. Results and Discussion

5.1. Implementation of Operational EE Measures by Seafarers Onboard Ships

The fleet's average MAC analysis study [28,41,42] identified a list of cost-effective operational EE measures commonly incorporated into SEEMPs across diverse shipping companies that align with shipping companies' recommendations to implement SEEMP measures on ships. Aside from voyage planning and weather routing, optimizing trim and ballast, monitoring hull and propeller performance, monitoring main and auxiliary engine performance, optimizing speed, just-in-time arrival, slow steaming, adaptive autopilot, retrofitting pumps and fans, optimizing power, recovering waste heat, and training crew members, there are several other measures worth mentioning [17,43,45]. As part of the survey, respondents are asked to identify which operational EE measures are being implemented as part of SEEMP on board their ships. Figure 3 shows a list of widely adopted operational EE measures adopted by respondents on board ships as part of SEEMP. Seafarers and ship managers reported that 57% of participants optimized speed, 54% monitored main engine performance, 54% trained crew members, 53% monitored auxiliary engines, 49% optimized power, 46% adaptive autopilot, 41 % hull efficiency monitoring, 40 % voyage execution, 38 % slow steaming, 38 % weather routing, 35 % propeller efficiency monitoring, 32 % waste heat recovery. Besides, other operational EE measures are also implemented, such as trimming and ballasting optimization, improving port operations, performing just-in-time arrival, and retrofitting pumps and fans with variable frequency drives (VFDs). We also included a “Others” checkbox to encourage respondents to share any additional measures not listed but implemented on their ships.

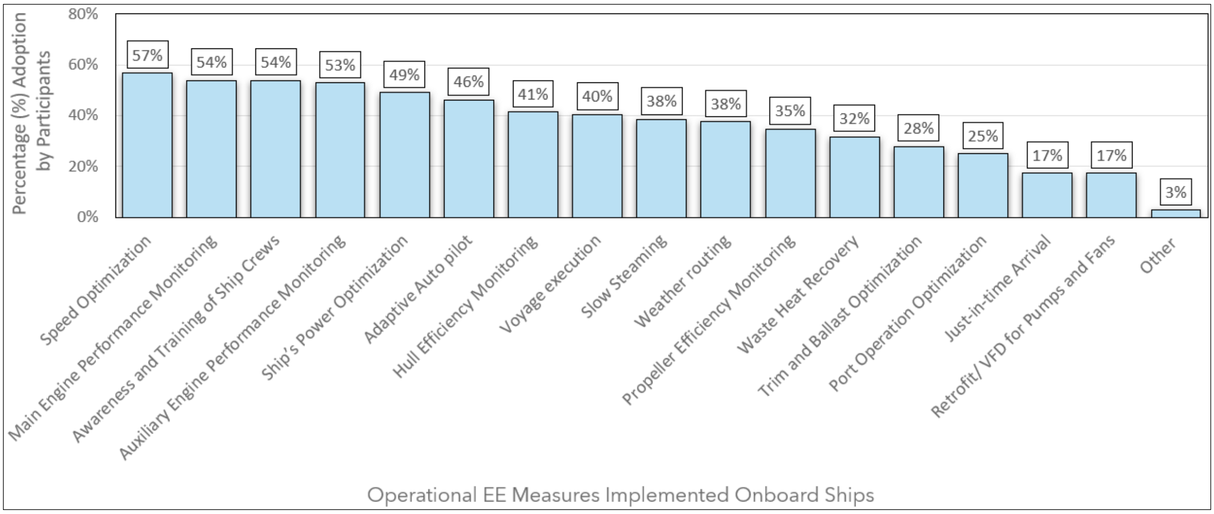

Fig. 3: Operational EE Measures Adopted Onboard Ships by Seafarers

5.2. Identifying Adaption of Working Culture of Seafarers for Implementation of SEEMP Onboard Ships

As demonstrated in Fig. 4(a), 19% of seafarers strongly agreed, and 56% agreed that energy-efficient ship operation over the past decade has impacted seafarers' traditional working cultures. In contrast, 10% of seafarers expressed disagreement, with none strongly disagreeing. Within this context, 15% took a neutral stance, indicating they did not agree or disagree.

The Figure 4(b) illustrates that seafarers have adopted various EE practices and cultures such as carefully recording and reporting of fuel consumption data (98%), strictly adhering to Planned Maintenance System (88%), always being available for PSC inspections (84%), using energy-saving measures by SEEMP (78%), and maintaining the main and auxiliary engines (75%), actions on saving energy and fuels taken promptly (73%), strict maintenance of EE documentation and records (71%), optimized power usage and machinery operation (70%). Additionally, adherence to company/charterer instructions for just-in-time arrival at the port, optimization of voyage planning and weather routines (66%), frequent onboard SEEMP training by the master/chief engineer (65%), energy-efficient lighting and fan usage (63%), awareness of EE and low-carbon emissions among the crew (60%), implementation of slow steaming for fuel savings (59%) and a zero compromise on excess power consumption (39%). Only 10% of seafarers have responded with other comments, including above mentioned working cultures followed by the seafarers.

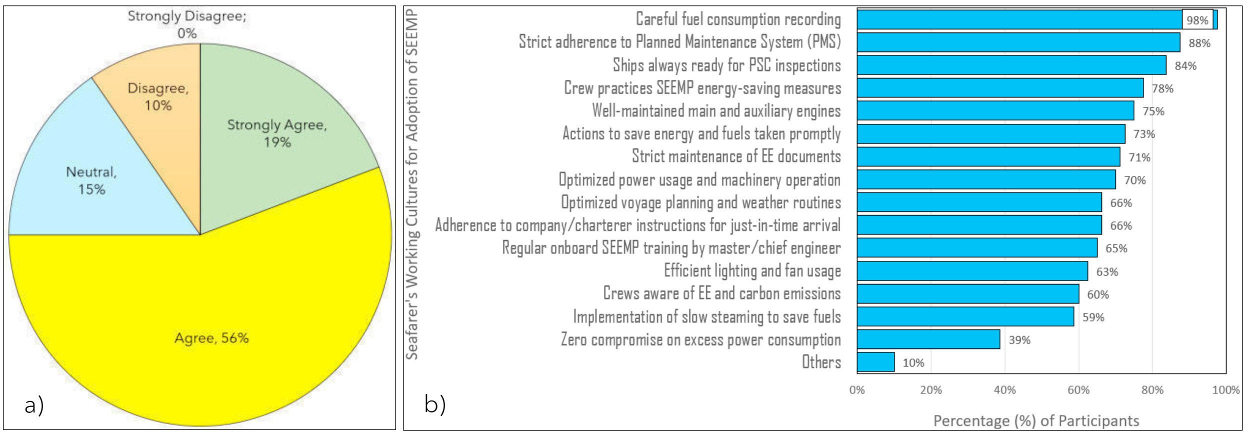

Fig. 4. (a): Impact on seafarers' traditional working culture; (b): Adopted New Practices and Work Cultures by Seafarers for Energy-Efficient Ship Operations (N=104).

5.3. Seafarers' Motivation for Adoption of SEEMP Onboard Ships

Using a comprehensive survey, seafarers were asked about their motivations to adopt new working cultures conducive to energy-efficient ship operations. When SEEMP was implemented successfully onboard ships, respondents were asked how they received rewards or recognition. Participants were asked about their experiences with shipping companies regarding energy conservation and reduced fuel consumption, which benefits them financially and contributes to environmental conservation. Over three-quarters (79%) of seafarers implemented SEEMP and met company goals, but they did not receive any recognition, as shown in Figure 5(a). Only 8% of participants received incentives, while 6% received annual bonuses. Further, 4% of participants were recognized, and another 4% were recognized with trophies. Although SEEMP can help shipping companies gain financial benefits and preserve the environment, seafarers do not receive tangible rewards or appreciation for implementing it. In Figure 5(b), our study reveals that 49% strongly agree and 27% agree that financial incentives motivate seafarers to implement SEEMP onboard ships.

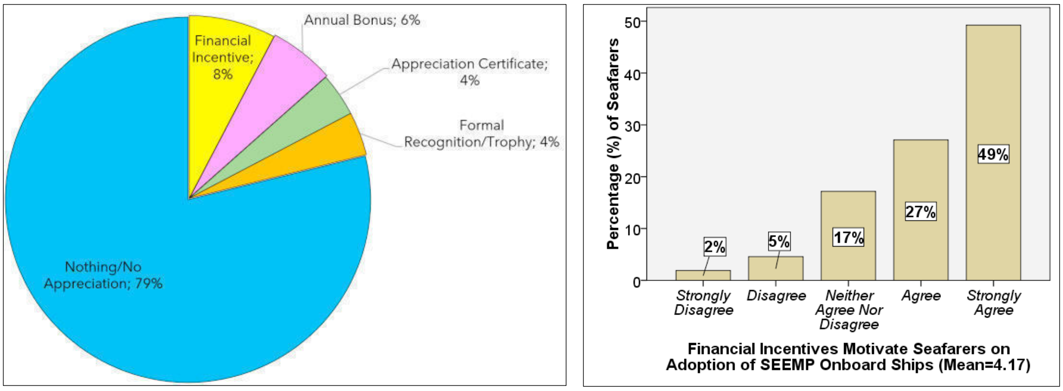

Fig. 5. (a): Seafarers' Rewards for Effective SEEMP Implementation (N=104); and (b): Financial Incentives Motivate Seafarers on Adoption of SEEMP onboard Ships (Mean=4.17)

6. Conclusions and Future Research Recommendations

Seafarers play an indispensable role as front-line stakeholders in the dynamic shipping industry, facing complex challenges due to tight regulatory requirements, cargo owners' expectations, and the need to operate a ship safely and pollution-free. Seafarers actively implement EE operational measures onboard ships despite the heavy workload and struggles in adhering to the work-rest guidelines of the Maritime Labour Convention (MLC), 2006 [78]. Our investigation reveals that 75% of seafarers acknowledge the transformative impact of energy-efficient ship operations on shaping their work cultures over the last decade. With the implementation of SEEMP onboard ships, new work paradigms have emerged, such as meticulous fuel consumption recording, strict adherence to maintenance plans, vigilance towards PSC inspections, the use of energy-saving methods prescribed by SEEMP, engine maintenance, accelerated energy and fuel savings, rigorous maintenance of EE documentation, optimized power management, and an unwavering commitment to various operational efficiency measures.

Despite many shipping companies worldwide reporting financial gains from improved EE practices and decreased fuel consumption, more than three-fourths of seafarers (79%) said they did not receive tangible recognition or incentives for successfully implementing their SEEMP and meeting the company's predefined objectives. Due to the dual benefits SEEMP offers in terms of financial growth and environmental conservation, this divergence becomes particularly significant. Nevertheless, it is shocking to learn that only one-fourth of seafarers are rewarded with incentives, bonuses, recognition, or trophies. The seafarer remains overlooked, and concrete rewards are often lacking. Our study reveals that three-quarters of seafarers believe that financial incentives motivate them to fully implement SEEMP onboard ships. This emphasizes the importance of financial incentives. This emphasizes the importance of financial incentives.

Future research avenues include exploring the integration of Industry 4.0 technologies to reduce seafarers' workloads and improve data reporting and recording accuracy for compliance with EE regulations. Automation, AI, and the IoT are advanced technologies that can streamline operations, reduce human error, and optimize decision-making. A more sustainable and harmonious maritime industry can be achieved by exploring how Industry 4.0 can ease seafarers' burdens and ensure precise compliance with energy efficiency protocols. The research direction will reshape maritime operations, providing seafarers with the support they deserve while driving the industry toward enhanced efficiency and environmental responsibility.

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A.4 Paper 4: Unveiling seafarers' awareness and knowledge on energy-efficient and low-carbon shipping: A decade of IMO regulation enforcement.

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Unveiling seafarers' awareness and knowledge on energy-efficient and low-carbon shipping: A decade of IMO regulation enforcement

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A B S T R A C T

The shipping industry contributes to global CO_2 emissions, raising concerns about its environmental impact and the need for energy-efficient (EE) and low-carbon (LC) shipping practices. This study aims to discover how seafarers are aware, knowledgeable, motivated, and dedicated to the EE and LC shipping processes after a decade of enforcement of IMO regulations. With a purposive sampling strategy, 262 active seafarers from diverse backgrounds and 41 shipping companies from 24 countries were sampled. A mixed-methods survey was conducted to determine seafarers' awareness and knowledge about EE regulations and measures to adopt them onboard ships. This study unveils seafarers' commendable awareness of environmental impacts in EE and LC ship operations. Social media platforms are becoming increasingly popular in recent years among seafarers as a knowledge source, while traditional sources have diminished in importance. Male seafarers demonstrate higher awareness and knowledge of EE and LC shipping compared to their female counterparts. Experience positively correlates with knowledge levels, emphasizing the importance of long-term service in the maritime industry. Most seafarers have consistent beliefs regarding carbon emissions mitigation, but only 47% show significant engagement. Meanwhile 76% believe that financial incentives and formal recognitions motivate ship crews to participate actively in carbon emissions mitigation. In the maritime industry, tailored training strategies are essential for addressing knowledge gaps and promoting sustainable practices. To better understand seafarers' awareness and knowledge of EE and LC ship operations in relation to their gender, age, experience, and positions, we conducted this investigation following a decade-old study of Banks et al. [1]. Policymakers can understand the trends by comparing seafarers' awareness and knowledge in these areas. Continuous education and training programs are crucial in order to promote sustainable and environmentally friendly EE and LC practices in the maritime industry. Furthermore, our study identified areas for improving the human element to ensure sustainable maritime practices by increasing EE and LC ship operations.

1. Introduction

The shipping industry substantially impacts global CO_2 emissions, contributing 2.76% in 2012 and 2.89% in 2018 global anthropogenic CO_2 emissions [2,3]. However, despite regulatory efforts, maritime CO_2 emissions are expected to rise significantly by 2050, with projected increases ranging from 50% to 250% [2]. The adverse effects of emissions from commercial ships due to burning fossil fuels have led to an increased focus on emissions control in the maritime industry, including impacts on human health, seawater temperatures, ocean circulation, oxygen levels, sea levels, marine biodiversity, polar ice caps, and glaciers [4–6]. Global commitments to combat climate change, as reflected in the Paris Agreement and the Kyoto Protocol, have emphasized the urgency of reducing shipping emissions and promoting energy efficiency [7,8]. Recognizing these concerns, the International Maritime Organization (IMO) has implemented several measures to mitigate carbon emissions and enhance energy efficiency (EE) in shipping industry.

As a United Nations (UN) organization, the IMO has introduced

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initiatives such as the Energy Efficiency Design Index (EEDI) and the Ship Energy Efficiency Management Plan (SEEMP) to reduce GHG emissions and improve energy efficiency [9,10] from the shipping industry. The IMO's initial GHG Strategy outlines ambitious targets to achieve a 40% reduction in global shipping's carbon intensity by 2030 and a 70% reduction by 2050 compared to 2008 [11]. In addition, the IMO revised GHG Strategy for 2023 emphasizes the importance of technological innovation and access to low-carbon (LC) emission solutions to achieve international shipping objectives, with indicative targets including a 20–30% reduction by 2030, a 70–80% reduction by 2040 compared to 2008 emissions, and a net-zero emissions target by 2050 [12]. Concurrently, the European Commission (EC) developed the Monitoring, Reporting, and Verification (MRV) system to monitor CO_2 emissions from ships operating in EU ports [13]. The shipping industry has developed and deployed EE and LC technology for years to lower fuel costs to achieve these aims. Numerous matured vessel design technologies, such as weight reduction, optimizing hull dimensions, bulbous bow reshaping, bow thruster tunnel modification, and ballast and trim optimization, were already in place on a large number of new vessels. The shipping industry employs low-carbon and zero-carbon fuels, cutting-edge innovations, and retrofits. To further advance EE and emission reduction, the IMO has recently introduced short-term measures such as the Energy Efficiency Existing Ship Index (EEXI) and the annual operational Carbon Intensity Indicator (CII) [14,15].

Several studies have identified cost-effective strategies for enhancing the EE of ships [16–19]. DNV GL [19] identified low levels of education and resistance to change as significant obstacles, while Dewan et al. [20] revealed information gaps, training and competence of ship crews, and operational difficulties as barriers. Recent studies highlighted the significance of training ship crews and onshore technical managers to conquer these barriers [19,21,22]. Hansen et al. [23] have discovered that a lack of training and crew involvement might hamper the efficacy of SEEMP in maintaining ship safety and minimizing environmental consequences. In order to overcome these obstacles, crewmembers must actively participate in SEEMP implementation, receive extensive training, and possess the necessary skills and knowledge. There is a significant knowledge gap among maritime sector stakeholders, including crew on board ships [20]. Unclear instructions from technical managers ashore or land-based organizations further impede the ability of seafarers to execute energy-efficient voyages [64].

The successful implementation of EE and LC practices onboard ships depends on the awareness and knowledge of seafarers directly involved in implementing operational measures [1,20,21]. Effective training is crucial for crew members and ship managers to implement cost-effective EE measures on board ships. For effective training, it is very important to know the knowledge level of seafarers. According to Banks et al. [1], seafarers perceive themselves as more knowledgeable about CO_2 emissions than they actually are. They reported that 74% of respondents expressed interest in learning how seafarers can reduce CO_2 emissions, even though only 6% thought themselves knowledgeable. This was the awareness and knowledge level of the seafarers when Banks et al. [1] conducted their study just after the enforcement of maritime EE regulations by IMO in 2013. A decade has passed since the IMO's EE regulations went into effect, but no study has been conducted further to evaluate seafarers' awareness and knowledge. Hence, the purpose of this study is to address this research gap. Therefore, this article aims to assess seafarers' awareness, knowledge, and motivation regarding energy-efficient ship operations in the context of maritime energy efficiency regulations, CO_2 emissions, and operational EE measures after a decade of regulation enforcement by the IMO. By exploring seafarers' perspectives, the research sheds a substantial understanding of the opportunities and difficulties associated with implementing operational EE practices onboard ships. The findings contribute to identifying the level of awareness and knowledge of ship crews and ship managers on energy efficiency regulations and measures and suggest strategies to the policymakers for enhancing EE and LC shipping practices in the maritime industry. Furthermore, this study identified areas for improving the human element to ensure sustainable maritime practices by increasing EE and LC ship operations.

The paper is structured into six sections. Section 2 provides a brief literature review on EE and LC shipping; Section 3 elaborates on the research approach and methodology adopted in this study. Section 4 presents the profile of the survey respondents; Section 5 describes the survey results and discussion; and finally, in Section 6, we have concluded our study with future research directions and recommendations.

2. Literature review

2.1. Energy efficiency journey of the shipping industry since 1970

Shipping companies faced numerous challenges during the 1970s, such as low freight rates, surplus vessels, and a significant rise in fuel prices. Over 50% of ship operating costs were attributed to rising fuel prices, which caused a deep recession in the maritime industry. The US Navy reduced operating costs by reducing ship speed slow steaming and using waste heat recovery systems to reduce energy consumption during the crisis. An energy conservation program on the ship included measures such as hull cleaning and painting, applying antifouling, optimizing its machinery system, and training the crew. Between 1973 and 1974, a comprehensive shipboard energy conservation research and development program that included hull cleaning, antifouling, and hull painting was introduced, which resulted in a 35% reduction in energy use overall. Onboard optimization of the mechanical system and crew training materials illustrate individual contribution's significance [24]. The low fuel prices in 1989 led to the abandonment of shipboard energy conservation. Under Article 2.2 of the Kyoto Protocol, the IMO became responsible for controlling GHG emissions in international shipping in 1997 [8]. As Bazari and Lee [25] highlighted, the Maritime Environment Protection Committee (MEPC) of IMO enacted regulations MEPC 40 to MEPC 62 after years of deliberation to address GHG emissions from ships. "Assessment of IMO-mandated energy efficiency measures for international shipping" was the final report of MEPC 63/INF.2 by [26] in 2011, which examined EE regulations and implementation guidelines. As of January 1, 2013, the SEEMP has been used to implement energy-saving measures on commercial ships [10]. All vessels must have a SEEMP onboard to obtain the first International Energy Efficiency (IEE) Certificate under Annex VI, Chapter 4, of the International Convention for the Prevention of Pollution from Ships (MARPOL) [9].

SEEMP has been outlined in four stages to improve environmental efficiency: planning, executing, monitoring, self-evaluation, and improvement. There are three parts to SEEMP: Part I of the SEEMP describes strategies for improving EE performance and carbon intensity over time and monitoring efficiency effectiveness [10], while Part II is the Data Collection System (DCS) for measuring and reporting consumed fuel data [27]. The vessel outlines its plans in Part III for achieving its CII goals [15]. Shipping companies with ISO 14001-based environmental management systems can use the SEEMP methodology to select measures, set objectives, and control and enhance performance [28,29]. Ships with 400 GT or more must adhere to EEXI requirements, whereas ships with 5000 GT or more participating in international trade must follow CII regulations [14,15]. A corrective action plan must be submitted outlining how the necessary CII rating (C or above) will be attained for a ship with a D or E rating for three consecutive years [30].

As part of the SEEMP, the ship must boost EE and minimize carbon emissions. Numerous operational EE measures are implemented as part of SEEMP to reduce fuel usage and carbon emissions. Ships can improve energy efficency and save fuel using alternative LC fuels, EE operational measures, and EE technical measures like retrofits, innovative software, and innovative tools [31,32]. Air lubrication, contemporary propulsion, and waste heat recovery systems can minimize ships' fuel consumption and GHG emissions [33]. Depending on ship type and size, voyage optimization systems, trim optimization software, and propulsion power optimization software can save fuel [30]. The SEEMP recommends best practices for each ship, including voyage planning, weather routing, speed optimization, vessel handling optimization, improved fleet management, optimized cargo handling, etc. Ships can improve their EE and reduce their carbon emissions by using a variety of EE measures during ship operations.

2.2. Implementation of energy efficiency regulations and seafarers' engagement

As a top decision-making organization, the IMO is responsible for making decisions, while flag states, member states, and ship operators are responsible for implementing those decisions. In addition to significant barriers to enforcing IMO regulations, the member states are primarily responsible for ensuring their effective implementation [34]. The maritime industry is structured in a clear hierarchy, with the IMO overseeing regulations and the maritime administrations of member states enforcing them. The implementation of maritime regulations involves the active participation of various stakeholders, including government organizations, classification societies, and crew members, all working together to ensure safety and environmental protection. However, this crucial task is becoming increasingly stressful due to the substantial volume of maritime traffic and the complex interplay between the IMO and member states. There are no clear warning signals, which can lead to inappropriate actions among involved parties. Additionally, inconsistencies in maritime regulations for port inspections across countries further complicate matters, which leads to varied implementation approaches [34,35]. Achieving greater transparency in the industry and engaging industry actors in self-regulation approaches will deliver the best results. While the IMO plays an essential role in advancing these goals, individual and collective port-state authorities are driving them forward [35]. Although the IMO issues directives to national maritime administrations, discrepancies occur due to varying interpretations and different jurisdictions. As flag states fail to enforce maritime regulations and port states fail to control them, unforeseen interactions arise, hindering effective implementation. To address these challenges, member states must prioritize comprehensive training programs for crew members, ship managers, port state control (PSC), and other government entities. These efforts necessitate increased awareness campaigns, the provision of essential knowledge and tools by member state administrations, and the strengthening of safety and environmental protection regulations. These regulations should be effectively implemented by both ship crews and managers, overseen by maritime flag state administrations, and ensured by the Port State Control (PSC) of member states during ship operations [34].

Global trade relies on safe and efficient ship operations, and seafarers play a crucial role in ensuring that goods are transported securely and efficiently. Researchers Banks et al. [1] found that seafarers' behavior and decision-making impact a vessel's EE and that their engagement and training help to implement EE operational measures effectively. The technical managers at the shore offices and crew members on board ships are responsible for ensuring the safety and energy-efficient ship operations outlined in the International Safety Management (ISM) Code and Safety Management System (SMS) manual. Besides emergency procedures, maintenance, and safety management, the SMS manual specifies the minimum requirements for ship safety and pollution prevention. In order to ensure a safe and efficient ship operation, different stakeholders, including the ship crews, have different roles and responsibilities [36,37]. Technical managers provide technical assistance and directions to the ship's master and chief engineer, ensuring that ships operate safely, efficiently, and responsibly [38]. The ship's master must be committed to implement the SEEMP, while the chief officer, chief engineer, and second engineer of the vessel's management team have particular obligations relating to ship operations and maintenance. It has been found by Dewan and Godina [39,40] that seafarers actively implement EE measures during the ship's operation. The ship's master and deck officers primarily perform navigation, cargo work, deck operations, and port energy efficiency measures, whereas the engine crew oversees EE measures pertaining to power generation and propulsion engines, as well as power and engine load management [39]. The operational EE measures and active involvement of ship crews in implementing them onboard ships are crucial for reducing the environmental impact of shipping and enhancing EE in the shipping industry. Although operational EE measures onboard ships have significant benefits, Dewan and Godina [39] argue that seafarers need to be adequately rewarded or acknowledged for their efforts. Moreover, Johnson et al. [41] found that ship crews need feedback and recognition for their efforts in implementing EE measures onboard ships. According to Banks et al. [1], the majority of seafarers believe that rewards are important to motivate crew members to improve EE and LC practices.

2.3. Status of seafarers' awareness and knowledge of EE and LC shipping

The maritime industry relies heavily on seafarers' awareness and training about EE and LC ship operations to achieve sustainable solutions and reduce emissions. The EE enhancements and fuel savings programs become successful only if crewmembers of the ship are well aware, motivated, cooperative, and involved [24]. Despite their participation in developing the SEEMP, many seafarers report a need for more training for SEEMP implementation [42]. Education and training are required to facilitate SEEMP implementation and empower crew members to make decisions that align with the SEEMP's goals [23,43]. The active participation and involvement of the crew are crucial for improving EE in ship operations, including utilizing new technological equipment and day-to-day operational measures. The EE and LC ship operations are only possible when the ship adopts SEEMP measures, a dynamic mechanism to optimize EE, emphasizing the assignment of specific individuals to implement technical and operational measures. Despite technological advancements in ship automation, ship crews continue to play an important role in vessel management and the implementation of EE measures, although with limited guidance. The SEEMP has a direct impact on seafarers' daily operations, necessitating their awareness, knowledge, skills, and motivation to make informed decisions and implement operational measures safely and efficiently [44]. While simulator-based training has been proposed [45], clarity is needed regarding what constitutes "necessary training." It is crucial for technical managers and crew members to understand and implement key regulations, including EEDI, SEEMP, EEXI, and CII [28,44].

Seafarers often lack of awareness of the impact of CO_2 and other GHG emissions, with less than one-tenth considering themselves knowledgeable [1]. Banks et al. [1] emphasize the importance of motivated seafarers receiving effective training programs, underlining the need for seafarers to understand the scientific basis of carbon emissions and their role in global warming and climate change, such as those driven by the United Nations Framework Convention on Climate Change (UNFCCC) and the Kyoto Protocol. To enhance their awareness and knowledge of carbon emissions and their adverse environmental impact, seafarers rely on various sources, including TV documentaries, news, radio, magazines, newspapers, books, discussions with peers, educational programs, and maritime training courses. Despite the IMO's enforcement of maritime EE regulations a decade ago, the knowledge and awareness levels of seafarers, as assessed by Banks et al. [1] in 2014, remain relatively unexplored. There have been no subsequent studies in this area to determine the current level of seafarer awareness and knowledge of EE and LC shipping, therefore leaving a gap in research.

2.4. Seafarers' training on energy efficient (EE) and low-carbon (LC) ship operations

As seafarers operate in complex environments that are influenced by norms, regulations, and economics, advanced technical skills are essential. As the maritime industry evolves and regulations change, continuous education and training become increasingly important for seafarers. Comprehensive training is crucial in handling the industry's complexity. Therefore, a number of amendments have been made to the International Convention on Standards of Training, Certification, and Watchkeeping for Seafarers (STCW), promoting modern training methods such as distance learning and web-based education, immersive and non-immersive simulator training [46], which enhance seafarers' preparedness for energy-efficient ship operation [47]. In collaboration with the Norwegian Government, IMO developed the IMO Green-Voyage2050 E-learning energy efficient ship operations training programs [48]. The Global Industry Alliance (GIA) has designed courses to promote EE and LC shipping. As part of the One UN Climate Change Learning Partnerships e-learning platform, these courses are offered free of charge to help improve global climate literacy by providing high-quality learning materials. Notably, the IMO has played a pivotal role in shaping the education and training of various stakeholders of the maritime industry on EE and LC ship operations to achieve sustainable solutions and reduce emissions. IMO's initiatives, like the "Train the Trainer" course, focus on enhancing existing Energy Efficient Ship Operation courses, emphasizing practical aspects [49]. In addition to improving existing courses in "Energy Efficient Operation of Ships (EEOS)'', this program facilitates capacity building in developing countries as well as other member states [49,50]. A deeper understanding of EE and LC ship operations can be gained by integrating maritime EE training into pre-sea and post-sea training curricula [43].

With the use of modern simulation technology, such as immersive and non-immersive simulators, it is possible to learn complex tasks in a virtual environment, making training more effective [51,52]. Researchers [23,53] have examined seafarers' awareness and knowledge of ship EE measures as well as training using ship bridge simulators [45], computer-based training (CBT) with gamification tools [47], and education for energy-efficient ship handling [54]. Immersive gamification tools were found to be effective for ship energy efficiency training, with 78% of participants liking the program and 81% learning about energy-efficient measures [47]. Moreover, full-mission simulators and game-based e-learning tools have become increasingly popular, allowing seafarers to practice EE and LC ship operations, reducing emissions and energy usage [45]. In addition to creating realistic scenarios, these initiatives foster a deep understanding of energy-efficient ship operations, empowering seafarers to make informed decisions. Jensen et al. [45] reveal that with increased awareness, full-mission simulators, which combine human and technical aspects, have helped reduce energy use by 10%. By increasing seafarers' familiarity with energy-efficient ship operations and reducing GHG emissions, these innovative training initiatives emphasize the importance of practical training methods [1]. Additionally, specialized training programs like the Maritime Energy Management System (MariEMS) funded by the EU focus on educating maritime personnel about efficient energy management. With simulation tools, online delivery platforms, and workshops, the program provides a holistic training experience [55]. As a result of these collective efforts, the industry is demonstrating its commitment to training seafarers effectively, thereby promoting EE and LC shipping practices in accordance with the latest amendments of the STCW convention.

Most seafarers receive training on EE and LC shipping regulations and measures through onboard training activities, including computer-based training (CBT) conducted by experienced personnel, retrofit vendors, or project teams, which have been shown to ensure energy-efficient ship operations [43]. Raising awareness, providing information, and offering training are of utmost importance, focusing on developing human elements [23]. Hansen et al. [23] also observed that insufficient crew engagement and training could hinder the effectiveness of SEEMP in ensuring ship safety and minimizing environmental impact. A comprehensive and effective training program that goes beyond formal education is essential for training seafarers in energy-efficient ship operations. The best learning outcomes are achieved when the crew has hands-on experience and interacts with the ship operations [56]. Seafarers can contribute to EE and LC shipping goals by acquiring the necessary skills and knowledge.

3. Research approach and methodology

3.1. Research approach and design

The study employs an abductive approach [57] incorporating inductive and deductive reasoning. Initially, in the deductive phase, we construct a theoretical model derived from Banks et al. [1], which is further enhanced through real-world observations and industry experience. Simultaneously, in the inductive phase, new data gathered from our survey drive the exploration of novel insights and theories. This dual approach enables a comprehensive assessment of seafarers' awareness and knowledge of energy-efficient ship operations, with a specific emphasis on enforcing IMO regulations over the past decade.

Our survey combines qualitative and quantitative data collection and analysis through an online mixed-methods design. The mixed-methods approach collects and analyzes quantitative and qualitative data to comprehensively examine the subject matter [58]. The purpose of this mixed-mode survey is to gain an understanding of seafarers' awareness and knowledge of energy-efficient ship operations and to identify the challenges of implementing IMO regulations. This research design involves an online mixed-methods survey to collect data that allow an in-depth evaluation of seafarers' awareness and understanding of EE measures onboard ships. The purpose of this study is to gain a better understanding of the research problem by using a mixed-mode survey.

3.2. Designing mixed mode survey and distribution method

A comprehensive questionnaire was designed for the mixed-mode survey to ensure the collection of accurate and essential data for analysis. The questionnaire consisted of single-answer and multiple-choice questions, statements with a Likert scale, utilizing checkboxes for selecting single or multiple responses. For qualitative questions, respondents were presented with predefined options accompanied by checkboxes. Additionally, an "others" option was provided, enabling participants to furnish open-ended responses.

For the successful implementation of SEEMP measures, the engagement and training of both onshore and onboard seafarers are vital. The survey targeted ashore operations, technical and environmental managers, and onboard crew members directly involved in SEEMP implementation. Including female seafarers and final-year students studying marine engineering and nautical studies programs at maritime education and training (MET) institutes in the survey expanded the participant pool. The online Google form survey link was distributed globally on June 5, 2023, via individual and group email addresses and through mobile apps like Facebook Messenger, Viber, and WhatsApp group chats for prompt responses and conducted for a month. Furthermore, the survey included 7 participants from Liberia and Ghana and 81 post-sea cadets/students from two MET institutes in Bangladesh who have 1 year of sea service experience and knowledge of MARPOL VI Chapter 4. Followings four groups (A – D) of research questions were included in a mixed-mode survey, which consisted of 12 research questionnaires in total:

A. Profile of the participants.

1. Details of the participants: (i) Gender, (ii) Age, (iii) Present job role, (iii) Years of experience at sea or sea and office, (iv) Types of vessels participants currently work or manage, (v) Country of participant's shipping company located.

B. Awareness and Knowledge of EE and LC Shipping

2. Participants' awareness of the effects of CO_2 and GHG emissions on our planet.

3. Participants' knowledge of the effects of CO_2 and GHG emissions on our world.
4. Participants' level of technical knowledge on EE and LC shipping.
5. Participants' methods for knowledge acquisition regarding the effect of CO_2 and GHG emissions on our world.
6. Training received by participants for awareness and knowledge in EE and LC shipping practices

C. Seafarers' Efforts on EE and LC Shipping Practices

7. Participant's interest in learning EE and LC ship operations.
8. Participants' efforts to improve EE and LC shipping based on their level of technical knowledge.

D. Seafarers' Perceptions on Carbon Emissions Mitigation from Shipping

9. How participants believe it is possible to reduce carbon emissions from shipping.
10. How participants believe it is possible for ship crews to reduce carbon emissions from ships.
11. How important do participants believe it is possible to reduce carbon emissions from shipping.
12. How participants believe incentives can motivate ship crews for EE and LC ship operations.

The above grouping allows for a clear distinction between questions related to participant seafarers' profiles, awareness and knowledge, efforts, and beliefs or perceptions in the effectiveness of EE and LC shipping practices.

3.3. Sampling strategy

The methodology employed in this research aims to assess seafarers' awareness and knowledge of EE ship operation, explicitly focusing on implementing IMO regulations over the past decade. The study recognizes the importance of organizational and legislative initiatives, such as the EE requirements introduced by the IMO in MARPOL Annex VI in 2013, in reducing CO_2 emissions in the maritime sector. The success of these initiatives relies on the ship crews' capacity to acquire new practices, skills, and knowledge [10]. The research targets onshore ship managers and onboard seafarers in various positions to gather comprehensive feedback, including masters, deck officers, chief engineers, engineer officers, ship operation managers, technical superintendents, marine superintendents, and environment managers. A purposive sampling strategy was employed, resulting in a total of 262 active seafarers from diverse backgrounds, including 31 female seafarers, representing 41 shipping companies worldwide. This also includes 88 final-year students studying marine engineering and nautical science programs in MET institutes in Bangladesh, Liberia, and Ghana who have a minimum of one year of sea service experience onboard ships.

3.4. Analysis of survey data

The survey collected data from 262 respondents, comprising 231 males and 31 females. The data obtained from the study were analyzed using SPSS Version-16 software and Excel formulas, with the percentages calculated as fractions of the total number of respondents. Graphs and charts presenting the participants' percentages included the total number of responses (N = Number of Participants) in the captions. Additionally, we have used M = "Total Male Seafarers" and F = "Total Female Seafarers." Additional comments provided by respondents under the "Others" option were interpreted as linguistic information. In cases where a variable was not filled out in dependent rating questions, the entire survey response was considered defective and excluded from the analysis.

4. Profile of the survey respondents

The survey collected responses to question (Q)1 from 262 respondents, comprising 231 males and 31 females (Fig. 1(a)). Among the participants, there were 26 senior engineers at the management level (chief and 2nd engineers), 14 senior deck officers at the management level (masters and chief officers), 5 Ship Managers (including Technical/ Marine Superintendents, Operation Managers, Environment Compliance Managers), 72 junior engineers at the operational level (3rd and 4th engineers), 57 junior deck officers at the operational level (2nd and 3rd officers), and 88 final-year students studying marine engineering and nautical science programs in MET institutes in Bangladesh, Liberia, and Ghana who completed their required practical sea services from onboard ships (Fig. 1(b), including both male and female seafarers). Fig. 1(c) displays the distribution of participants' years of experience, comprising both male and female seafarers working onboard ship and ashore offices. The survey gathered responses from a diverse group, including 24 participants with over 15 years of experience, 19 participants with 11 to 15 years of experience, 29 participants with 6 to 10 years of experience, 102 participants with 1 to 5 years of experience, and 88 post-sea cadets/ students who had 1 year of experience working onboard ships. A comparison of female and male seafarers' positions and years of experience is provided in Fig. 1(b) and 1(c).

Respondents were employed in onboard ships and ashore shipping companies in 24 countries worldwide. These countries included Bangladesh, Singapore, Japan, China, Hong Kong, UAE, Saudi Arabia, India, Greece, Liberia, Taiwan, Malaysia, Korea, Denmark, Belgium, Germany, Iran, Qatar, Cyprus, Italy, USA, UK, Canada, Ghana, and the Netherlands (Fig. 2). Fig. 3(a) shows the age distribution of seafarers, including both males and females. Among the participants, 55% were under 25 years old, 31% within the age range of (25 to 34), 7% within (35 to 44) and (45 to 55) age ranges, and only 1% were 55 and above. Regarding job positions, Fig. 3(b) indicates that respondents were actively involved in operating and overseeing various types of ships, such as tanker ships, bulk carriers, container ships, gas carriers, and car carriers or Ro-Ro ships. Only 5 seafarers reported working on offshore or other types of commercial vessels. At the same time, 88 participants were final-year cadets/students studying marine engineering and nautical science programs in MET institutes in Bangladesh, Liberia, and Ghana.

5. Results and discussion

5.1. Seafarers' general awareness and knowledge of CO_2 emissions

Seafarers who are directly involved in implementing operational EE measures onboard ships are required to be aware and knowledgeable about the EE regulations and practices [1,20,21]. The success of energy-efficient ship operations and fuel-saving programs depends on crew awareness, knowledge, motivation, cooperation, and participation, according to the study findings of Bertram et al. [24]. Indeed, technical innovations have significantly contributed to the energy-efficient operation of ships, simplifying various operational practices such as optimized voyage planning, improved weather routines, and engine performance monitoring. These innovations have undoubtedly made the implementation of EE and LC practices onboard ships more efficient. However, our study emphasizes the crucial role of seafarers as on-field stakeholders in implementing these practices. Their awareness and knowledge are paramount, as they are the individuals operating the vessel and making real-time decisions during ship operations to enhance energy efficiency and reduce CO_2 emissions [31,33,59]. While technical improvements facilitate these processes, seafarers' understanding, and active participation are indispensable in achieving optimal results. However, shipping companies can meet their ambitious goals if crew members understand how EE and LC operation of ships works. Our findings from the received responses for Q2 and Q3 reveal that among

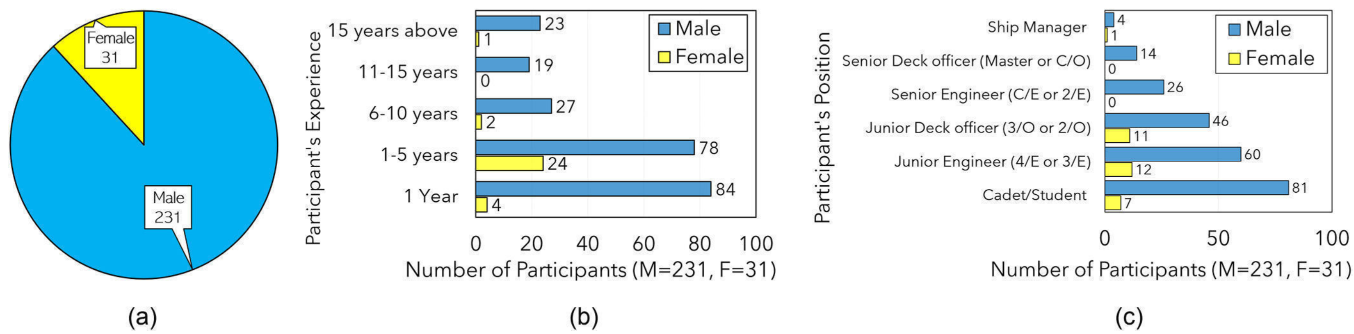

Fig. 1. (a): Gender of participant seafarers; Fig. 1(b): Participants' job roles. Fig. 1(c): Participants' years of experience onboard ships/ashore offices.

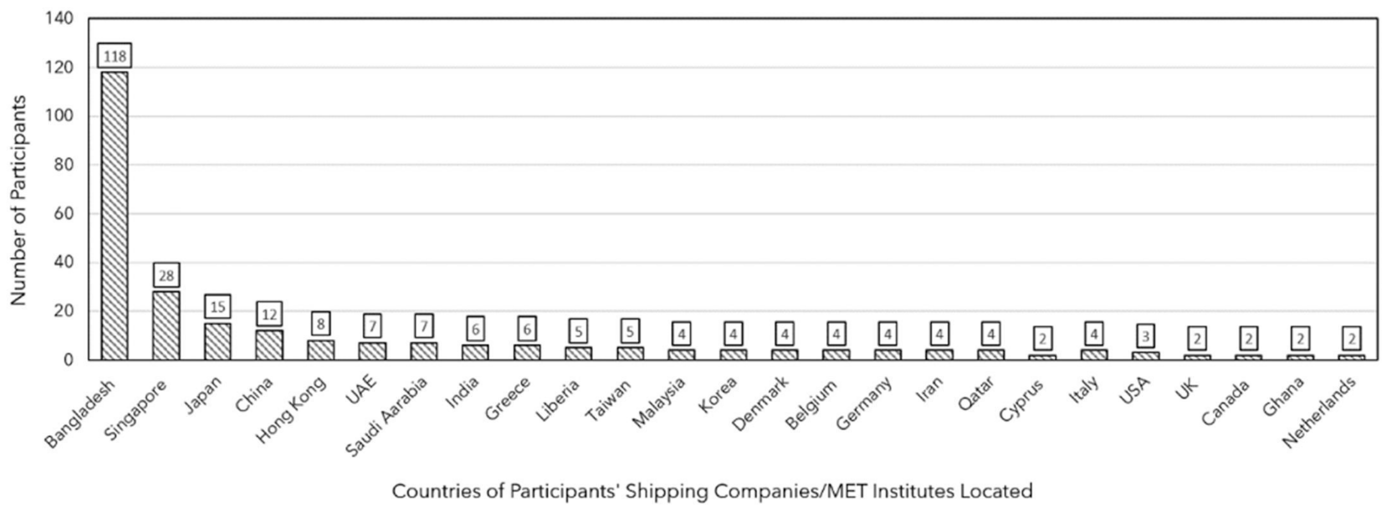

Fig. 2. Countries of participants' shipping companies/MET institutes located.

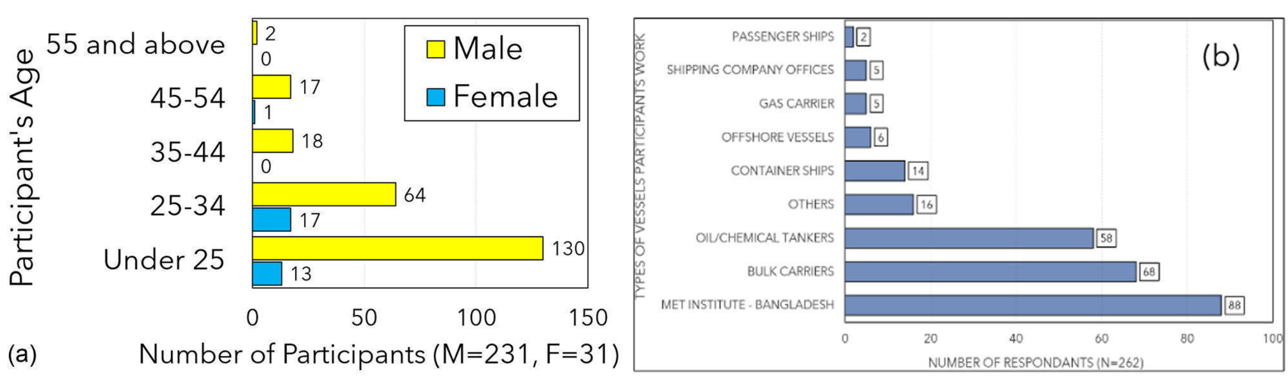

Fig. 3. (a) Participants' age; and 3(b) Types of vessels participants work.

262 participant seafarers, 22% are extremely aware, 39% are very aware, 32% are moderately aware, and only 1% are unaware of the effects of CO_2 and GHG emissions on the environment (Fig. 4(a)). Additionally, male seafarers show higher awareness levels than female seafarers (Fig. 4(b)). In the previous study, Banks et al. [1] found that 20% of seafarers were highly aware, 56% were aware, and 23% had some awareness of carbon emissions and their negative impacts on our environment.

Our findings reveal that 22% are extremely aware, 39% are very aware, 32% are moderately aware, and only 1% are unaware of the effects of CO_2 and GHG emissions on the environment (Fig. 4(a)). Additionally, male seafarers show higher awareness levels than female seafarers (Fig. 4(b)). According to Fig. 4(c), seafarers' awareness of EE and LC shipping is positively correlated with their experience levels. Specifically, 83% of seafarers with 15 years or more express extremely or very high awareness, compared to 69% with 11 to 15 years of experience, 58% with 6 to 10 years experience, 52% with 2 to 5 years experience, and 63% with 1 year of experience. This data emphasizes the increasing awareness with experience in the maritime industry. In Fig. 4 (d), it's evident that 72% of seafarers aged 35 and above express

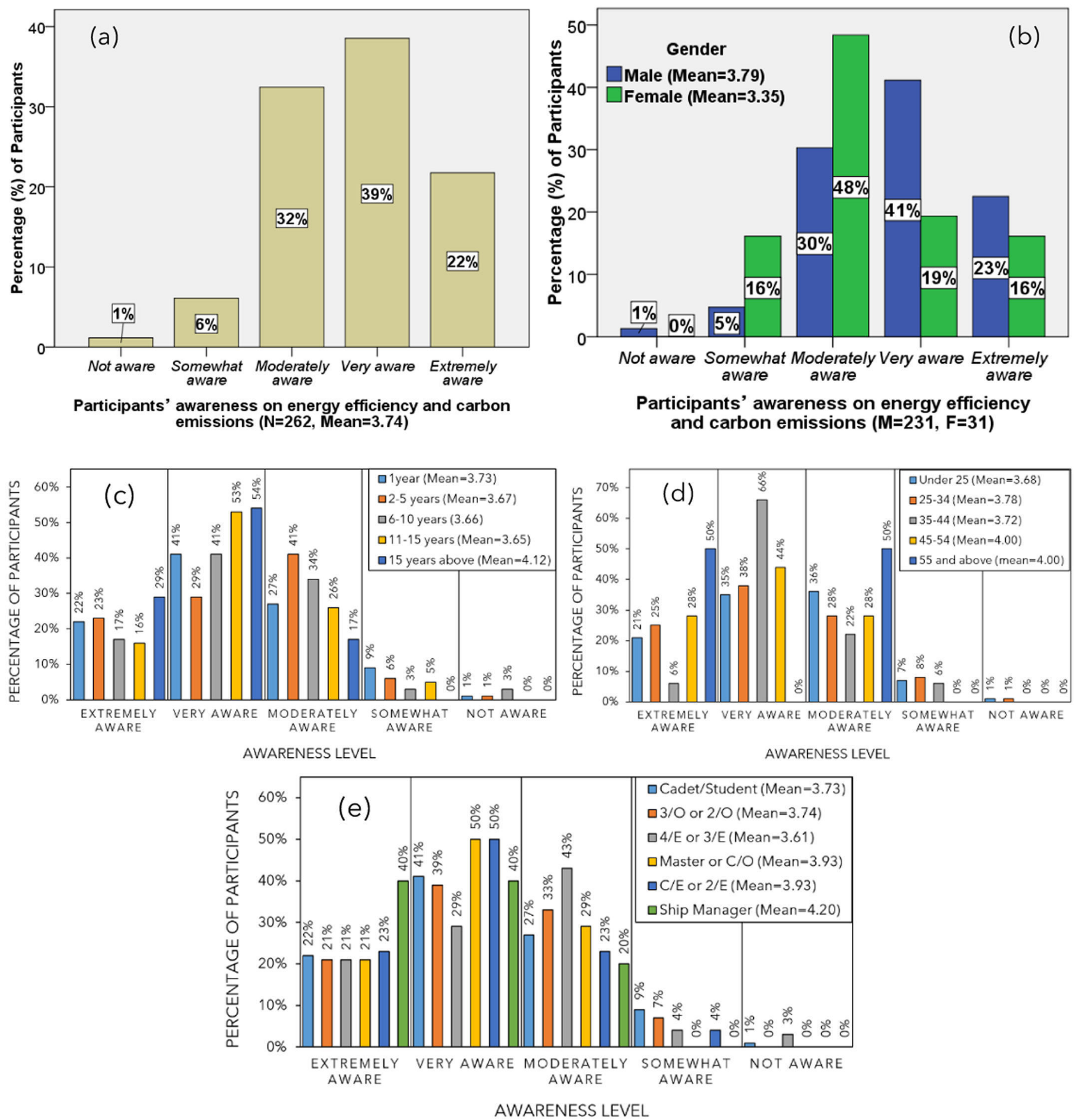

Fig. 4. (a): Participants' awareness of energy efficiency and carbon emissions (N = 262); Fig. 4(b): Participants' awareness of energy efficiency and carbon emissions (M=231, F=31). Fig. 4(c): Participants' awareness based on years of experience; Fig: 4(d): Participants' awareness based on age; Fig. 4(e): Participants' awareness based on positions (ranks).

extremely or very high awareness of EE and LC in shipping. Comparatively, awareness levels slightly decrease among younger age groups, with 63% for those aged 25 to 34 and 56% for seafarers under 25. This data underscores a correlation between age and awareness levels regarding EE and LC shipping in the maritime industry. Fig. 4(e) indicates that seafarers in higher positions in the maritime sector are more aware of EE and LC shipping. 80% of ship technical managers are extremely or very aware, followed by 73% of senior engineers (chief and 2nd engineers) and 71% of senior deck officers (masters and chief officers). As compared to senior positions, 64% of junior engineers (3rd and 4th engineers), 60% of junior deck officers (2nd and 3rd officers), and 63% of 1-year experienced cadets/students demonstrate similar levels of awareness.

Regarding knowledge, Fig. 5(a) demonstrates that 9% of respondents have excellent knowledge, 45% have good knowledge, 27% have moderate knowledge, and 4% have very limited knowledge of the effects of CO_2 and GHG emissions. Fig. 5(b) indicates that male seafarers (mean value 3.79) have more knowledge of maritime energy efficiency and

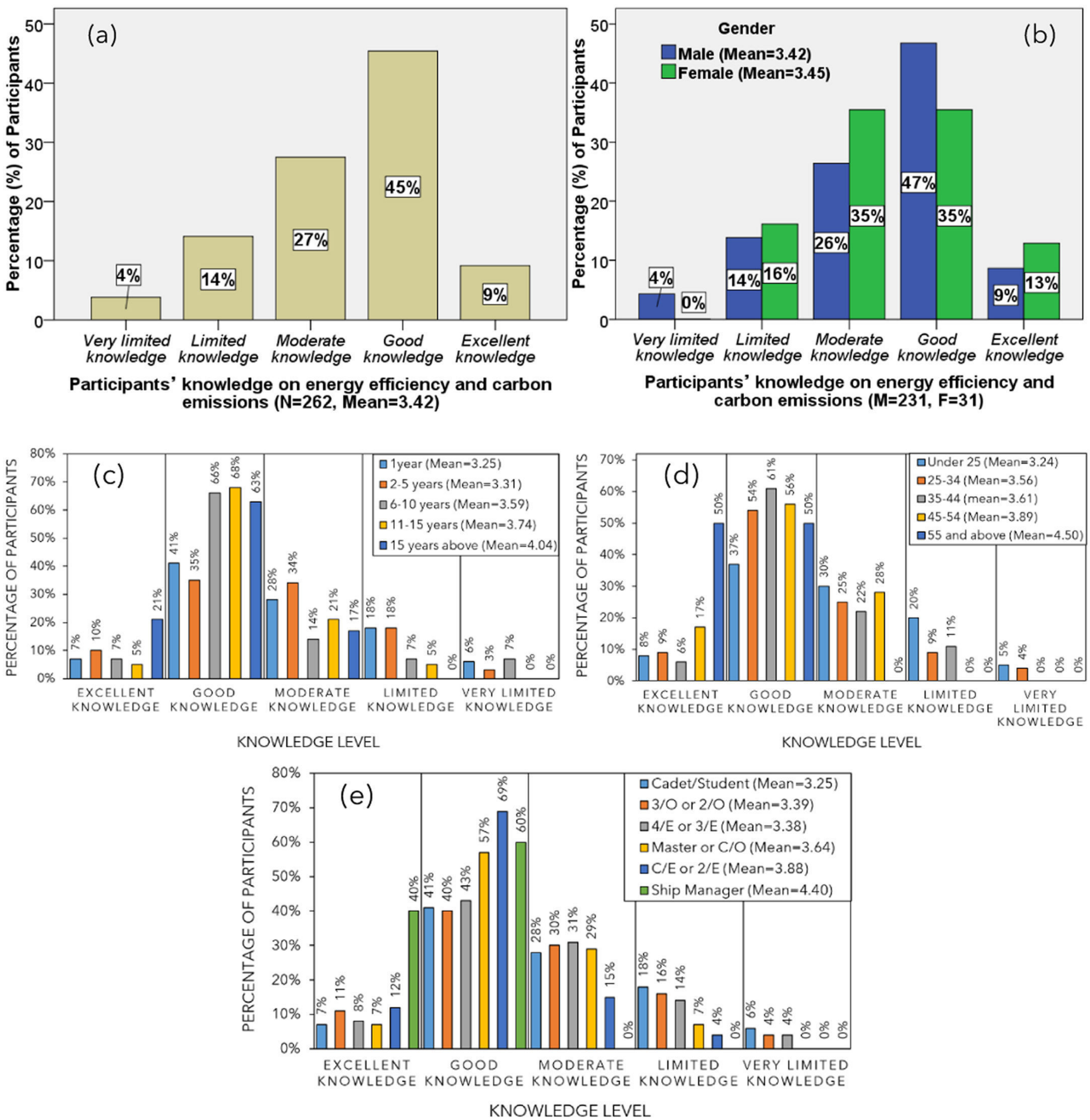

Fig. 5. (a): Participants' knowledge of energy efficiency and carbon emissions (N = 262); and Fig. 5(b) Participants' knowledge of energy efficiency and carbon emissions (M=231, F=31); Fig. 5(c): Participants' knowledge of energy efficiency and carbon emissions based on experience; Fig. 5(d): Participants' knowledge of energy efficiency and carbon emissions based on ages and Fig. 5(e): Participants' knowledge of energy efficiency and carbon emissions based on positions.

carbon emissions than their female counterparts (mean value 3.35). In addition, 4% of male seafarers expressed a need for more knowledge about carbon emissions and their effects on the environment. Previously, Banks et al. [1] reported that 6% of seafarers were very knowledgeable, 52% were knowledgeable, and 41% had fairly or limited knowledge regarding the topic.

According to Fig. 5(c), 84% of seafarers with 15 or more years of experience possess excellent or good knowledge, compared to 73% (11–15 years), 73% (6–10 years), 45% (2–5 years), and 48% (1 year). In Fig. 5(d), age is a determining factor in knowledge levels, with 86% of seafarers aged 55 and above exhibiting excellent or good knowledge. Comparatively, knowledge levels decrease across younger age groups: 73% (45–54 years), 67% (35–44 years), 63% (25–34 years), and 45% (under 25). Fig. 5(e) reveals a hierarchy of knowledge levels across maritime positions. 85% of ship technical managers have excellent knowledge, followed by 81% of senior engineers (chief and second engineers) and 64% of senior deck officers (masters and chief officers). In comparison to senior positions, 51% of junior engineers (3rd and 4th engineers), 51% of junior deck officers (2nd and 3rd officers), and 48% of cadets/students with 1 year experience show similar levels of knowledge. However, Experience positively correlates with knowledge levels, and age influences the understanding of energy-efficient and low-carbon shipping. Varied knowledge levels are observed across maritime positions, emphasizing the necessity of targeted training initiatives.

5.2. Source of Awareness and knowledge on energy efficiency (EE) and low-carbon (LC) emissions

In order to implement energy-saving measures successfully during ship operations, crew members need to be educated and trained. As stated in the resolution MEPC.213(63), SEEMP success, as well as energy-efficient ship operations, depend on increasing awareness and training [10] onshore and onboard personnel. Crews' ability to learn new skills, practices, and knowledge is crucial to the success of these efforts [19,59–62].

5.2.1. Source of general awareness and knowledge on EE and LC emissions

Our study findings reveal that 54% of seafarers acquire general awareness and knowledge about EE and LC emissions through educational programs and social media platforms like Facebook, YouTube, Twitter, LinkedIn, etc., mostly from the shared authentic news links published by the IMO, UN, and other national and international organizations. Fig. 6 indicates that pre-sea and post-sea maritime training programs/courses contribute to the knowledge of 43% of seafarers, while TV news/documentaries contribute to 41% of awareness. Newspapers/magazines, onboard ships, and shipping companies' in-house training activities account for 35%, and discussions with colleagues and other people make up 32% of awareness. Books and publications contribute 31% of knowledge, and educational courses/programs provide information to 25% of seafarers. Comparing these findings with the previous study by Banks et al. [1], it is evident that modern seafarers increasingly use social media platforms to gain awareness and knowledge, while traditional sources such as books, publications, and newspapers have significantly diminished in importance. There is a clear shift in information consumption among seafarers, emphasizing the need for training and awareness programs to take advantage of social media platforms to disseminate relevant information on carbon emissions and the sustainability of the environment.

5.2.2. Methods of acquisition of awareness and knowledge on EE and LC shipping

Our findings, Fig. 7, indicate that among 262 respondents, 70% of seafarers have acquired awareness and knowledge through training activities provided by shipping companies and institutional training courses or programs. These activities include onboard ship training, computer-based training (CBT), in-house training, and institutional training courses or programs on the Energy Efficient Operation of Ships (EEOS) offered by MET institutions. Furthermore, 17% of seafarers obtained the required knowledge from IMO's online/E-learning EEOS courses or workshops organized by maritime administrations in member-state countries. Notably, a substantial portion, comprising 23% of seafarers, reported not attending any available training courses or programs on EEOS. This suggests a gap in training opportunities and highlights the need for greater emphasis on awareness and knowledge in this area.

5.2.3. Seafarers' current level of technical knowledge on EE and LC shipping

Our study findings in Fig. 8(a) indicate that 7% of seafarers have excellent technical knowledge of carbon emissions and maritime energy efficiency, 32% have good technical knowledge, and 31% have moderate technical knowledge of carbon emissions regulations and maritime EE measures based on their responses to Q4. Among those who reported, 19% had limited knowledge of carbon emissions and maritime energy efficiency, and 10% needed more knowledge. Moreover, Fig. 8(b) shows that male seafarers (mean value 3.10) possess a higher level of technical knowledge than female seafarers (mean value 2.74).

Based on Fig. 8(c), the analysis reveals a correlation between experience and technical knowledge in energy-efficient and low-carbon shipping. Fig. 8(c) demonstrates that 66% of seafarers with 15 years or more experience have excellent or good technical knowledge regarding energy-efficient and low-carbon shipping, compared to 58% of seafarers with 11 to 15 years experience, 48% of seafarers with 6 to 10 years experience, 30% with 2 to 5 years experience, and 36% with one year's experience. In Fig. 8(d), age becomes a factor influencing technical knowledge. Fig. 8(d) indicates that 50% of seafarers aged 55 and over have excellent or good technical knowledge about EE and LC in shipping, while 55% of seafarers between 45 and 54 years old, 50% of seafarers between 35 and 44, 44% of seafarers between 25 and 34 age range and 32% of seafarers under 25 have the same level of technical knowledge. Fig. 8(e) shows that 77% of senior engineers (chiefs and 2nd engineers), 36% of senior deck officers (masters and chief officers), and 80% of ship technical managers have excellent or good technical skills. Comparatively, to senior positions, 35% of junior engineers (3rd and 4th engineers), 32% of junior deck officers (2nd and 3rd officers), and 34% of 1-year experienced cadets and students have similar levels of technical proficiency. But 44% of cadets and students with 1 year of experience, 35% of junior deck officers (2nd and 3rd officers), and 24% of junior engineers (3rd and 4th engineers) reported limited or very limited technical knowledge about EE and LC shipping.

5.3. Seafarers' motivation towards EE and LC ship operations

5.3.1. Importance of EE and LC ship operations according to seafarers

Based on the analysis of our study's data, the findings provide insights into seafarers' motivation toward energy-efficient ship

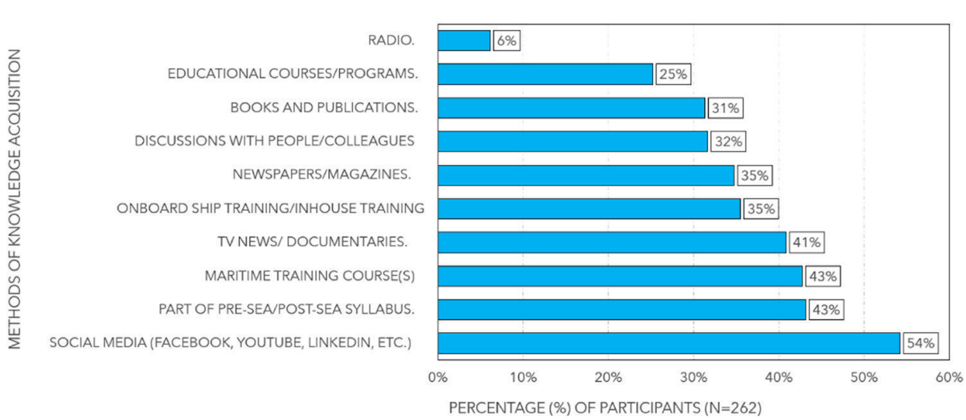

Fig. 6. Participants' awareness and knowledge acquisition methods (N = 262).

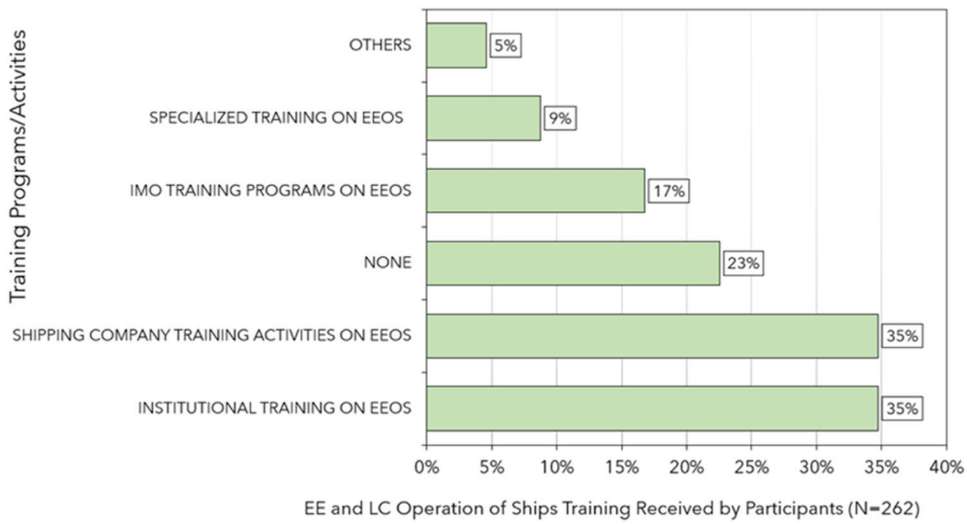

Fig. 7. Methods of EE and LC ship operations training received by participants (N = 262).

operations. In response to Q11 regarding the importance of reducing carbon emissions from shipping, Fig. 9(a) shows that 57% of seafarers believe it is extremely important, 32% believe it is very important, and 10% believe it is moderately or somewhat important. This belief is consistent among male and female seafarers (Fig. 9(b)).

It is evident from Fig. 9(c) that seafarers with different levels of experience believe that reducing carbon emissions from shipping is very important. Seafarers with 15 years or more experience, 94% with 11 to 15 years, 86% with 6 to 10 years, 90% with 2 to 5 years, and 91% with 1 year of experience consider it extremely or very important. Fig. 9(d) shows that age is a defining factor, with 100% of seafarers 55 and older, 77% (45 to 54 years), 89% (35 to 44 years), 90% (25 to 34 years), and 91% (under 25 years) expressing the belief that reducing carbon emissions from shipping is extremely or very important. A consistent sentiment is evident in Fig. 9(e). A total of 100% of ship technical managers, 93% of senior engineers (chief and 2nd engineers), and 72% of senior deck officers (masters and chief officers) believe that reducing carbon emissions is extremely or very important. This viewpoint is also shared by 95% of junior engineers (3rd and 4th engineers), 84% of junior deck officers (2nd and 3rd officers), and 91% of 1-year-experienced cadets and students. Across various levels of experience and roles in the maritime industry, the importance of carbon emission reductions is widely acknowledged.

5.3.2. *Participants' perceptions of carbon emissions mitigation by individuals*

When asked about reducing carbon emissions from shipping (Q9), Fig. 10(a) reveals that 21% of seafarers believe it is extremely possible, 47% believe it is very possible, and 25% believe it is moderately possible. Importantly, none of the respondents, both male and female, expressed the belief that it is not possible to reduce carbon emissions (Fig. 10(b)).

Fig. 10(c) shows that 84% of seafarers with 15 years or more experience, 84% with 11 to 15 years, 51% with 6 to 10 years, 60% with 2 to 5 years, and 76% with 1 year of experience believe that it is extremely or very possible. In Fig. 10(d), age influences perception, with 86% of seafarers aged 55 and above, 84% aged 45 to 54, 73% aged 35 to 44, 59% aged 25 to 34, and 72% aged under 25 believing that reducing carbon emissions from ships is extremely or very possible.

Maritime roles exhibit consistent perspectives in Fig. 10(e). 80% of ship technical managers, 75% of senior engineers, 74% of senior deck officers, 65% of junior engineers, 65% of junior deck officers, and 77% of 1-year experienced cadets/students reported that individual contributions are extremely or very possible. Within the maritime industry, individual actions can help reduce carbon emissions, as shown by these data.

5.3.3. *Participants' perceptions of carbon emissions mitigation by seafarers*

Regarding the perception of ship crews' ability to reduce carbon emissions (Q10), Fig. 11(a) demonstrates that 16% of respondents are confident it is possible, 43% believe it is very possible, and 27% believe it is moderately possible. Fig. 11(b) shows that male and female seafarers generally hold the same level of belief, with mean scores of 3.56 and 3.54, respectively. In contrast, a small percentage (4%) of female seafarers' express doubt about the ability of ship crews to reduce carbon emissions. Comparing our study's findings with Banks et al. [1], it is evident that seafarers are highly positive in their belief regarding reducing carbon emissions from the shipping industry since the enforcement of EE regulations in 2013. These findings reflect a strong motivation among seafarers towards achieving energy-efficient ship operations and reducing carbon emissions in the maritime sector.

There is a prevailing sentiment among seafarers regarding the potential for seafarers themselves to contribute towards reducing shipping carbon emissions, as shown in Fig. 11(c). According to 71% of seafarers with 15 years or more experience, 58% with 11 to 15 years, 51% with 6 to 10 years, 55% with 2 to 5 years, and 67% with one year, it is extremely or very possible. It is evident in Fig. 11(d) that age influences these perceptions, as 100% of the seafarers aged 55 and over, 66% of those aged 45 to 54, 55% of those aged 35 to 44, 49% of those aged 25 to 34, and 63% of those under 25 believe that reducing carbon emissions by ship crews is extremely or very feasible. A consistent perspective is evident across maritime positions or ranks in Fig. 11(e). According to Fig. 11(e), 100% of ship technical managers, 73% of senior engineers, 71% of senior deck officers, 49% of junior engineers, 54% of junior deck officers, and 67% of 1-year cadets/students, it is extremely or very possible to reduce carbon emissions from the shipping industry by ship crews. It is evident from this data that seafarers hold differing beliefs about how they may contribute to reducing carbon emissions from shipping industry.

5.4. *Incentives to motivate seafarers for EE and LC ship operations*

A recent study by Dewan and Godina [39] reveals that more than three-quarters of seafarers and ship managers at sea have not been rewarded or appreciated for implementing SEEMP and meeting targets. They reported an only 8% of them received financial incentives, 6% received bonuses, and 4% received trophies. However, the data analysis from our survey of 262 respondents provides valuable insights into the

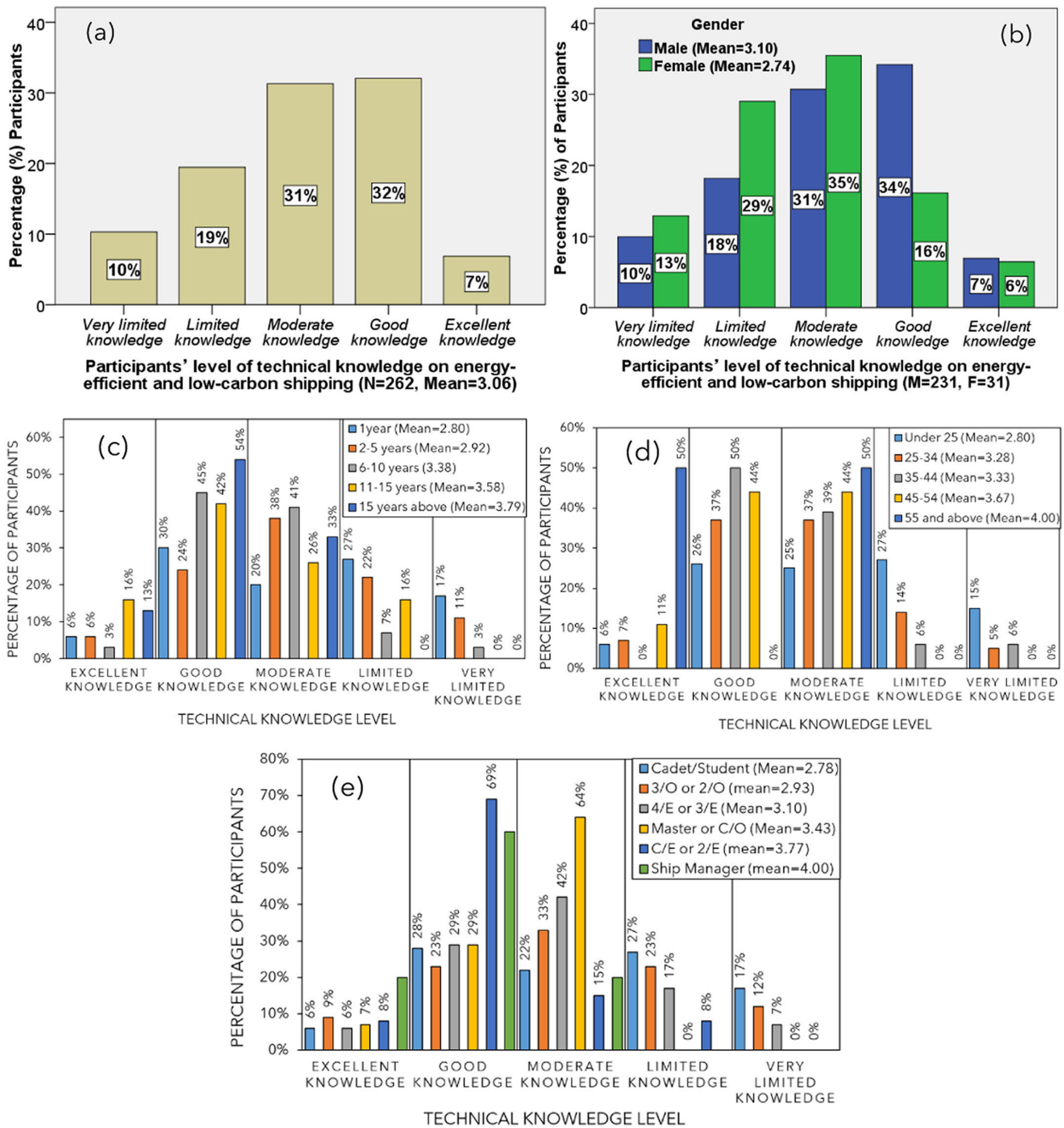

Fig. 8. (a) Participants' level of technical knowledge on energy-efficient and low-carbon shipping (N = 262); and Fig. 8(b) Participants' level of technical expertise on energy-efficient and low-carbon shipping (M=231, F=31); 8(c): Participants' specialized knowledge of energy efficiency and carbon emissions based on experience; Fig. 8(d): Participants' technical knowledge of energy efficiency and carbon emissions based on ages and Fig. 8(e): Participants' Technical knowledge of energy efficiency and carbon emissions based on positions.

incentives that can motivate seafarers for EE and LC ship operations. As a result of our findings in response to Q12 regarding incentives for ship crew motivation, 76% of seafarers believe that financial incentives or rewards can be a significant or quite a bit motivating factor in EE and LC ship operations, with 17% considering it moderately encouraging (Fig. 12(a)). Furthermore, Fig. 12(b) indicates that both male and female seafarers generally hold the same level of belief, with mean scores of 4.17 and 4.16, respectively. However, a small percentage (2–3%) of both male and female seafarers express doubt regarding the effectiveness of incentives.

Among seafarers, there is a consensus regarding the benefits of financial incentives for motivating crews to operate energy-efficient and low-carbon ships. Specifically, 87% of seafarers with 15 years or more experience, 84% with 11 to 15 years, 82% with 6 to 10 years, 72% with 2

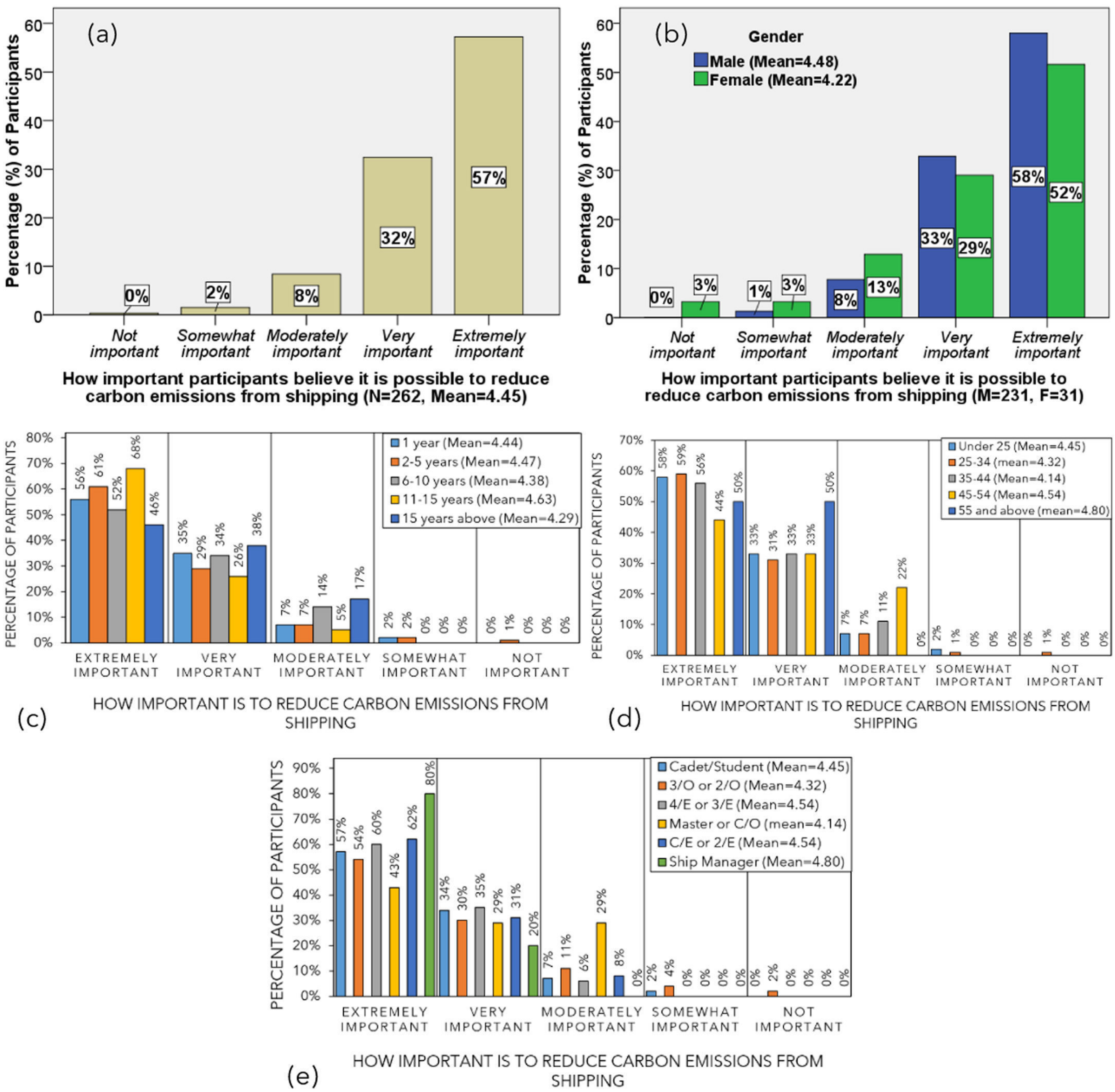

Fig. 9. (a): How important participants believe it is possible to reduce carbon emissions from shipping (N = 262); Fig. 9(b): How important participants believe it is possible to reduce carbon emissions from shipping (M=231, F=31); Fig. 9(c): How important participants believe it is possible to reduce carbon emissions from shipping based on seafarers' experience; Fig. 9(d): How important participants think it is possible to reduce carbon emissions from shipping based on seafarers' ages; Fig. 9(e): How important participants believe it is possible to reduce carbon emissions from shipping based on seafarers' positions.

to 5 years, and 74% with 1 year of experience believe incentives can significantly or quite a bit motivate ship crews (Fig. 12(c)). Fig. 12(d) reveals age-related variations in this belief, with 100% of seafarers aged 55 and above expressing this viewpoint, compared to 83% (45 to 54 years), 78% (35 to 44 years), 82% (25 to 34 years), and 72% (under 25 years). In Fig. 12(e), a consistent perspective is observed across different maritime roles. All ship technical managers, 89% of senior engineers (chief and 2nd engineers), and 78% of senior deck officers (masters and chief officers) express the belief that financial incentives can significantly or quite a bit motivate ship crews. In contrast, 78% of junior engineers (3rd and 4th engineers), 70% of junior deck officers (2nd and 3rd officers), and 74% of 1-year experienced cadets/students share this viewpoint. According to these findings, most seafarers recognize the benefits of financial incentives and formal recognition in motivating them for EE and LC ship operations.

5.5. Participant's interest in learning EE and LC ship operations

The survey data analysis report from responses of Q7 indicates that a majority of seafarers exhibit a strong interest in learning about EE and LC ship operations. Fig. 13(a) reveals that 84% of seafarers are extremely or very interested, while 13% express a moderate level of interest. Comparing male and female seafarers, males have a higher interest in learning EE and LC ship operations than female seafarers

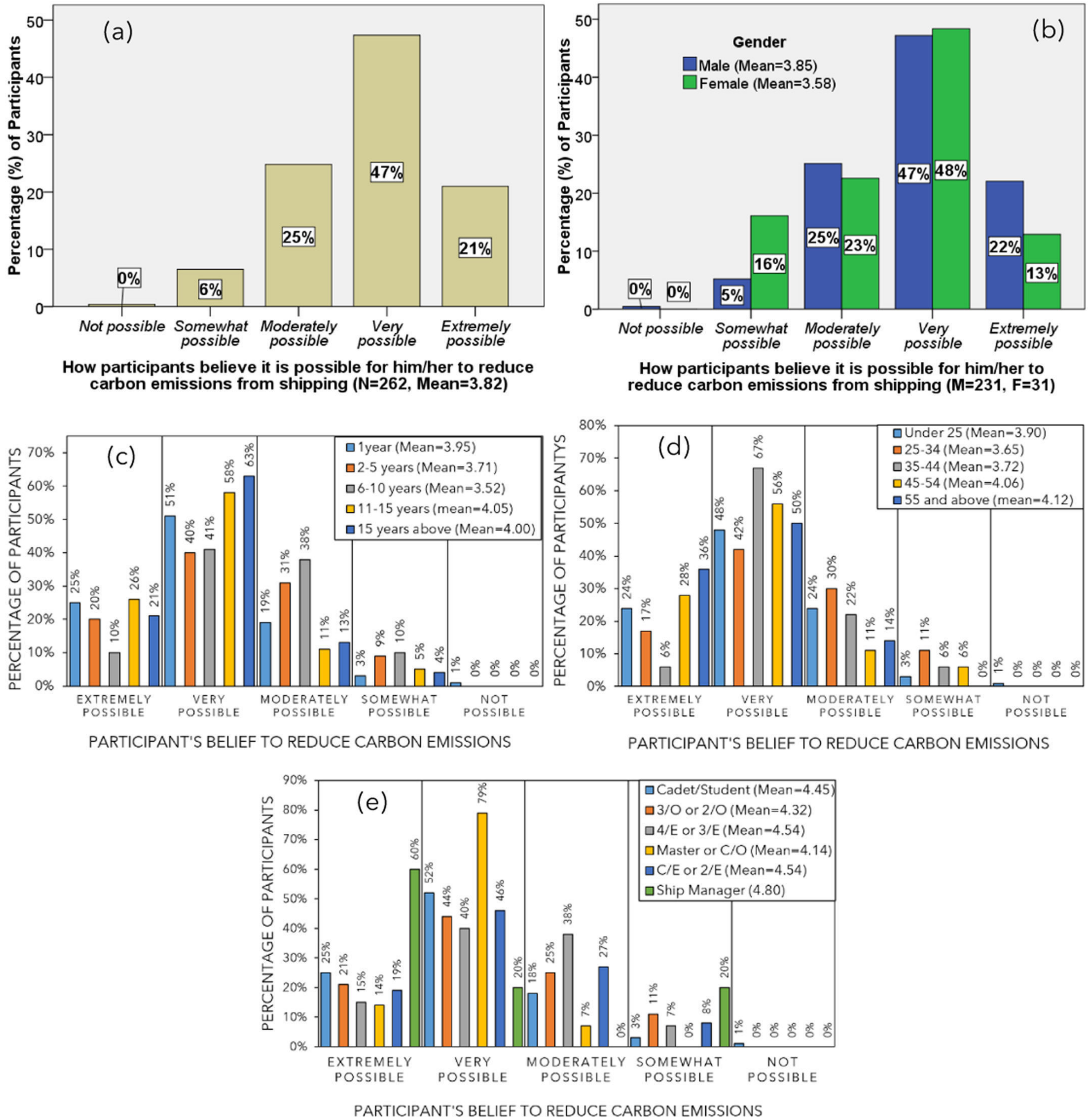

Fig. 10. (a) How participants believe they can reduce carbon emissions from shipping (N = 262, Mean=3.82); Fig. 10(b) How participants believe they can reduce carbon emissions from shipping (M=231, F=31); Fig. 10(c) How participants believe to reduce carbon emissions from shipping by individuals based on experience; Fig. 10(d) How participants believe to reduce carbon emissions from shipping by individuals based on ages; Fig. 10(c) How participants believe to reduce carbon emissions from shipping by individuals based on positions.

(4.23 for males and 4.06 for females). Only a small percentage (3%) of female seafarers show no interest in learning about these topics (Fig. 13(b)).

Seafarers are highly interested in learning about energy-efficient and low-carbon shipping, based on Fig. 13(c). According to the survey, 87% of seafarers with 15 years or more experience, 95% with 11 to 15 years of experience, 89% with 6 to 10 years of experience, 77% with 2 to 5 years of experience, and 86% with 1-year experience express extreme or very high interest in the topic. Fig. 13(d) illustrates the age-related variation in this interest, with 100% of seafarers 55 and above expressing extreme interest, compared with 78% (45 to 54 years), 89% (35 to 44 years), 88% (25 to 34 years), and 81% (under 25 years). Fig. 13(e) shows a uniform level of interest among maritime roles. 100% of ship technical managers, 84% of senior engineers, and 93% of senior deck officers express a significant or very high level of interest. 81% of junior engineers, 81% of junior deck officers, and 86% of cadets and students with one year of experience all share a similar enthusiasm for learning about energy-efficient and low-carbon shipping.

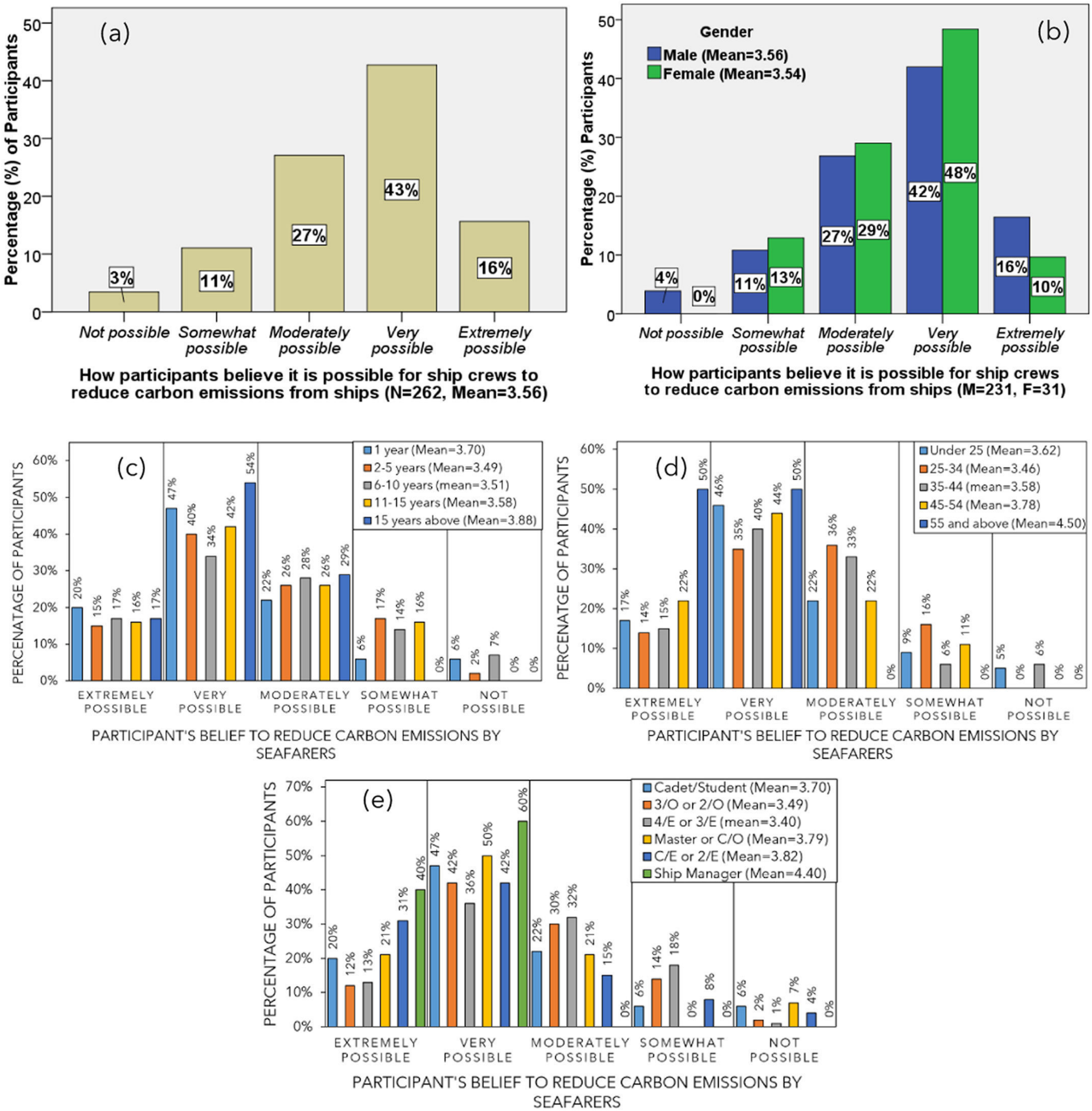

Fig. 11. (a): How participants believe it is possible for ship crews to reduce carbon emissions from ships (N = 262, Mean=3.56); and Fig. 11(b): How participants believe it is possible for ship crews to reduce carbon emissions from ships (M=231, F=31); Fig. 11(c) How participants believe in reducing carbon emissions from shipping by ship crews based on experience; Fig. 11(d) How participants believe to reduce carbon emissions from shipping by ship crews based on ages; Fig. 11(e) How participants believe to reduce carbon emissions from shipping by ship crews based on positions.

In comparison, a study by Banks et al. [1] found that 74% of participants expressed a desire to learn more about how the crew can contribute to EE and LC ship operations and reduce carbon emissions from the shipping industry, while 27% were less enthusiastic about learning additional knowledge. Based on our study, seafarers of both genders, all experience levels, age groups, and maritime positions, are highly interested in learning about energy-efficient and low-carbon shipping. It underscores a positive industry trend towards the net-zero target of IMO by 2050.

5.6. Efforts to improve EE and LC ship operations based on level of technical knowledge

The findings from our data analysis provide insights into the efforts made by seafarers to improve the EE and LC ship operations based on their level of technical knowledge. Excluding students (with 1 year of sea service experience as post-sea cadets as they are not certified watchkeeping engineers or officers yet) from the survey question (Q8), our study focused on 174 experienced seafarers. Fig. 14(a) indicates that 47% of seafarers made extensive or considerable efforts to improve EE

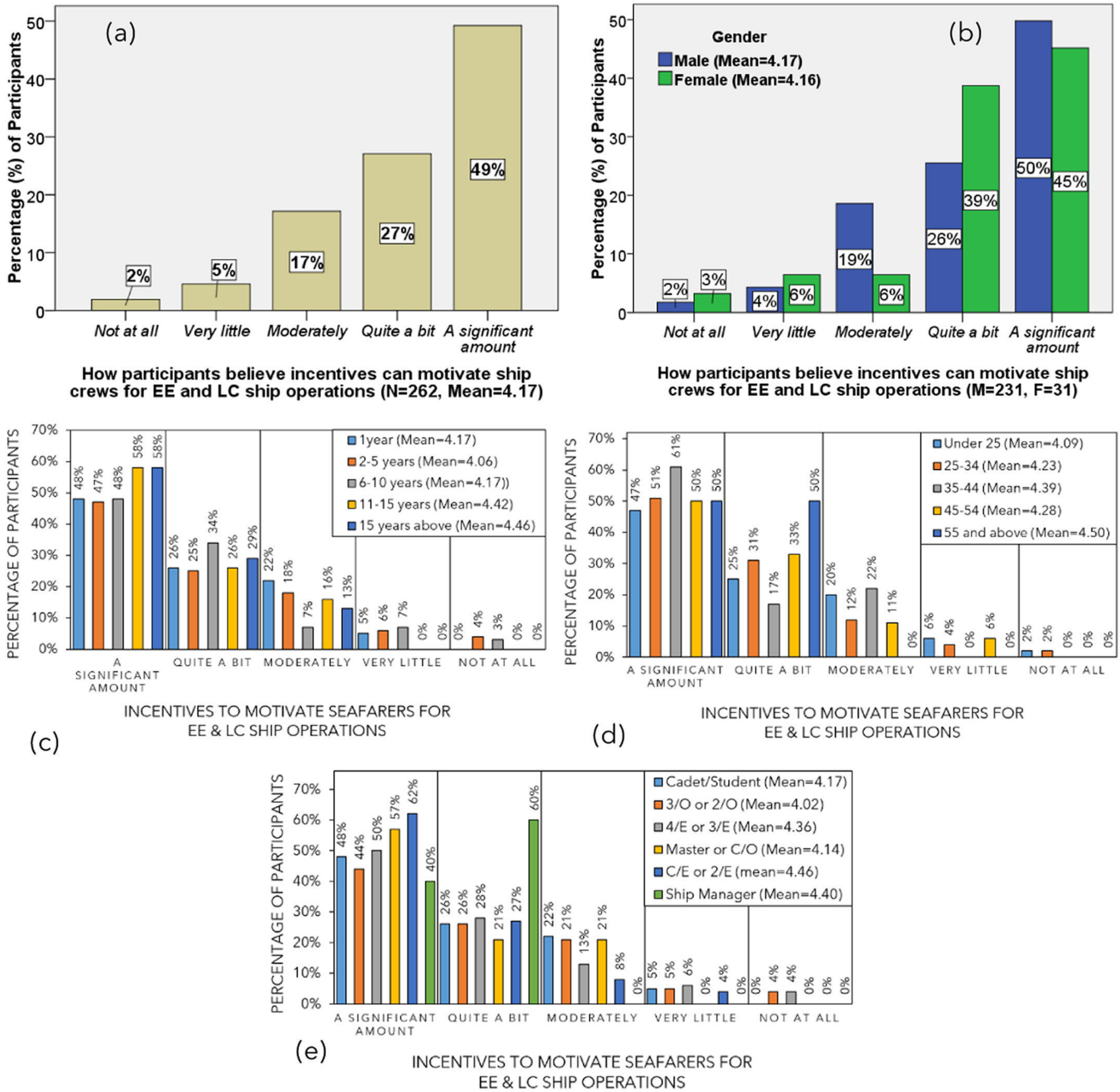

Fig. 12. (a) How participants believe incentives can motivate ship crews for EE and LC ship operations (N = 262, Mean=4.17); and Fig. 12(b) How participants believe incentives can motivate ship crews for EE and LC ship operations (M=231, F=31); Fig. 12(c) How participants believe incentives can motivate ship crews for EE and LC ship operations based on experience; Fig. 12(d) How participants believe incentives can motivate ship crews for EE and LC ship operations based on ages; Fig. 12(e) How participants believe incentives can motivate ship crews for EE and LC ship operations based on positions.

and LC ship operations based on their technical knowledge while working onboard ships. It is also shown in Fig. 14(a) that 53% of seafarers moderately, very little, or not at all make efforts to improve EE and LC ship operations. In comparison, the previous study by Banks et al. [1] reported that 49% of seafarers moderately, or very little or never made any effort onboard ships. Fig. 14(b) illustrates that male seafarers (mean value 3.41) exert greater effort to enhance EE and LC ship operations based on their technical knowledge compared to female seafarers (mean value 3.24).

Fig. 14(c) illustrates the level of effort seafarers put into improving energy-efficient and low-carbon shipping, revealing a clear trend. According to the survey, 71% of seafarers with 15 years or more experience, 53% of seafarers with 11 to 15 years of experience, 51% of seafarers with 6 to 10 years' experience, and 38% with 2 to 5 years of experience make significant or quite a bit of effort to make shipping more energy-efficient and low-carbon. In Fig. 14(d), a clear pattern emerges as 100% of seafarers aged 55 and above demonstrate substantial efforts to enhance EE and LC ship operation. The effort gradually decreases with younger age groups, with 61% (45 to 54 years), 50% (35 to 44 years), 52% (25 to 34 years), and 32% (under 25 years). Fig. 14(e) illustrates distinct efforts across maritime roles. Over 80% of ship technical managers contribute significantly or quite a bit to improving EE and LC shipping, followed by 63% of senior engineers and 66% of senior deck officers. However, junior engineers (42%) and junior deck

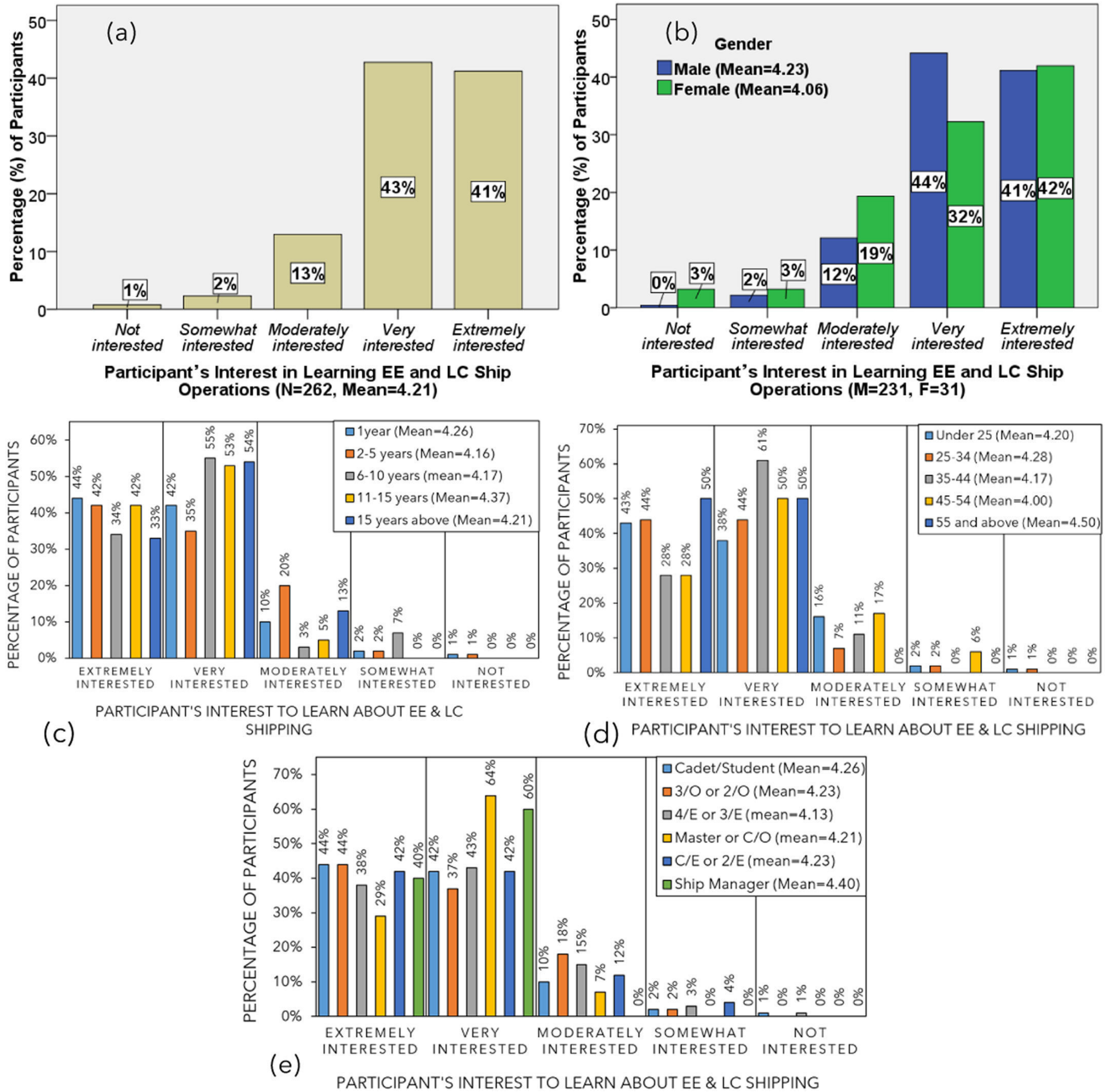

Fig. 13. (a): Participant's Interest in Learning EE and LC Ship Operations (N = 262, Mean=4.21); and 13(b) Participant's Interest in Learning EE and LC Ship Operations (M=231, F=31); Fig. 13(c): Participant's Interest in Learning EE and LC Ship Operations based on Experience; Fig. 13(d): Participant's Interest in Learning EE and LC Ship Operations Based on Ages; and Fig. 13(e): Participant's Interest in Learning EE and LC Ship Operations Based on Positions.

officers (37%) have lower levels of engagement. These findings underscore the diverse commitment levels across genders, experiences, ages, and positions in advancing energy efficiency in the maritime industry. However, it is concerning that 19% of males and 24% of females make very little or no effort in this area, suggesting a possible lack of technical knowledge of EE and LC ship operations. Female seafarers put less effort into operating ships in an energy-efficient and low-carbon manner as their junior positions and younger age groups entail fewer responsibilities onboard ships. Tailored training strategies for different demographic segments are crucial for a comprehensive impact on EE and LC ship operations.

6. Conclusions and recommendations for future research

In unveiling the awareness and knowledge of seafarers concerning EE and LC ship operations, this study underscores their commendable understanding of environmental impacts. Although progress has been made, there are still areas for improvement, particularly among younger and female seafarers. Gender disparities reveal that male seafarers exhibit higher awareness levels, indicating a need for targeted training initiatives to address knowledge gaps comprehensively. Experience emerges as a key factor positively correlating with knowledge, emphasizing the significance of long-term service in the maritime industry. Senior positions, particularly those occupied by older seafarers,

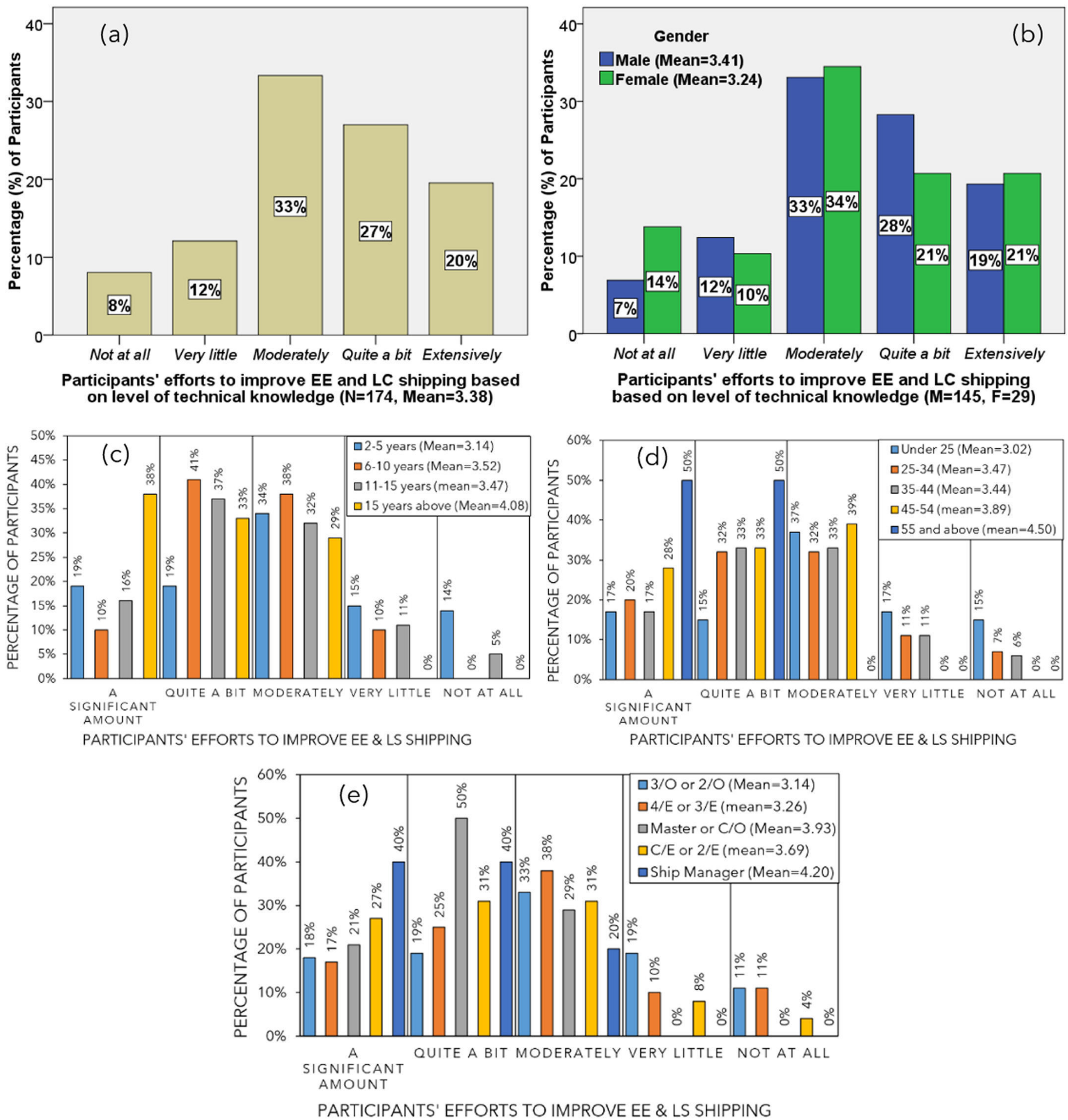

Fig. 14. (a): Participants' efforts to improve EE and LC ship operations based on level of technical knowledge (N = 174, Mean=3.38); and Fig. 14(b): Participants' efforts to strengthen EE and LC ship operations based on level of technical expertise (M=145, F=29); Fig. 14(c): Participants' efforts to improve EE and LC ship operations based on experience; Fig. 14(d): Participants' efforts to strengthen EE and LC ship operations based on ages; and Fig. 14(e): Participants' efforts to improve EE and LC ship operations based on positions.

demonstrate higher awareness and technical knowledge, reinforcing the impact of age and position. Senior positions, particularly onboard senior engineers and ashore technical managers demonstrate strong technical knowledge. According to our study, female seafarers work in junior positions, are younger, and have less experience than their male counterparts. Since awareness, knowledge, and technical expertise in EE and LC ship operations increase with experience, older ages, and senior positions in the maritime industry, female seafarers have a lower rate of awareness, knowledge, and technical expertise than male seafarers. The perception of carbon emissions mitigation in the maritime industry is consistent across gender, experience level, and position. Seafarers also believe that individual contributions can result in significant reductions in GHG emissions. Nevertheless, our study showed that 47% of respondents demonstrated extensive or considerable engagement. In comparison, 19% of males and 24% of females make very little or no effort in this area, suggesting a possible lack of technical knowledge of

EE and LC ship operations. Age and experience influenced commitment levels, emphasizing the need for tailored training strategies across demographics. Despite gender, experience, and roles, most seafarers (76%) agree that financial incentives and formal recognitions encourage them more for energy-efficient and low-carbon ship operations.

The shipping industry needs comprehensive education and training for seafarers to safely transition to a decarbonized future as the IMO's revised GHG Strategy targets net-zero emissions by 2050. According to DNV Maritime Forecast [63], 1.8 million seafarers will require to be trained in decarbonization by 2050. A seafarer with skills in digitalization, information technology, and technical expertise is needed by the maritime industry. There is a variation in knowledge levels across the maritime sector depending on gender, experience, and hierarchical position, emphasizing the need for targeted training initiatives to bridge existing gaps in knowledge and promote sustainable practices. Across genders, experience levels, and roles, there is high interest in learning about EE and LC ship operations, underscoring a positive industry trend and emphasizing the need for a targeted and well-designed training framework. The IMO's 2023 GHG Strategy emphasizes the urgency for net-zero emissions by 2050, necessitating future research on effective training methods, comprehensive frameworks aligned with digital tools and evolving technologies, and interventions addressing gender disparities. Investigating the sustained effectiveness of incentives and rewards in driving long-term behavior change is also crucial. Achieving energy efficiency improvement and carbon emissions reduction requires a holistic training framework, integrating computer-based programs, simulators, gamification, and social media for continuous seafarer education. Collaborative efforts among industry stakeholders are paramount for developing sustainable, industry-wide training initiatives. These comprehensive measures align with the imperative of achieving environmentally friendly shipping practices in line with the IMO's ambitious net-zero emission targets by 2050.

CRediT authorship contribution statement

Godina Radu: Formal analysis, Funding acquisition, Supervision, Validation, Visualization, Writing – review & editing. **Dewan Mohammud Hanif:** Conceptualization, Investigation, Methodology, Software, Writing – original draft, Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data Availability

No data was used for the research described in the article.

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A.5 Paper 5: Effective Training of Seafarers on Energy Efficient Operations of Ships in the Maritime Industry.

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Effective Training of Seafarers on Energy Efficient Operations of Ships in the Maritime Industry

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Abstract

About 90% of the world's economy depends on the maritime industry. The Fourth Greenhouse Gas (GHG) Study, 2020 by the International Maritime Organization (IMO) reported that 2.89% of total global anthropogenic CO_2 emissions had been emitted by international shipping. Though shipping transport is the most energy-efficient transport compared with other forms of transport, its massive effect on the environment must be mitigated. IMO's initial strategy is to set carbon intensity goals of at least a 40% reduction in CO_2 emissions per transport work by 2030, and a 70% reduction by 2050 must be met. To reach the Paris Agreement's targets, the IMO's Initial GHG Strategy and actions urge the deployment of energy-saving measures on commercial ships. Many small companies struggle to comply with MARPOL Annex VI regulations for existing old ships. Even though ship propulsion systems with new technology and low-carbon fuels are costly, many low-cost operational measures improve energy efficiency and reduce carbon emissions. Many shipping companies worldwide have reported substantial financial and environmental benefits from fuel savings by embracing energy-efficient innovative design and operating measures. But there is not enough information on which training activities are more effective for seafarers to implement operational energy efficiency measures on board ships. This study has shown onboard training activities such as computer and simulator-based training; onboard training by the technical manager or master and ship crews; training by the technical manager during the pre-joining briefing; and special training by the project teams/retrofits vendors onboard ships are the most effective training programs for seafarers for energy efficient operation of ships. Shipping companies are making many efforts to train their seafarers, but not all are effective. Seafarers need more effective training programs and corporate motivations to increase their awareness and willingness to contribute more to pollution-free green shipping.

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Keywords: Energy Efficient Operations of Ships; EEDI; SEEMP; EEOS; EEXI; CII; Maritime Industry; MARPOL

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1. Introduction

Commercial shipping represents 90% of international trade, making it one of the most vital industries in the global economy [1]. The United Nations Conference on Trade and Development (UNCTAD) estimated that there were 98,140 commercial ships with 100 billion gross tonnages and 2.06 billion deadweight tonnages at the beginning of 2020 [2]. These vast numbers of commercial vessels consume millions of tons of fossil fuel for propulsion and daily operations, producing emissions of various greenhouse gases (GHGs), which contribute to climate change [3]. The Third IMO GHG Study 2014 revealed that commercial shipping emitted 2.76% of global anthropogenic CO_2 in 2012 [4], which increased to 2.89% in 2018, according to the Fourth IMO GHG Study 2020 [5]. Rising seawater temperatures, acidification, and deoxygenation are caused primarily by human-caused CO_2 emissions and other GHGs. It changes oceanic circulation and chemistry, rising sea water levels, accelerated storm intensity, and abundant marine species [6]. The increasing global temperature and climate change cause floods in low-lying lands, melting glaciers and arctic ice, and rising seawater levels [7]. Therefore, global warming and climate change are becoming a trending concern in every part of the globe. The Paris Agreement pledges that all governments should keep the earth's temperature well below 2°C, which is much higher than industrialization, with a goal of 1.5°C. By 2100, the World Meteorological Organization (WMO) projects a rise in world average temperature of 3-5ºC based on recent statistics [8].

Since the last decade, emissions control from the shipping industry has gained continuous focus globally [9], not for its contribution to the reduction of GHG emissions to the environment but also because of growing awareness of the negative impact on health due to emissions of the harmful by-product substances while burning fossil fuels. As a result of these factors, the shipping industry has been forced to optimize its energy usage and environmental impact by regulatory and financial pressures. The IMO passed a resolution establishing a new plan for reducing ship-related emissions. The goal of the strategy is to cut the GHG emissions from the shipping industry by half by 2050 compared to what they were in 2008 [4]. New regulations for preventing and reducing air pollution caused by the maritime industry have been incorporated into Annex VI of the International Convention for the Prevention of Pollution from Ships (MARPOL) Convention [10]. In this context, the IMO has carried out a great deal of research and studies and adapted a few measures, such as the Energy Efficiency Design Index (EEDI) and the Ship Energy Efficiency Management Plan (SEEMP), both of which were included in the MARPOL agreements under Annex VI in 2011. In Chapter 4, energy efficiency (EE) criteria have been adopted to ensure that CO_2 emission obligations are met in designing and building new ships and in the operations of all existing new and old vessels used for commercial purposes. To reduce CO_2 emissions from commercial vessels, both the EEDI and SEEMP regulations came into effect on 1st January 2013 [10].

The IMO established the Energy Efficiency Operational Indicator (EEOI) to enable ships to calculate their CO_2 emissions and monitor them for their maritime operations. An efficiency indicator for all existing vessels, calculated on fuel utilization, total distance traveled in knots on a particular voyage, and total cargo carried in tonnes. The EEOI is calculated as the ratio of CO_2 emissions per unit of transportation work. It does not work for ships steaming at sea without the cargo or anchorage with the cargo [10]. In 2013, the European Commission (EC) came up with a three-step plan to cut down on the amount of GHG emissions from commercial ships: The first phase is to monitor, report, and verify (MRV) CO_2 emissions from large vessels operating in EU ports [11]; the second step is to establish GHG reduction objectives for the maritime transport sector, and the third step is to incorporate market-based policies as supplementary measures over the medium to long term. This regulation, passed on April 29, 2015, applies to ships with a gross tonnage of more than 5,000 that call at EU ports starting on January 1, 2018. The goal is to collect and share data on CO_2 emissions. The EC says the MRV system will lead to a 2% drop in CO_2 emissions [12].

The IMO has accepted several new guidelines to reduce the carbon intensity of all commercial ships. The necessary methods were already recommended by the Marine Environment Protection Committee (MEPC) of IMO during its 76th session from 10 to 17 June 2021. The upcoming two new methods are the Energy Efficiency Existing Ship Index (EEXI) and the Carbon Intensity Indicator (CII) [13]. The technical requirement to cut down on carbon intensity is based on a new Energy Efficiency Existing Ship Index (EEXI) [14], and the operational requirement on carbon intensity is introduced as a new operational CII and CII ratings [15]. These updates of MARPOL Annex VI Chapter 4 were accepted at MEPC's 76th Meeting in June 2021 and will take effect in coming January 2023 [16]. Smith et al. (2015) anticipated that if no regulatory measures were developed, CO_2 emissions would grow by 200% - 300% by 2050 [17], notwithstanding practical market-driven efficiency improvements. Even with such regulations in place, the continuous growth of the shipping business will continue to increase emissions [10].

Most shipping companies have started implementing the MARPOL energy efficiency regulations mainly due to complying with IMO regulations to run their shipping business internationally. Lots of research have been carried out on Energy Efficiency (EE) in the last two decades to develop innovative technologies for design and operational measures as well as alternative fuels to reduce GHG emissions by improving EE in the shipping industry. Many shipping companies are getting benefits from it. However, some shipping companies are following it reluctantly as they are not getting any remarkable financial and environmental benefits from it, as claimed by retrofit-technology vendors [18].

Many barriers exist that hinder the SEEMP measures from being implemented in the shipping sector. Several studies have been conducted in the last few years to determine "barriers and gaps" in adopting EE measures in the shipping industry of developed countries. The four significant barriers to the implementation of all cost-free EE operational measures are a lack of knowledge about EE measures, a lack of competence and capacity among ship crews (deck and engine), a lack of knowledge and understanding among ship crews (deck and engine), and operational difficulties [19].

1.1. Background Study

The maritime industry operates on a global scale and is very competitive. Yet there is less cooperation among the stakeholders in the shipping business [20]. When it comes to environmental protection, governments and the maritime sector no longer share the same objectives. Despite the expansion of governmental programs to support environmentally sustainable shipping, the environmental regulations of maritime transport have become more dispersed. Due to a lack of necessary coordination and harmonization on a global scale, there is some uncertainty when setting regulatory compliance laws and regulations [21,22]. Various stakeholders still have a wide range of options and solutions to apply EE requirements in their maritime operations through modern technologies and operational EE measures. Despite the considerable progress achieved in developing new solutions for modernizing the ship's automation and control systems, there is still a dependency on ship crews to manage the vessel, maintain operating procedures, and take responsibility for validating the work to be done on board ships [19]. It has already been noticed that the concept of energy management and implementation of various EE measures are not so well understood and clear by the multiple stakeholders in the maritime industry including ship crews [19]. It has also been noted that onboard seafarers sometimes face trouble executing energy-efficient voyages due to imprecise guidance from ashore technical managers or other land-based organizations [23]. According to Banks et al. [24], many seafarers think that they have less knowledge than awareness regarding the impact of CO_2 emissions on our environment. They have studied 312 numbers of seafarers worldwide and found that only 6% of individuals consider themselves knowledgeable. They have also noticed a lack of sufficient knowledge, training, and motivation among seafarers in the maritime industry. Among them, 74% of respondents are interested in learning more about how seafarers can contribute to reducing CO_2 emissions from ships. But there is not enough study on which training programs or activities are more effective for seafarers to implement EE operational measures on board ships. Finding the answer to the above question has motivated us to undertake this study.

2. Energy Efficiency in Maritime Industry

2.1. Energy Efficient Operation of Ships

The IMO's enforcement of EEDI and SEEMP helps raise awareness of energy-efficient ship designs and operations. Still, it could not get enough attention from the maritime industry stakeholders [25]. SEEMP offers a potential strategy for enhancing fleet efficiency and alternatives to ship performance optimization [26]. The main goal of the SEEMP is to set up a way for the company and the ship to make it more energy efficient in day-to-day operations. It is a management document intended to improve EE on board ships by improving the ship's operational functions such as optimized voyage planning, weather routing by taking sea and current conditions into account, optimized main and auxiliary engines performance by doing proper maintenance, and so on. On the other hand, the mandatory new EE measures indicate the technical and operational need to reduce carbon intensity based on the new EEXI and the operational CII. The dual methods integrate technical equipment status regarding retrofits and operational level on carbon intensity. Carbon intensity connects the quantity of CO_2 emissions to the amount of cargo transported and the distance covered [27].

2.1.1. Energy Efficiency Operational Measures and their onboard Implementation

The SEEMP has been implemented onboard ships to enhance EE during their operations. The SEEMP provides a comprehensive plan to improve the vessel and the fleet's EE over a predetermined period and options for boosting ship performance while cutting energy usage. The SEEMP provides guidelines and recommendations for adopting the best EE practices onboard ships during their operations, including improved voyage execution, weather routing, speed reduction, reduced energy consumption, improved ship operation and management, optimized fleet management, optimized cargo operations, etc. [28]. All vessels must have SEEMP before issuing the initial International Energy Efficiency (IEE) Certificate as per MARPOL Annex VI Chapter 4.

For shipboard EE to work effectively, the Master must be fully committed to it. The Chief Officer, the second-in-command, has essential responsibilities regarding cargo and loading/discharging operations, ballast management; trim optimization; and other aspects of ship management. Under his direct supervision, all deck officers and ratings work in the deck department. In the engine department, the responsibility of the Chief Engineer is to ensure the propulsion and auxiliary engines and other equipment are properly maintained, used, and operating at optimum efficiency. The Second Engineer is another essential person in the engine department who is next to the Chief Engineer and is responsible for the day-to-day operation and maintenance of the entire shipboard machinery plant. Under his supervision, all engineers and engine ratings work in the engine room. Many vessels have been fitted with intelligent software/tools that transmit real-time ship and machinery operational data and weather parameters through satellite technology to the onshore ship management offices. These modern technologies allow onshore technical managers to check and analyze the vessel's operating data from their office, give necessary feedback to the onboard master and ship crews, and advise them on the improvement of the energy-efficient operation of the vessel [10,24,29].

Table 1: Various Energy Efficiency Operational Measures and Responsible Ashore and Aboard Personnel.

Sl. No.	SEEMP Measures	Brief Description
01	Speed Optimization	Optimal speed implies the speed at which fuel utilized per tonne mile is at a minimum for that voyage by keeping a steady main engine load [26].
02	Voyage execution	Ensuring the vessel arrives on schedule reduces the time spent in port and waiting at the anchorage or berth [30]. Considering logistics, berthing schedules, and contractual restrictions, improving ship operations can result in CO_2 emissions reductions of up to 10% [31].
03	Weather routing	To maximize the efficiency of the voyage, use weather routing to avoid rough seas and the flow of the sea current [30], [32]. Usually, the ship's master is responsible for weather-related routing concerns [15].
04	Just-in-time Arrival/ Reduced Buffer time for ETA to next Port	Just-in-time allows ships to operate at an optimal speed throughout the route to reach the pilot boarding point when an assured berth, fairway, and navigational facilities are available. It minimizes buffer time to the next port and saves up to 14% fuel and CO_2 emission [33].
05	Trim and Ballast Optimization	Trim optimization determines the appropriate trim that protects from the loading condition and provides better service speed [34].
06	Hull Efficiency Monitoring	Monitoring of the vessel's hull performance to avoid excess fuel consumption is evaluated monthly by using Hull Performance Monthly Evaluation (HPME). Regular cleaning & painting of hulls are required for energy saving [30].
07	Propeller Efficiency Monitoring	Monitoring of vessel's propeller efficiency to avoid excess fuel consumption due to fouling and increase propeller efficiency by cleaning and polishing [30].
08	Main Engine Performance Monitoring	The main engine operates optimally by maintaining the well-tuned engine parameters, especially all units' combustion pressure, close to shopping trial data [35] by following the VPOA tool for fuel saving.
09	Auxiliary Engine Performance Monitoring	Running Aux. Engines with optimum load and avoids excess auxiliary engines in service by well power management and cutting non-essential consumers to save energy [35].
10	Waste Heat Recovery	Use of exhaust gas boiler or economizer to produce the required amount of steam for ship's daily usages during sea passage [10] by dry washing of exhaust gas economizer regularly and wet washing at ports.
11	Ship's Power Optimization/ Basic Load Monitoring	Savings are earned by growing awareness among the crew, using energy-saving lights, and switching off non-essential consumers, fans, and pumps at port for energy saving [10].
12	Retrofit/ Variable Frequency Drive for Pumps and Fans	A retrofit installation like harbour HT pump for Main Engine, using Variable Frequency Drive for Pumps and Fans for energy saving [10].
13	Port Operation Optimization	From a shipping business standpoint, the waiting period in port represents an unproductive time for the ship. In addition to cargo operation, a port call includes administrative processes, cargo loading/ discharging, preparation, cold ironing, and pilotage [36], [37].
14	Slow Steaming	Reduce the main engine's fuel consumption at slow steaming [10], [38]. At slow steaming, cutting off additional turbochargers and reducing the number of fuel valves for injection and saving fuel energy.
15	Awareness and Training	Raising organization-wide awareness for energy saving [10]. All levels and departments need training to raise awareness and gain the necessary knowledge for the energy-efficient operation of ships [26].

2.1.2. Education and Training for Seafarers for Energy Efficient Operation of Ships

The ship crews operate the vessel and navigate it from port to port for transporting cargo. As stated in Section 4.1.6 of the MEPC.213(63) Resolution, increasing awareness, and providing essential training for staff onshore and aboard are crucial parts of the SEEMP for its successful and steady execution [26]. While the SEEMP guideline has already stated the requirement of *"raising awareness and providing necessary training for personnel onshore on board"* for effective and steady adoption of the EE operational measures onboard, it is not clear what "necessary training" means. Few research has studied vessel energy management education and training in recent years. Still, it is mainly highlighted the utilization of simulators or computer-based training (CBT) to enhance seafarers' knowledge and increase awareness of energy-efficient ship operation [12]. One of the indicators stated and evaluated as representing best practice was increased awareness throughout the company. To acquire a higher level of understanding, training in EE measures and energy management needs to be carried out by managers ashore and ship crews onboard ships [39]. Because the technical managers onshore and crewmembers' onboard ships are ultimately responsible for implementing MARPOL Annex VI on board ships. The ashore technical managers must guide and monitor onboard ship personnel [26]. It is vital to train and educate them well regarding regulations such as EEDI, SEEMP, EEXI, and CII and various EE design, operational measures, and innovative retrofits to enhance EE on board ships. Hence, it is crucial to find maritime education and training (MET) institute that can educate seafarers about the requirements of MARPOL Annex VI and their implementation on board ships [40]. Beside institutional training programs, seafarers also go through some onboard training programs, such as computer/simulator-based training programs, onboard training by an ashore technical manager/Master and Chief Engineer, in-house training on how to implement SEEMP measures by the shipping company before joining, and special training by company project teams or retrofits/tools vendors on board ships, etc.

2.1.3. Training Programs on Energy Efficient Operation of Ships for Seafarers

In most cases, seafarers receive training on EE operational measures for their effective implementation through following institutional and onboard training programs and activities: (i) It is standard practice for the master or chief engineer to train ship crews on EE operational measures and implementation procedures in accordance with the SEEMP guidelines provided by the company. (ii) During the pre-joining briefing, the shipping company provides masters and chief engineers some in-house training on SEEMP measures and how they can be implemented effectively on ships by technical managers ashore. (iii) Sometimes EE project teams or providers of retrofit technologies offer specialized training to ship crews on implementation of a particular EE method on board ships on occasion. (iv) The computer-based training programs use immersive or non-immersive simulators to employ game-based e-learning tools where seafarers make choices in realistic situations. 78% appreciated the session, and 81% learned more about ship EE measures [41]. (v) Together with World Maritime University (WMU), IMO has prepared the "Energy Efficient Operation of Ships (EEOS) - IMO Model Course No. 4.05" on the implementation of SEEMP measures to promote energy-efficient ship operation. It covers GHG emissions, climate change, and IMO regulations and activities. It integrates operational and technical components into a realistic training program to encourage energy-efficient shipping operations. The training sets performance standards for the shipping industry. (vi) The "Train the Trainer (TTT) Course on Energy Efficient Ship Operation" of IMO [35] helps training providers and their teaching staff arrange and deliver new training courses to improve, update, or augment current training content for EE training courses. Both methods aim to promote seafarers' awareness, knowledge, and best practices for following MARPOL Annex VI, Chapter 4 regulations for energy-efficient ship operation and reduction of GHG emissions from the shipping industry [35]. Similar course "Ship Energy Management Team (SEMT) has been developed under MeriEMS project funded by European Union (EU). (vii) Like other IMO conventions, MARPOL is part of the pre-sea and post-sea courses to teach marine pollution rules and regulations to maritime students and seafarers. The MARPOL Annex VI Chapter 4 is part of both pre-sea and post-sea training curricula. It covers EE measures and how they can be used in the shipping industry.

3. Method and Scope

A decade ago, the IMO launched energy efficiency regulations in MARPOL Annex VI and made them mandatory from 1st January 2013 to improve the EE to reduce CO_2 emissions from the maritime industry [30]. The effectiveness of such an organizational and legislative initiative to improve EE in the maritime sector, and specifically the execution of operational initiatives, lies in the ability of the ship crews to adopt new habits, skills, and knowledge [29,42]. Raising awareness and growing understanding among seafarers is vital for adopting SEEMP measures onboard ships and their effective implementation to reach the goals targeted by the shipping company. Necessary education and training for capacity-building ashore managers and onboard seafarers is facilitated and should be treated as a vital part of planning and an essential part of the execution of the SEEMP on board ships [26]. According to Dewan et al. [19], implementing cost-free operational measures is difficult due to lack of information, lack of seafarer awareness and capacity, and operational concerns. This study focuses on feedback from shipboard and ashore seafarers to determine their knowledge and understanding. This study includes onboard masters, deck officers, chief engineers, and engineer officers from all over the world, as well as ashore ship managers, technical and marine superintendents, and environment managers.

3.1. Pilot Survey and Questionnaire Design

A pilot survey was conducted by interviewing 22 experienced onshore ship managers and onboard ship crews, mostly Masters and Chief Engineers, to obtain an overview of the education and training of ashore technical managers and onboard seafarers from Bangladesh, India, Croatia, Cyprus, Hong Kong, Liberia, Malaysia, and Singapore. They play a vital role in enforcing SEEMP procedures on ships. For more than a decade, they have been working with the marine sector to manage and operate ships. They have been asked the following three questions to design questionnaires and develop the required hypothesis to conduct an online qualitative survey through the Zoom online meetings or phone calls from 01 to 10 June 2022:

i. Section 4.1.6 of the MEPC.213(63) Resolution states, *"For the effective and steady implementation of the adopted measures, raising awareness of and providing necessary training for personnel both onshore and onboard are an important element."* As an ashore technical manager or a crewmember at sea, do you agree with this statement?
ii. What kind of training is required to improve the awareness of personnel both ashore and aboard ships to implement EE operational measures onboard ships effectively?
iii. Which training have you received from your shipping company to implement EE operational measures on board ships effectively?

The required hypothesis has been created based on the findings of the pilot survey, and the questionnaire has been created in an online Google form to conduct both qualitative and quantitative surveys. The surveys' aims and objectives are briefly explained in the introduction part with a few convincing and encouraging words.

3.2. Qualitative Survey Questionnaires and Method of Distribution

A comprehensive questionnaire was designed for the qualitative survey to ensure the gathering of accurate and necessary data for analysis. The questionnaire was prepared with both single-answer and multiple-choice questions (MCQ) with checkboxes to select both single and multiple answers, which seemed appropriate. The results were analyzed using Excel Formulas and Charts as a fraction of the total number of respondents. In the case of graphs presenting the percentages (%) of participants, the total number of responses is mentioned with "N=Number of Participants" within each graph caption). In the "Others" option, the additional comments of the respondents were interpreted as linguistic information in a separate section (section 5.4.). Where one variable wasn't filled out in the dependent rating questions, the complete survey response was considered defective and taken out of the analysis.

For the effective and steady implementation of the SEEMP measures onboard the ship as well as in the entire fleet of a shipping company, providing necessary education and training of their seafarers both onshore and onboard are very crucial [24,26,29]. However, we have targeted to get responses from ashore ship managers, technical/marine superintendents, environmental managers, and onboard seafarers who are directly involved in implementing the SEEMP measures on board ships of the shipping company. We have selected seafarers who are well-experienced and working for the ship's operation and management, such as the Master, Chief Officer, Chief Engineer, and Second Engineer. We have also considered the Third Engineer and Second Officer as they are directly responsible for ship power generation and voyage planning, respectively. Getting seafarers in mailing home addresses is quite tricky. Therefore, we have posted the link of the Google Form survey globally on 20th June 2022 to individual email addresses of seafarers and ship managers, group email addresses of various maritime communities, and mobile apps such as Facebook Messenger, Viber, and WhatsApp group chat platforms of the onshore and onboard seafarers to get quick responses. We have also made some phone calls to notify them.

4. Profile of the Survey Respondents

A total of 112 responses have been received by June 29, 2022, from seafarers from Bangladesh, Canada, Croatia, Cyprus, Hong Kong, India, Liberia, Malaysia, Portugal, Russia, Saudi Arabia, Singapore, and United Kingdom. They have been actively working onboard ships and onshore shipping companies for over a decade. To know their profile and nature of responsibilities, the first question was asked about their ranks or positions onboard ships or ashore offices of shipping companies. The second question was about the type of vessels they have been sailing onboard or managing from ashore. We received survey responses from 47 Chief Engineers, 27 Masters, 18 Onshore Ship Managers/Technical Superintendents/Environmental Managers, 06 Second Engineers, 05 Third Engineers, 04 Chief Officers, 04 Second Officers, and 01 Environment Officer, presented in Figure 1(a). They work ashore offices and on-board ships in international shipping companies. Figure 1. (b) demonstrates that among them, 58% work in Engine Department and 33% work in Deck Department onboard ships, and 9% work onshore offices in shipping companies.

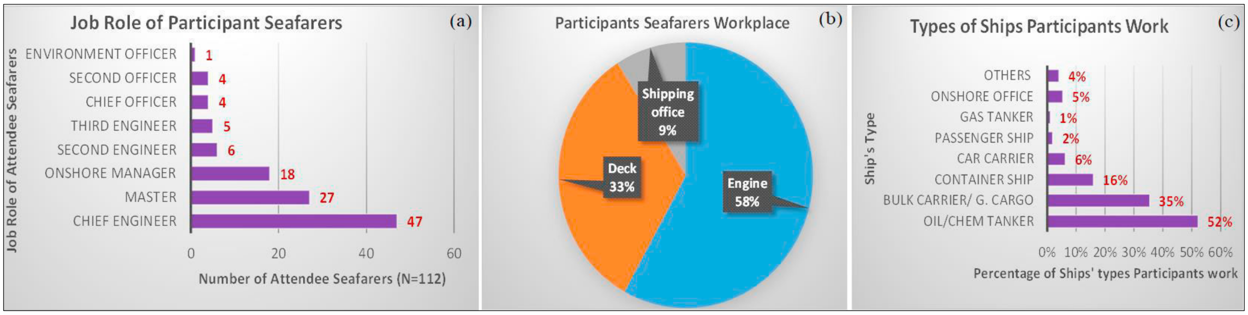

Fig. 1. (a) Job Role of Participants (N=112); (b) Participants Seafarers' Workplace; (c) Types of Ships Participants Work.

Figure 1. (c) indicates that among participants seafarers, 52% worked onboard oil & chemical tanker vessels, 35% onboard bulk carriers or general cargo ships, 16% onboard container ships, 6% onboard car carriers & Ro-Ro vessels, 2% onboard passenger ships, 1% in the gas tanker, 5% works in shore offices and 4% works in other types of vessels. Few seafarers worked multiple types of ships in the past too. Therefore, they have selected numerous types of vessels in their online Google form responses.

5. Survey Results and Discussion

5.1. Importance of Training on Energy Efficient Operation of Ships

Regulations on EEDI and SEEMP were enforced on shipping companies almost a decade ago, in January 2013. It has been a while since the SEEMP measures have been implemented on board ships, and both onshore and onboard seafarers should be aware of it now. All participant seafarers were asked a general question, Section 4.1.6 of the MEPC.213(63) Resolution states, "For the effective and steady implementation of the adopted measures, raising awareness of and providing necessary training for personnel both onshore and onboard are an important element." Do you agree with this statement as an onshore manager or onboard seafarer?" [43]. Here, 100% of the onshore and onboard seafarers have answered affirmatively by selecting "Yes" from the multiple answers. So, all seafarers who work onshore offices and onboard ships agree that for effective implementation of the SEEMP measures onboard ships, education and training of the seafarers are crucial, and there is no alternative.

5.2. Effective Energy Efficient Operation of Ships (EEOS) Training Programs for Seafarers

Based on the literature reviews and the findings from the pilot survey, the survey questionnaires were developed with a list of training programs which seafarers receive from their shipping companies to effectively implement EE operational measures on board ships. Table 2 indicates that 39% of seafarers have actively participated in "Onboard Training by Ship Managers/Master sand Chief Engineers", 36% have taken part in "Computer/Simulator Based Training (CBT) on the EEOS course onboard ships," and so on.

Table 2: Effectiveness of Energy-Efficient Operation of Ships (EEOS) Training Programs/Activities

Sl. No.	**Energy-Efficient Operation of Ships** (EEOS) **Training Programs**	Attended by Seafarers (%)
1	Onboard Training by Technical managers / Master & Chief Engr	39%
2	Computer / Simulator Based Training on EEOS Course	36%
3	Training on EEOS by Ship Manager Prior to Joining	23%
4	Energy Efficient Operation of Ships (EEOS) Course by MET Institute	13%
5	IMO Train the Trainer Course/Workshop	13%
6	EEOS E-Learning Course by GMN-IMO/DNV	10%
7	Special training by Company Project Team/ Retrofit's Vendor	9%
8	Pre-sea training with Ship Energy Management Syllabus	5%
9	EEOS - 4.05 Training by immersive/ non-immersive simulators	3%

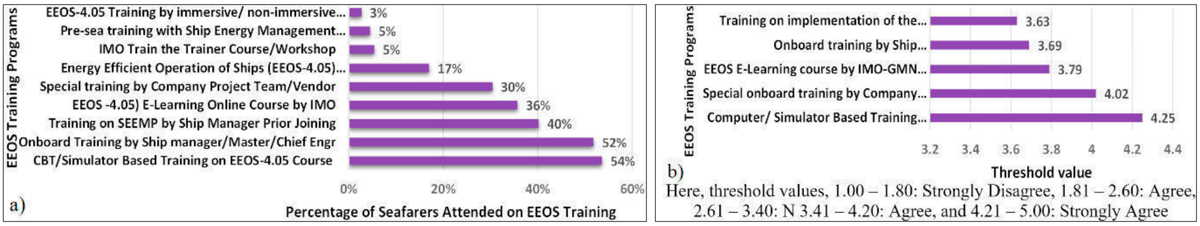

Fig. 2. (a) Recommended as Effective EEOS Training Programs by Participants; (b) Effectiveness of EEOS Training Programs (N=112)

Another question was asked to the participating seafarers: which training programs from the list, do you recommend as effective EEOS training courses? According to responses from the participants, as shown in Figure 2. (a), *Computer/ Simulator Based Training on EEOS course onboard ships; Onboard training by Ship Manager/Master &Chief Engineer; Training on implementation of the SEEMP measures by Ship Manager prior joining; EEOS E-Learning Course by IMO-GMN Project* and *Special training by the Company Project Teams/ Retrofit's Vendors onboard ships"* are the most recommended effective training programs for implementation of the SEEMP measures onboard ships by the participants. Figure 2(b) indicates that 52% of seafarers strongly agreed that the *Computer/Simulator Based Training on EEOS course* is the most effective training program for energy efficient operation of ships. In addition, they also agreed that *Special training by Company Project Team/ Retrofit's Vendor; Onboard training by Ship Manager/Master & Chief Engineer; and Training on EEOS by Ship Manager Prior to Joining* are effective training programs. It has been noticed from this study that institutional or e-learning EEOS training programs are not so effective and popular to seafarers.

5.3. Shipping Companies Training Programs for Onshore managers and Onboard Seafarers

The participants' seafarers were asked whether they are experiencing any challenge due to lack or insufficient knowledge to implement SEEMP measures onboard ships. Figure 3(a) shows that 57% of them experiencing challenge due to lack or insufficient knowledge. They were also asked whether the shipping companies make sufficient efforts to effectively implement the SEEMP measures and raise awareness of seafarers on board ships. Figure 3. (b) shows that 64% of seafarers agreed that shipping companies make sufficient efforts to effectively implement the SEEMP measures and raise awareness of their personnel works in both ashore offices and onboard ships. But 36% of seafarers did not agree with this statement. Sametime, they were asked about the effectiveness of shipping companies' training programs or activities for their seafarers working office and onboard ships ashore. Figure 3. (c) shows that 50% of seafarers think training activities provided by shipping companies are ineffective, whereas 41% think it is effective. But 9% of seafarers feel they need more training to gain further knowledge and increase awareness for effectively implementing the SEEMP measures onboard ships.

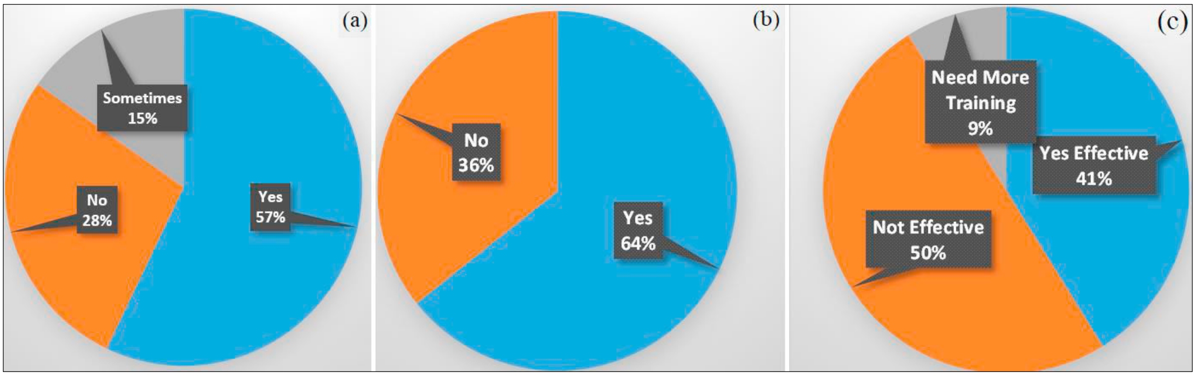

Fig. 3. (a) Experiencing Challenge by Seafarers Due to Lack/Insufficient Knowledge (N=112); (b) Percentage of Sufficient Efforts Making by Shipping Companies for Seafarers (N=112); (c) Effectiveness of Shipping Company's Training Activities for Seafarers (N=112).

5.4. Experienced Seafarers' Suggestions for Improvement of Energy Efficiency Training Activities

In the final section of the survey questionnaire, participants were provided the opportunity to make suggestions for the improvement of EEOS training activities to effectively implement the SEEMP Measures onboard ships. Nearly 85% of seafarers have suggested that by increasing awareness and willingness through proper motivations and training activities, sailors' attitudes toward pollution-free green shipping and reducing the marine sector's GHG emissions might be altered. After that, they suggested implementing more efficient training activities by the ship's Master and Chief Engineers, as well as providing high-quality training videos and CBT programs on the efficient use of energy at sea. They have also proposed prioritizing ship-to-shore collaboration. They believe that both onshore and aboard personnel must be appropriately motivated to effectively apply SEEMP procedures onboard ships. Almost 90% of onboard seafarers have expressed their true feelings in the survey forms that they have never been asked for their feedbacks regarding implementation of shipboard energy efficiency measures onboard ships. They think shipowners and managers can get better ideas and useful input by asking their feedbacks time to time to implement the SEEMP measures onboard ships effectively.

6. Conclusion

This study reveals that all seafarers are aware of and concerned about EE regulations and measures implemented by shipping companies. Both onshore and aboard seafarers understand the necessity for training to gain the technical knowledge related with EE measures for more effective implementation onboard ships. The IMO, MET institutions, training service providers, and shipping companies have established numerous training programs and activities. This research found that many training programs and activities are given to both ashore technical managers and onboard crewmembers, but all of them are not equally beneficial. Most seafarers have participated in numerous training programs on energy-efficient ship operation, but 52% of seafarers strongly agree that the *Computer/Simulator Based Training* is the most effective training program on EEOS course. In addition, they agree that Special training by *Company Project Team/ Retrofit's Vendor; Onboard training by Ship Manager/Master & Chief Engineer;* and *Training on EEOS by Ship Manager Prior to Joining* are effective training programs for seafarers to apply SEEMP measures onboard ships. Seafarers reported that shipping companies are making adequate efforts to train their personnel ashore and aboard ships, but all training programs and activities are not always effective. It has been noticed from this study that all training programs conducted onboard ships are more effective than institutional or e-learning training EEOS courses. They have suggested making ship-shore collaboration for more effective training activities and corporate motivations to grow their awareness and willingness and to change their attitudes positively toward green shipping and a pollution-free clean environment.

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A.6 Paper 6: Exploring Seafarers' Knowledge, Understanding, and Proficiency in SEEMP: A Strategic Training Framework for Enhancing Seafarers' Competence in Energy-Efficient Ship Operations.

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Research article

Exploring seafarers' knowledge, understanding, and proficiency in SEEMP: A strategic training framework for enhancing seafarers' competence in energy-efficient ship operations

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SEEMP

ABSTRACT

With 2.89 % of global carbon emissions caused by human activity, the maritime industry faces an imminent challenge in curbing its carbon footprint despite regulatory initiatives. As the shipping sector expands, the industry faces a projected increase in carbon emissions. Recognizing the key role of seafarers in emission reduction, this article introduces a comprehensive training framework designed to enhance awareness, knowledge, understanding, and skills for implementing energy-efficient ship operations. This study utilizes structural equation modeling to assess the effectiveness of seafarers' training on energy-efficient operation of ships (EEOS) by surveying 144 seafarers across 42 shipping companies worldwide and using structured questionnaires. This study found significant positive correlations between implementing the Ship Energy Efficiency Management Plan (SEEMP) and the training programs initiated by the International Maritime Organization (IMO) and shipping companies. The results of this study indicate that traditional institutional and specialized training programs on EEOS are relatively ineffective for seafarers in implementing SEEMP onboard ships. Furthermore, the study argues that computer and simulator-based training facilitates knowledge, understanding, and proficiency of SEEMP among seafarers more effectively than the onboard training provided by the ship's master and the chief engineer. The proposed training framework emphasizes the importance of initial training using the IMO E-Learning course and IMO "Train the Trainer" programs, followed by shipping companies' in-house training by classification societies, company project teams, and simulator-based training by service providers. The study proposes a strategic training framework that encompasses in-house training conducted by shipping companies in collaboration with partners, simulator-based training provided by specialized training providers, and ongoing onboard training facilitated by the vessel's master and chief engineer, with integration of computer-based training (CBT). This strategic approach intends to improve seafarers' competence in energy-efficient ship

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operations to meet predetermined carbon intensity targets, which aligns with the broader goal of leading the maritime industry toward a future of net-zero emissions.

1. Introduction

Increasing temperatures of seawater caused by human-generated carbon dioxide (CO_2) pollution affect sea levels, ocean dynamics and chemistry, deoxygenation, and marine species' variety and abundance [1]. Flooding in low-lying regions and the melting of arctic glaciers are occurring concurrently due to the global temperature increase caused by CO_2 emissions [2]. In 2018, the maritime sector contributed 2.89 % of all human-caused CO_2 emissions, according to the Fourth Greenhouse Gas (GHG) Study 2020 published by the International Maritime Organization (IMO) [3]. Forecasts from the United Nations Conference on Trade and Development (UNCTAD) indicate a projected growth of over 2 % in the maritime industry between 2024 and 2028, with a 2.4 % expansion anticipated in 2023 [4]. Despite regulatory measures, maritime CO_2 emissions are projected to grow by half or the same amount as the growth of the sector between 2012 and 2050 for business-as-usual operations (BAU) in the shipping industry [5,6]. To address this challenge, the IMO has implemented technical and operational measures, including the mandatory Energy Efficiency Design Index (EEDI) and Ship Energy Efficiency Management Plan (SEEMP) for existing ships, as well as the Energy Efficiency Operational Indicator (EEOI) that monitors ships' carbon emissions [7–9]. Complementary frameworks, including the IMO's Data Collection System (DCS) for vessels exceeding 5000 gross tonnage (GT) and the European Union's (EU) Monitoring, Reporting, and Verification (MRV) system, have been enacted to augment emission reduction efforts [10,11]. Recent advancements include the IMO's approval of the Energy Efficiency Existing Ship Index (EEXI) and the Carbon Intensity Indicator (CII), effective from January 1, 2023, signifying a concerted effort to reduce carbon intensity [12,13]. Furthermore, IMO's 2023 Revised GHG Strategy aims for a 40 % reduction in carbon intensity from international shipping by 2030, 70 %–80 % by 2040, and net-zero GHG emissions by 2050 [14].

After a decade of enforcing maritime energy efficiency regulations in the shipping industry, a wide range of technical and operational measures, as well as innovative technologies and low-carbon fuels, are now readily available to improve energy efficiency and reduce GHG emissions from ships. Researchers have successfully identified economically viable operational measures aimed at enhancing ships' energy efficiency [15–18]. Many of these measures, integral components of the SEEMP adopted by numerous shipping companies, have demonstrated their cost-effectiveness through rigorous validation. Despite their proven efficacy, implementing these initiatives faces challenges stemming from resource constraints and inherent resistance to change within the maritime industry.

Enhancing seafarers' awareness and knowledge regarding energy efficiency requires a concerted effort towards education and research [19,20]. In Ref. [17] it has been pinpointed low levels of education and a reluctance to embrace change as significant barriers hindering the improvement of ship energy efficiency. Similarly [21], have identified key obstacles such as a lack of information on these measures, deficiencies in crew training and competence, and operational complexities, all impeding the widespread adoption of cost-free operational measures. The authors in Ref. [22] emphasized the critical role of effective collaboration between the IMO and stakeholders, proposing solutions such as technical cooperation, capacity-building programs, guideline publications, data exchange, and periodic updates of MAC Curves. These initiatives were identified as addressing barriers to training and awareness and facilitating the adoption of energy efficiency measures in the shipping industry. Furthermore, researchers [23–26], and [27] have examined the barriers to the adoption of these cost-effective operational energy efficiency measures. The following studies [28,29], and [17] emphasized the significance of training ashore technical managers and ship crew members who are responsible for ship operations to conquer these barriers.

Effective implementation of energy-saving measures in the maritime industry is hinged on the active participation and adequate training of seafarers. Inadequate participation and training could potentially undermine the efficacy of the SEEMP in enhancing ship safety and reducing environmental impact [30]. Research indicates that crewmembers encounter challenges in operating ships energy-efficiently due to unclear instructions from ashore ship managers and organizations [31,32]. Moreover, in Ref. [33], it was discovered that ship officers exhibited a lack of awareness of energy efficiency measures and their benefits. The successful implementation of energy efficiency practices onboard ships depends on the awareness and knowledge of seafarers directly involved in implementing energy efficiency operational measures in ships [19,21,28]. In Ref. [19], it is argued that implementing energy efficiency measures requires motivation, inspiration, and effective training programs for seafarers. As a result, crew members onboard the ship and ship managers ashore require effective training to implement energy efficiency operational measures onboard ships. In Ref. [19], the authors also claim that there is currently no formally recognized institutional course focused on enhancing energy efficiency in the maritime sector. By recognizing these research gaps described above, this article aims to reshape an effective training framework that supports the successful implementation of energy efficiency measures onboard ships and enhances seafarers' awareness, knowledge, and skills regarding energy efficiency practices.

The paper is structured into seven sections. Section 2 provides a literature review on SEEMP, the implementation of SEEMP onboard ships by ship crews, the importance of seafarers' training on energy efficient operation of ships (EEOS), and various EEOS courses elaborating on knowledge gaps. Section 3 elaborates on the research approach and methodology adopted in this study. Section 4 presents the results of the mixed-mode survey conducted on seafarers. Section 5 discusses the findings of the study in detail. Section 6 provides a training framework for seafarers to implement SEEMP onboard ships effectively. Finally, section 7 summarizes the conclusions drawn from this study, describes the limitations of the study, and provides recommendations for future research.

2. Literature review

The SEEMP was made mandatory for all new and existing ships on January 1st, 2013, to increase a vessel's energy efficiency over four stages: planning, execution, monitoring, self-evaluation, and improvement [8]. Part I of SEEMP discusses methods for improving energy efficiency performance and carbon intensity over time and monitoring efficiency performance [8], while Part II provides a plan for collecting data on used fuel, including measures and reports [34], and Part III focuses on measuring the cost of operating the ship in terms of carbon intensity [13].

2.1. Cost-effective energy efficiency operational measures in SEEMP

A Ship has to adopt the SEEMP while in operation to increase its energy efficiency and reduce GHG emissions. The SEEMP provides a thorough approach for raising the ship's and the fleet's energy efficiency over time, as well as prospective techniques for increasing performance while reducing energy usage and saving fuels [8]. In addition to maritime energy management, the SEEMP guides best practices for each ship, such as improved voyage planning, weather routing, speed optimization, decreased power consumption, optimal ship handling, increased fleet management, and optimized cargo operations [8,15,34,35]. The reduction of the environmental impact of shipping has been identified as a cost-effective solution by implementing energy efficiency operational measures. The DNV GL Energy Management Study 2014 indicates that 91 % of companies clean and coat their hulls, while 88 % do propeller cleaning and polishing, 86 % optimize their auxiliary and main engines, and 83 % retrofit their energy efficiency devices in pumps and blowers in the engine room [16]. The study also found that many companies play a proactive role in familiarizing their crews with energy management practices through awareness and incentive activities and providing them with dedicated functions for energy management.

Maritime stakeholders identify several operational measures, including trim optimization, slow steaming, hull and propeller maintenance, weather routing, and auxiliary engine conservation, that are cost-effective to enhance a ship's energy efficiency and reduce GHG emissions. The study of [36] reveals that investing in operational and technical energy efficiency measures is more cost-effective than alternative energy fuels. In 2011, the marginal abetment cost (MAC) for each reduction measure in 2030 was among the most economically advantageous measures for shipping companies in a study published by Ref. [37]. The study identified some cost-effective energy efficiency operational measures, such as the "Low Hanging Fruits" included in the SEEMP by most shipping companies. It includes executing optimized voyages, routing through weather conditions, arriving just-in-time, optimizing trim and ballast, monitoring hull efficiency and propeller efficiency, monitoring auxiliary and main engines performance, reducing steaming/speed, recovering waste heat, optimizing power consumption on ships, retrofitting pumps and fans with variable frequency drives (VFDs), and training ship crews [15,37]. Maintaining a constant engine load during a voyage achieves the lowest fuel costs per tonne mile, reducing fuel consumption by minimizing the main engine's power output [38]. AIS data enables navigation officers to optimize vessel speed, resulting in up to 4 % time savings and earlier arrivals [31]. Effective voyage planning, constant speed mode, and optimized weather routing can yield time savings of 4 % and earlier arrivals of the vessel [39]. Factors like wind and wave conditions, vessel characteristics, and cargo features influence weather routing, which can contribute to fuel savings [40]. Providing adequate facilities at pilot boarding locations reduces idle waiting time and fuel consumption by 14 % [41]. Sea Traffic Management (STM) can reduce fuel consumption by 15–23 % [42]. Optimal trim, draft, and regular propeller polishing and hull cleaning contribute to fuel efficiency significantly [43–45].

Monitoring specific fuel consumption (SFOC), propulsion engine load, and effective propeller maintenance contribute to fuel savings [46,47]. Ship's engineers are responsible for maintaining the main engine's operation and performance. Steam production from exhaust gas boilers during sea passages provides another fuel-saving opportunity [35]. Regular cleaning of exhaust gas economizers enhances their performance and improves the energy efficiency of the vessel [47]. Effective scheduling, sequencing, and optimizing port calls reduce waiting times, idle time, fuel consumption, and emissions [48,49]. Slow steaming the main engine minimizes resistance, significantly reducing fuel consumption [50]. The successful SEEMP implementation relies on seafarers' awareness, knowledge, and active involvement in energy efficiency measures, emphasizing their crucial role [19,21,28]. Promoting knowledge, communication, and situational awareness among ship crew members is pivotal for enhancing energy efficiency and performance [51]. The study by Ref. [52] reveals that onboard masters, chief engineers, and shore technical managers are directly involved in the implementation of these cost-efficient energy efficiency operational measures. Seafarers' experience is central to SEEMP's success, influencing behavior, decision-making, and overall engagement in sustainable shipping practices [53,54].

2.2. Adoption of energy efficiency operational measures onboard ships

The ship crews play a vital role in improving energy efficiency in the shipping industry. During cargo transportation, crew members of the ship operate the vessel and navigate it safely from port to port. The ship's energy efficiency can be enhanced during operation by implementing various technical and operational measures. The owner or ship charterer can provide low-carbon fuels to increase energy efficiency and reduce emissions from ships [55]. Cutting-edge technologies and retrofits, including photovoltaic power generation, waste heat recovery, and air lubrication, are introduced and classified into energy-efficient categories by IMO to enhance vessel energy efficiency and reduce carbon emissions [56]. Investing in cutting-edge technology, like Flettner rotors, propeller boss cap fins, and hull air lubrication, requires substantial investment from ship owners. Operational measures such as speed reductions, ballast and trim optimizations, engine load optimizations, weather routine optimization, and just-in-time arrival can be implemented efficiently and cost-effectively [18,34].

Ship crewmembers' responsibilities and authority are outlined in the Safety Management System (SMS) of the International Safety Management (ISM) code for safe and efficient ship operations [57]. Generally, ship crews are arranged in a hierarchical structure, with the master at the top, followed by the chief officer, chief engineer, other officers, and ratings. The deck department is responsible for cargo operations, deck maintenance, and navigation, while the engine department operates and maintains the propulsion engines and auxiliary machinery. The chief engineer oversees the engine department, while the chief officer oversees the deck department. Many of the existing technical and operational measures are already included in the SEEMP by shipping companies to improve the energy efficiency on board ships, including voyage execution, ship speed optimization, cargo operation optimization, capacity utilization, and trim optimization [58]. These measures have direct impacts on ship masters, deck officers, chief engineers, and engine officers on a daily basis [59]. Recent studies have emphasized the role played by the ship crew in improving energy efficiency and mitigating GHG emissions [19,28,53,59–63].

Six key stakeholders and their respective roles directly impact ship operations and GHG emissions in commercial shipping: cargo owners, charterers, ship owners, ship operators, and technical and commercial managers [64]. As the owner of a commercial shipping company, the shipowner holds the decision-making authority over the entire shipping operation. Cargo owners and charterers are crucial in managing cargo and utilizing ships through various chartering contracts with the shipowner. Technical, operation, and commercial managers, responsible for vessel technical and commercial management, ensure ships' safe and seaworthy operation for cargo transportation and financial outcomes. Onboard ships, the master and ship crews operate the vessel. All these stakeholders, both directly and indirectly, contribute to the energy-efficient operation of ships.

The IMO circular MEPC.1/Circ.896 [56] encourages innovation in the maritime sector by promoting technological advancements that reduce GHG emissions. Energy-efficient technologies and retrofits that shift the vessel's power curve (low friction coatings, bare optimization), reduce main engine power (hull air-lubrication systems, Flettner-Rotors, sails, kites), and reduce auxiliary power (photovoltaic cells, waste heat recovery, etc.) help ship owners and ship operators meet IMO energy efficiency standards and improve environmental performance [56]. Regulatory compliance is made easier by clarifying how these technologies are treated in EEDI and EEXI calculations. This helps the maritime industry achieve its emission reduction goals of lowering fuel usage. Although seafarers are not directly involved in adopting such technological measures onboard ships, they are actively involved in the operation and maintenance of these measures and retrofits. Familiarity with these technologies is crucial for crew members to enhance operational efficiency and improve performance.

From navigation to port operations and ship propulsion to power generation and management, the ashore managers have reasonable control of the fleet's energy efficiency operations because they supervise the master and the chief engineer of the ship. In Ref. [59], it is revealed that masters and deck crew are directly engaged in implementing speed optimization, voyage planning and execution, weather routing, just-in-time arrival, and hull efficiency optimization, whereas chief engineers and engine crew are directly involved in monitoring the main and auxiliary engines, optimization of ship's power, monitoring propeller performance, waste heat recovery and slow steaming operational measures aboard ships. However, in this study, we are focusing more on crew members onboard ships and various ship managers ashore offices as they are directly involved with vessel operation. As shown in Fig. 1, the energy efficiency operational measures onboard ships can be mapped by summarizing the discussion in sections 2.1 and 2.2, focusing on engagement between ship owners, ship managers, and crew members.

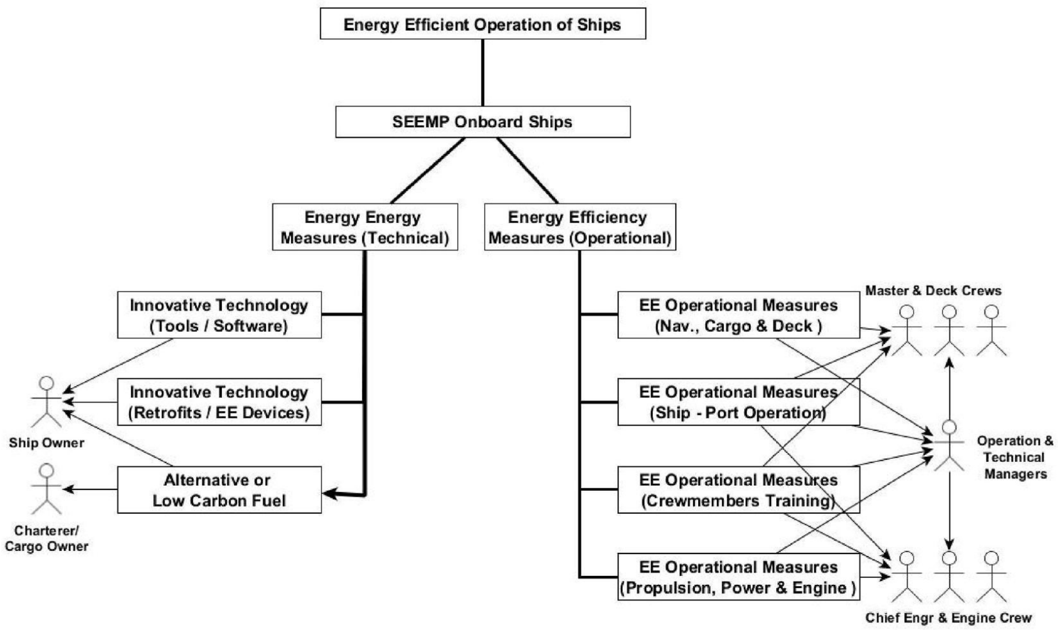

Fig. 1. Engagement map of shipowners, ship managers, and crewmembers on energy efficiency operations (Source: [65]).

2.3. Factors influencing implementing SEEMP onboard ships

The maritime sector heavily relies on seafarers for operational duties, but their well-being and behavior are profoundly influenced by shipboard culture and hierarchy [66,67]. Organizational support, including effective training and fair treatment, is crucial to address stress-related challenges [68]. Besides, the industry's reactive human resource practices hinder sustainable training and development efforts [69]. Furthermore, a more complicated issue arises regarding maritime operations, where multiple stakeholders impact the decision-making process. The SEEMP principles provide a framework for EE standards, stressing stakeholder collaboration to achieve energy-saving goals [70]. However, implementing EE measures is frequently impeded by complicated decision-making processes in which commercial interests, cargo owner preferences, and charterers' instructions all play vital roles [43,49,64]. The researcher [71,72] found that carbon pricing as an operational surcharge increases transparency in charter contracts, encouraging vessel operators to adopt low-carbon solutions such as renewable fuels and encouraging ship owners to provide more efficient vessels, especially for the time charter contracts. In fact, charterers are not particularly concerned about environmental issues and are primarily concerned with low consumption costs [32]. However, commercial decisions, particularly those involving ship and cargo fixing, route selection, and vessel speed choices, significantly impact energy efficiency implementation SEEMP in the shipping industry [49,64]. In shipping companies, vessel operation managers and crews view speed reduction as the primary means for enhancing energy efficiency, with cargo owners often influencing speed decisions, whose priorities may not align with fuel savings [24]. Charter parties, cargo owners, and vessel operation departments make these decisions based on market conditions and transit time preferences, which may sometimes prioritize speed over fuel savings [43,73,74]. As a result, external directions may limit ship crews' agency in adopting operational EE measures due to the principal-agent problem, impeding their motivation and involvement in EE practices onboard ships [32,49,75]. However, in several recent studies, researchers have pinpointed numerous factors shaping the adoption of energy efficiency operational measures onboard ships:

Principal-Agent Problem: The principal-agent problem can hinder energy efficiency in shipping when the interests of the principal (shipping company) and agent (seafarer) do not align [24]. Principal-agent problems can also arise if charter parties' interests are not aligned with ship owners, according to Dirzka and Acciaro [71].

Decision-Making Framework: Developing decision-making frameworks aids in evaluating trade-off solutions, increasing energy efficiency and seafarers' participation in energy-efficient ship operations [76].

Human and Social Factors: Human and social factors can influence seafarers' involvement in energy-efficient ship operations. Several factors to consider include organizational culture, leadership, training, communication, and motivation [28,77].

Knowledge and Awareness: Seafarers' engagement is profoundly influenced by their awareness, knowledge, and understanding of low-carbon, energy-efficient operations [19,78].

Education and Training: The efficient operation of ships requires education and training. Decision support systems and onboard learning systems are essential for seafarers to acquire the skills to perform them efficiently [79]. It has been shown that ship officers' communities of practice adopting energy-monitoring technology and energy-efficient operational training through ship bridge simulators influence seafarers' engagement in energy-efficient ship operations [80,81]. Seafarers can gain knowledge and training about energy-efficient ship operation via onboard learning systems [82].

Communication and Situational Awareness: Seafarers' ability to engage in energy-efficient ship operations is heavily influenced by their communication skills and situational awareness. Communication and coordination among seafarers are essential for reducing energy consumption and operating ships efficiently [30].

Attitudes and Perceptions: Seafarers' positive attitudes toward energy efficiency increase the likelihood of their engagement [83].

Participation in SEEMP Process: The development and implementation of SEEMP are critical for seafarers' participation in energy-efficient ship operations [30,84].

Organizational Support**:** Leadership and organizational support significantly impact seafarers' engagement [85]. Shipping companies must provide the necessary resources and support to encourage energy-efficient practices.

Reward and Recognition: A reward and recognition program for seafarers who achieve energy efficiency targets may be one of the best incentives to encourage energy-efficient ship operations [19,86].

Private Voluntary Initiatives: Private voluntary initiatives for decarbonizing short-sea shipping are key factors influencing seafarers' involvement [87].

Policy and Regulation: Policies and regulations to reduce carbon emissions can encourage seafarers to operate energy-efficient ships [88].

Energy Audits: Audits provide valuable insights into energy efficiency, identifying areas for improvement [32].

Decision Support **Systems:** Assist seafarers in making informed decisions about energy-efficient ship operations [89].

Innovations and Technological Factors: The availability and effectiveness of energy-saving technologies influence seafarers' engagement [90]. Innovations, such as dual-fuel vessels, can provide seafarers with new opportunities and increase their engagement in energy-efficient ship operations [91].

Barriers to Energy Efficiency: Barriers such as financial constraints, a lack of incentives, and inadequate infrastructure can negatively affect seafarers' participation in energy-efficient ship operations [92,93]. Lack of awareness, lack of training, and resistance to change are some of the barriers to energy efficiency in shipping [19]. Barriers to energy-efficient ship operations can hinder seafarers' involvement. Short-sea shipping is susceptible to barriers that prevent seafarers from engaging in energy-efficient ship operations [70,93,94].

A recent study [65] reported a list of 13 factors that influence the engagement of seafarers for energy-efficient ship operations.

Their review study emphasizes that a combination of individual, organizational, technological, and environmental factors influence the implementation of SEEMP by seafarers onboard ships. However, the crucial elements encompass awareness, knowledge, communication skills, motivation, educational training, technological solutions, and overcoming barriers. This holistic understanding illuminates the intricate interplay of diverse factors driving seafarers toward energy-efficient ship operations.

2.4. Importance of seafarers' training in implementing SEEMP onboard ships

The article [17] identifies low education levels and reluctance to embrace change as major barriers impeding the enhancement of ship energy efficiency. A study by Ref. [30] revealed that lack of training and engagement of ship crews can reduce the effectiveness of SEEMP in ensuring ship safety and minimizing environmental impacts. For these obstacles to be overcome, the crew must be involved in the SEEMP process, receive adequate training, and have the skills and information necessary. Classification societies and researchers argue that the success of these efforts depends on crews' ability to learn new skills, practices, and knowledge [17,25,75,95,96]. A successful energy efficiency enhancement and fuel-saving program relies on crew comprehension, motivation, cooperation, and participation [61]. The DNV Energy Transition Outlook 2023 report [97] supports incorporating energy-efficient practices within digital systems and investigates sustainable shipping alternatives, including carbon capture, nuclear propulsion, and liquefied hydrogen technologies. Only crews with an understanding of energy-efficient and low-emission operations can accomplish the ambitious objectives set forth by IMO. Therefore, continuous education and training for crew members are essential for successfully adopting energy-saving measures and technologies onboard ships. Moreover, the MEPC.213(63) Resolution states that SEEMP success depends on raising awareness and training onshore and onboard personnel [9]. Although they actively participated in setting and revising objectives, many crew members claim they never received any formal training regarding using the SEEMP [20,91]. Researchers have not examined seafarers' current awareness, knowledge, skills, and motivation about energy efficiency nor documented what they believe are the most energy-efficient practices [19].

2.5. Seafarers' training programs on energy efficient operation of ships (EEOS)

For energy-efficient measures to be effective, seafarers need to possess a good level of knowledge and cognition. Crewmembers who have been adequately trained, have learned the importance of energy efficiency, and are aware of it are more likely to consistently prioritize energy efficiency in their shipboard duties and adhere to the company's strategies. Various training programs are available to improve the energy-efficient operation of ships. These programs fall into four categories: Shipping Company Training, Institutional Training, IMO Training, and Specialized Training.

i. IMO Training on EEOS:

IMO E-Learning Training (IMOEL): The Global Industrial Alliance (GIA), a collaboration within the IMO-Norway GreenVoyage2050 Project, introduced a complimentary, self-paced E-learning program titled "An Introduction to Energy Efficient Operation of Ships" in May 2021. This course is designed for seafarers and other individuals involved in the maritime industry [98]. The program aims to provide energy efficiency training to all individuals in the maritime industry, promote sustainable practices in developing nations, and encourage the adoption of green shipping. The authors in Ref. [99] argue that the efficacy of training programs may influence shipowners' energy efficiency decisions.

IMO Train the Trainer (IMOTTT): Through capacity-building initiatives, the IMO conducts various training workshops for its Member States' administrations and stakeholders, addressing SEEMP implementation onboard ships [100]. This initiative contributes to GHG reduction and sustainability in the shipping industry, reflecting global collaboration. Specialized training ensures effective SEEMP implementation in ships. This initiative is for training providers and their teaching staff to improve, update, and enhance the content of current Energy Efficient Ship Operation training courses through the "Train the Trainer" course of IMO [101]. In both approaches, seafarers' awareness, knowledge, and best practices are used to reduce GHG emissions from the shipping industry through energy-efficient ship operations. This is one of the most effective EEOS training initiatives by IMO [19]. Based on the literature mentioned above reviewing IMO's training initiatives, we can formulate the following hypothesis.

Hypothesis 1. The training provided by the IMO on EEOS (IMOEL and IMOTTT) for seafarers positively correlates with implementing SEEMP onboard ships.

ii. Institutional Training on EEOS:

MET Institute Training (METIT): In collaboration with the WMU, the IMO developed a model course on energy-efficient ship operations to promote energy-efficient ship operations and set performance standards for the shipping industry in 2012. This program integrates operational and technical components into a realistic training environment, covering topics such as GHG emissions, climate change, and IMO regulations and activities [79]. A simulation exercise illustrates key principles through theoretical and practical activities. In Ref. [102]'s module, the authors cover the basics of maritime energy efficiency to make ship operations greener and more cost-effective. In Ref. [19], the authors criticized it for under-addressing awareness training and seafarers' current competence, knowledge, and motivation levels. It has been updated in 2015 to cover the most recent developments in this field. IMO also developed a model course for trainers based on the training modules developed in 2013 with the WMU [103].

EEOS Training Integrated in Pre-sea and Post-sea Training (PSPST): Seafarers need special training to operate large, entirely automated vessels safely and effectively. Through theoretical education in the classrooms and hands-on practical training in workshops and labs, seafarers have acquired the necessary skills for maritime employment [104]. Furthermore, pre-sea and post-sea training curricula incorporate lessons on energy efficiency measures and MARPOL Annex VI Chapter 4 regulations [65]. Integrating maritime energy efficiency training into pre- and post-sea training curricula can provide a deeper understanding of energy efficiency concepts and practices [105]. This will lead to more energy-efficient and sustainable ship operations. Based on the above literature review on Maritime Institutional training programs, the following hypothesis can be formulated.

Hypothesis 2. The institutional training courses on EEOS (METIT and PSPST) for seafarers significantly influence SEEMP implementation onboard ships.

iii. Shipping Company Training on EEOS:

Onboard Training (OBT): By undergoing on-the-job training (OJT) in the shipping industry, seafarers learn how to handle their duties using cutting-edge technology following new regulations imposed by IMO [106]. According to the study [105], most seafarers get basic training on maritime energy efficiency from the ship's masters and ship crews during onboard training (OBT). Onboard learning and decision support tools are critical for crew onboard ships to obtain the skills needed to efficiently perform their energy efficiency-related responsibilities [79]. Standard practice within the maritime industry is to train crews on energy efficiency operations according to the SEEMP guidelines provided by the company, which technical managers or masters and chief engineers provide. Nevertheless, this method is limited as it heavily depends on the trainer's motivation, skills, and knowledge [19].

In-house Training (IHT) by Shipping Companies: Shipping companies often provide masters and chief engineers with in-house training on SEEMP implementation during vacation or as part of the pre-joining briefing [105]. Technical managers ashore discuss the various operational energy efficiency measures implemented onboard their ships.

Computer and Simulator-based Training (CSBT): A game-based e-learning tool is used to train seafarers on operational energy efficiency measures through computer-based training programs onboard ships [105]. These programs provide seafarers with realistic scenarios that allow them to make informed decisions. A study by Ref. [82] found that over 78 % of seafarers appreciated the session, and 81 % of them learned more about the ship's energy efficiency measures. Simulator-based training improves seafarers' energy-efficient ship operations knowledge. Seafarers can practice low-carbon, energy-efficient operations safely with rapid feedback via simulation exercises [19]. Full-mission simulators include human aspects and technical issues to teach students by doing. According to Ref. [62], adding technological equipment and boosting awareness reduces energy use by 10 %.

Classification Society and Project Team Training (CPTT): Many shipping companies and classification societies have already developed energy-efficient ship operation courses and materials [19]. The company's Energy efficiency project team or departments must have qualified personnel with the required knowledge, technical skills, and energy efficiency experience. In addition, they should periodically provide necessary training to ship crews to improve the energy efficiency culture within the company [107]. Ship retrofitting companies can also provide EEOS training for crew members by the initiative of shipping companies. Crew members can be trained on the new energy efficiency systems installed on the vessel by the project team or retrofit vendor [105].

The most effective training programs for seafarers are delivered through onboard training by the master, chief engineer, or the ship manager ashore, in-house training in pre-joining briefings by technical managers, and specialized training by retrofit vendors or project teams [65]. Based on the literature review of shipping companies' training activities on EEOS, the following hypothesis can be formulated.

Hypothesis 3. The shipping companies' training activities on EEOS (OBT, CSBT, IHT, and CPTT) for Seafarers have a significant positive relationship with SEEMP implementation onboard ships.

iv. Specialized Training on EEOS and SEEMP

WMU Maritime Energy Management Program (WMUP): Maritime Energy Management Masters' Program at WMU focuses on sustainable energy management on ships as part of a comprehensive postgraduate program. Training covers energy audits, ship design, and regulatory compliance. Furthermore, students receive hands-on experience with the most recent tools and technologies in the field [108].

MariEMS Program (MariEMSP): The Maritime Energy Management System (MariEMS) is an EU-funded specialized training program that teaches maritime personnel how to operate ships energy efficiently. The MariEMSP relies on the Ship Energy Management Team (SEMT). The ship's energy efficiency is managed by the SEMT, which also recommends and implements energy-saving solutions. The program includes simulation tools, online delivery platforms, and workshops [109].

Investigations into online platforms for delivering training in maritime energy management systems (MariEMS) and the establishment of a comprehensive postgraduate-level maritime energy management program at WMU [100,108] have underscored the crucial role of education and training in advancing sustainable solutions and curbing emissions in the maritime sector. Based on the literature review on the specialized training programs on energy-efficient ship operations, the following hypothesis can be formulated.

Hypothesis 4. The specialized training programs on EEOS (WMUP and MariEMSP) significantly impact the implementation of SEEMP onboard ships.

2.6. Knowledge, understanding, and proficiency requirements of the STCW in maritime training

In 1995, the STCW convention introduced competency-based training, which included the requirement that qualified officers be able to demonstrate knowledge, understanding, and proficiency [110]. The STCW Code provides a comprehensive list of competencies, knowledge, understanding, and proficiency, along with methods for evaluation and demonstration. As part of the code, education and training objectives and standards of competence are also defined, along with appropriate levels of knowledge, understanding, and skills for assessments and examinations. To meet the STCW Code's KUP requirements, MET schools combine theoretical and practical instructions through hands-on training, virtual training through simulators, and on-the-job training at sea [111].

The maritime industry requires a balance between knowledge, understanding, and proficiency to acquire cognitive, affective, and psychomotor skills [112]. Knowledge acquisition involves learning theoretical principles, whereas understanding involves comprehending and applying information to new situations. Proficiency is the ability to perform something with competence and expertise. These skills are essential for a person to become competent and expert in a particular skill. There are three domains of achievement in Bloom's Taxonomy: cognitive, psychomotor, and affective [113]. The STCW Code indeed emphasizes cognitive and psychomotor domains, but learning outcomes to describe the affective and psychomotor domains are not specified by the Code [110]. However, in the research methodology, the survey questionnaires were designed to measure the learning outcomes of seafarers from various types of EEOS courses by asking four questions about knowledge, understanding, proficiency, and satisfaction with individual courses.

3. Research approach and methodology

In this research, we aim to gain insight into onshore ship managers and shipboard seafarers' skills as ship crews' ability to acquire new skills, practices, and knowledge is crucial for successfully implementing these requirements [37]. The implementation, monitoring, and evaluation of SEEMPs depend on the education and training of onboard seafarers and onshore management [9]. Using an abductive approach, the research examines the effects of training seafarers in energy-efficient operations of ships for implementing SEEMP measures onboard ships within the context of the research approach [114]. The study also integrates observations from real-world experiences and data gathered through surveys, representing an inductive component. Combining these deductive and inductive components is an example of the abductive approach, which makes it possible to explore novel ideas and theories outside of what is specifically stated in the body of current literature. Furthermore, the study's focus on seafarers' training courses and their effectiveness in enhancing knowledge, understanding, proficiency, and satisfaction among participants underscores applying an abductive approach by bridging theoretical concepts with empirical observations.

3.1. Pilot survey

A pilot survey was conducted to obtain an overview of the education and training received by onshore technical managers and onboard crew members. A total of 22 experienced ashore ship managers and onboard crew members from different countries were interviewed. The following three questions were asked of attendees in the pilot survey conducted through face-to-face interviews, online Zoom meetings, or phone calls in June 2022.

i. Can energy efficiency measures be successfully implemented if personnel onboard and onshore are made aware and trained according to section 4.1.6of the MEPC?213(63) Resolution?
ii. What training is needed to implement energy-efficient measures on ships?
iii. What training have you received from your shipping company regarding effectively implementing energy-efficient measures on ships?

The results of this pilot survey were used for the testing of the main online survey questionnaires and adjustment of the comprehensive hypothesis of this study.

3.2. Designing of online mixed-mode survey

Based on the primary data collected from the literature review, a well-formed mixed-mode survey questionnaire was developed. Academic and industrial experts validated the survey questionnaires using the "Content Validity Index (CVI)" method described by Refs. [115,116]. Later, the main survey questionnaires were tested and adjusted to ensure reliability and relevance with a pilot study (described in section 3.1).

The questionnaires were structured into four (04) parts: Part 1 focused on gathering personal background information from the participants. Part 2 consisted of questionnaires designed to measure the participants' knowledge, understanding, proficiency, and satisfaction with all ten available training courses/programs on EEOS. Part 3 assessed the participants' knowledge, understanding, and proficiency in implementing SEEMP onboard ships. Part 4 allowed participants to provide feedback for effectively implementing SEEMP onboard ships.

The survey data was collected by creating an online survey using Google Forms. The survey included single-answer and multiple-choice questions and checkboxes for selecting single and multiple responses. EEOS courses or programs were rated on a Likert scale of 1–5 based on the respondent's level of knowledge, understanding, proficiency, and satisfaction.

The online Google Form was used to develop the survey questionnaires, distributed to seafarers and ship managers across various countries via email, social media, and other online platforms from February 7, 2023, and continued till June 12, 2023. In the introductory part of the survey, a brief explanation of the objectives of the survey, along with a few encouraging and promising words, are given to convince participants. A total of 158 responses were obtained from seafarers who participated in the online survey during its four-month duration, which spanned from February 7, 2023, to June 12, 2023. Each of the participants can respond to the survey questionnaire only once.

3.3. Sampling strategy

A purposive sampling strategy was employed in Part 1 of the survey questionnaire, where participants were asked about their positions in shipping companies, years of experience, and the country of their organization. Although the possibility of non-response biases is recognized, we have taken measures to mitigate this issue by utilizing multiple communication channels to disseminate the survey link globally. This approach has enabled us to reach a wide range of participants, including seafarers in deck officers and engineers ranks onboard ships, ashore ship managers, surveyors, and maritime educators. The purpose of these enhancements is to improve both the replicability and transparency of the sampling strategy employed in our study. The survey link was distributed to 38 shipping companies worldwide using various communication channels, such as email, instant messaging, and social media platforms, reaching seafarers working in different roles and ashore managers, as well as surveyors and maritime educators. A total of 158 responses were received, with 14 excluded for not meeting the criteria for the study, resulting in 144 participants providing reliable and relevant data for analysis. The profiles of survey participants are shown in Fig. 2(a) and (b), illustrating the percentage of participants according to years of experience.

3.4. Analysis of survey questionnaires

A Likert scale with numeric values was used in the study to collect descriptive and subjective data from questionnaires. As an ordinal data set, the categories have a mathematical value and relate to one another in a specific order. A quantitative analysis was conducted with SPSS Version 26 and SmartPLS 3.2.9, and graphs were generated with Excel. A Likert Scale was used to assign values between 1 and 5, with 1 being the least desirable and 5 being the most desirable. Displaying results were based on the frequency of category selection, and ranking was based on the mean value. A mean value can be used to rank variables, but specific values should not be considered independently. We included the N number of participant responses in the captions in Fig. 2 and excluded incomplete responses from the analysis.

3.5. Data analysis for seafarers' training programs/activities on EEOS

In Part 2 of the mixed-mode survey, participants were asked the following questionnaires to measure their knowledge, understanding, proficiency, and satisfaction gained from all available ten training programs or activities on EEOS discussed in section 2.4 of the literature review.

1) Level of knowledge in implementing SEEMP onboard ships (1 = Knowledge)
2) Level of understanding in implementing SEEMP onboard ships (2 = Understanding)
3) Level of proficiency in implementing SEEMP onboard ships (3 = Proficiency)
4) Level of satisfaction with the training program or learning activity and outcomes about implementing SEEMP onboard ships (4 = Satisfaction)

3.5.1. Conceptual framework

A total of four independent constructs (1 = Knowledge, 2 = Understanding, 3 = Proficiency, and 4 = Satisfaction) are included in this exploratory study, including IMO Training (linked to two variables: IMOEL and IMOTTT), Institutional Training (linked to two variables: METIT, and PSPST), Shipping Company Training (linked to four variables: OBT, CSBT, IHT, and CPTT), Specialized Training (linked to two variables: WMUP and MariEMSP), as well as one dependent construct, SEEMP. Fig. 3 illustrates the conceptual model.

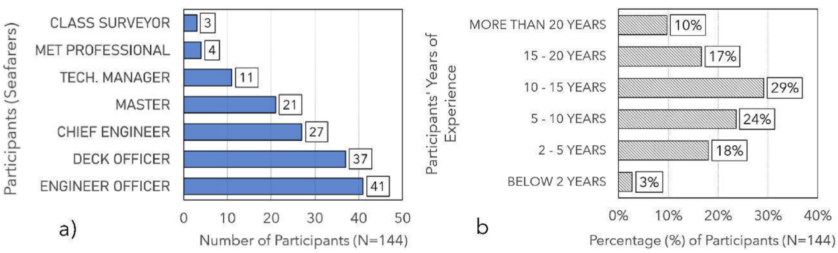

Fig. 2. (a): Number of Participants According to their Position in Shipping Companies; 2(b): Percentage (%) of Participants According to Years of Experience.

3.5.2. Univariate normality of the data

Regarding skewness, the latent factor indices we used had a high normal distribution relative to the latent factor. Although this deviates from rigorous normality criteria [117], who proposed 3.3 as a higher threshold for normality in their study, proposed a more flexible concept to handle this case (Table 1).

3.5.3. Multivariate Normality

When analyzing Cook's distance by Influential Data (ID) using SPSS Version 26, no cases greater than one were observed. A large majority of the cases were less than 0.05 (Fig. 4). The results indicate that all the items were normally distributed.

4. Results of mixed-mode survey

4.1. Seafarers training programs/activities on EEOS

4.1.1. Measurement model

The factor analysis, indicator reliability, and model fitting information were done with SmartPLS Version 3.2.9. The data analysis presented in Table 2 evaluates the effectiveness of eleven distinct maritime training factors in enhancing energy-efficient ship operations.

1. Computer-and Simulator-Based Training (CSBT): seafarers reported that they received substantial advancements in new knowledge, understanding, proficiency, and overall satisfaction from CSBT.
2. Classification Society and Project Team Training (CPTT): participants in CPTT demonstrated positive outcomes, acquiring required knowledge, understanding, proficiency, and expressing satisfaction.
3. Inhouse Training (IHT): The IHT provided sufficient knowledge and proficiency, but participant satisfaction fell below expectations.
4. IMO E-Learning (IMOEL): The IMOEL yielded significant gains in new knowledge, understanding, proficiency, and satisfaction.
5. IMO Train the Trainer (IMOTTT): Seafarers engaging in IMOTTT experienced positive outcomes across all parameters, such as knowledge, understanding, proficiency, and satisfaction.
6. MET Institute Training (METIT): The METIT facilitated necessary knowledge and proficiency, with satisfaction expressed exclusively.
7. Onboard Training (OBT): The OBT provided commendable understanding and proficiency, with intermittent satisfaction, but it did not deliver sufficient new knowledge.
8. Pre-sea & Post-sea Training (PSPST): The PSPST demonstrated comprehensive benefits, offering good knowledge, understanding, proficiency, and satisfaction.
9. Ship Energy Efficiency Management Plan (SEEMP): The participants' seafarers reported good knowledge, understanding, and proficiency in SEEMP measures and implementation procedures.
10. Maritime Energy Management System program (MariEMSP): The MariEMSP provided participants with knowledge, understanding, proficiency, and overall satisfaction.
11. World Maritime University Program (WMUP): The WMUP specialized training resulted in seafarers acquiring new knowledge, understanding, and proficiency in energy-efficient ship operations.

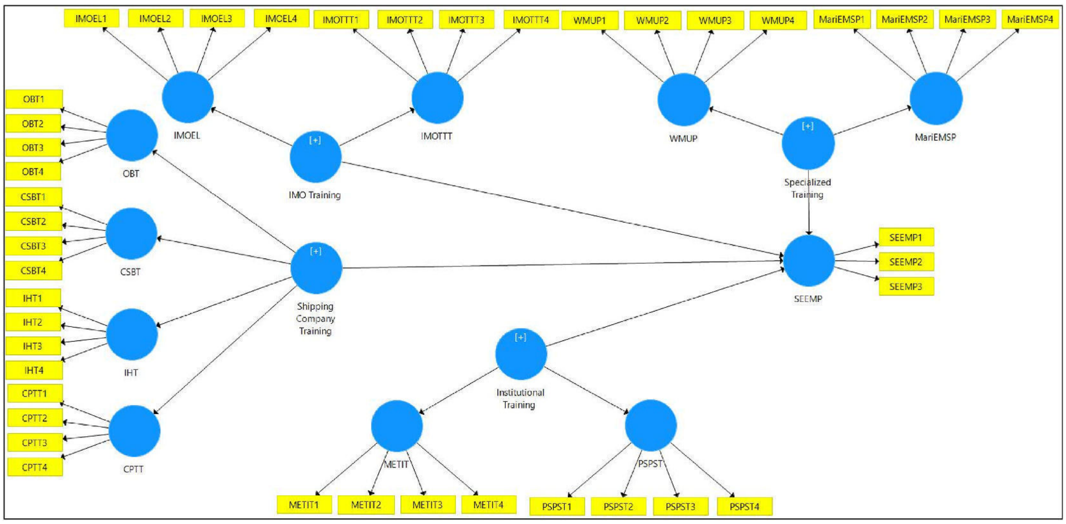

Fig. 3. Conceptual model (Source: SmartPLS 3.2.9).

Table 1
Normality of the data.

Items	Mean	SD	Kurtosis	Skewness
SEEMP1	3.188	0.858	−0.717	−0.240
SEEMP2	3.361	0.962	−0.920	0.165
SEEMP3	3.535	0.897	−0.172	−0.280
OBT1	3.201	1.011	0.014	−0.456
OBT2	3.410	0.908	0.476	−0.571
OBT3	3.451	0.919	0.476	−0.696
OBT4	3.569	0.998	0.202	−0.787
CSBT1	3.479	1.054	−0.272	−0.556
CSBT2	3.014	0.935	−0.423	0.127
CSBT3	3.569	0.879	1.067	−1.020
CSBT4	3.139	0.969	−0.780	−0.191
IHT1	3.431	0.796	0.936	−0.937
IHT2	3.493	0.898	0.034	−0.503
IHT3	3.306	0.915	−0.593	0.123
IHT4	3.653	0.776	−0.133	−0.387
METIT1	3.750	0.939	0.536	−0.699
METIT2	3.389	0.906	−0.937	−0.230
METIT3	3.444	0.806	−0.202	−0.501
METIT4	3.653	0.869	−0.094	−0.480
IMOEL1	3.549	1.079	−0.708	−0.328
IMOEL2	3.556	0.926	−0.327	−0.217
IMOEL3	3.708	0.857	0.458	−0.601
IMOEL4	3.375	0.942	0.311	−0.515
CPTT1	3.549	0.798	0.553	−0.575
CPTT2	3.583	0.854	0.107	−0.229
CPTT3	3.618	0.979	−0.229	−0.515
CPTT4	3.653	0.974	0.067	−0.574
PSPST1	3.764	1.208	0.357	−1.113
PSPST2	3.847	1.276	0.079	−1.086
PSPST3	3.972	1.280	0.915	−1.394
PSPST4	3.681	1.267	−0.147	−0.950
WMUP1	3.931	1.206	0.612	−1.211
WMUP2	3.792	1.258	0.223	−1.081
WMUP3	3.653	1.169	0.296	−1.034
WMUP4	2.931	1.295	−1.221	0.053
IMOTTT1	3.167	1.374	−1.255	−0.175
IMOTTT2	3.722	1.145	0.704	−1.119
IMOTTT3	3.153	1.174	−0.842	−0.041
IMOTTT4	2.944	1.373	−1.321	−0.062
MariEMSP1	2.764	1.338	−1.307	0.090
MariEMSP2	2.625	1.327	−1.073	0.357
MariEMSP3	2.750	1.233	−1.050	0.174
MariEMSP4	3.639	1.217	0.314	−1.146

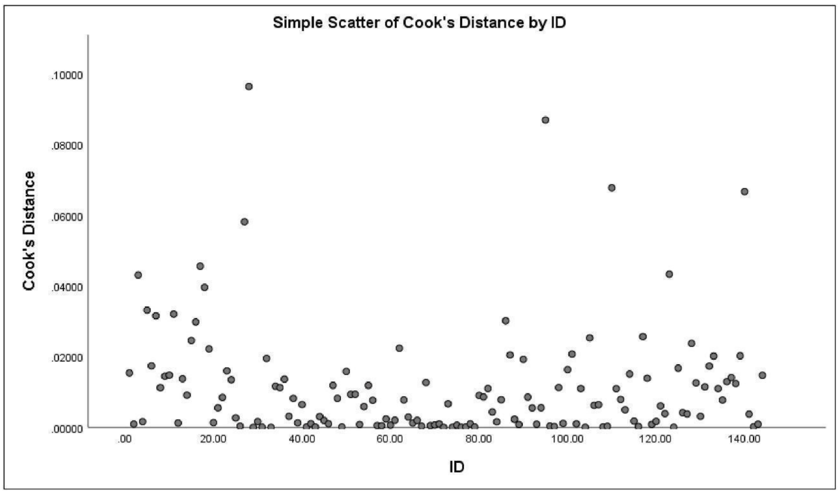

Fig. 4. Multivariate normality (Source: SPSS 26).

Table 2
Exploratory factor analysis with indicator reliability and model fitting information.

Factors Name	Associations	Factor Loading	SM	SD	T Statistics	IR	CA	CR	AVE
1. Computer and Simulator-Based Training (CSBT)	Knowledge (1)	0.730	0.726	0.052	14.032	0.533	0.710	0.820	0.534
	Understanding (2)	0.640	0.637	0.074	8.698	0.410			
	Proficiency (3)	0.760	0.759	0.043	17.795	0.578			
	Satisfaction (4)	0.785	0.783	0.042	18.556	0.616			
2. Classification Society and Project Team Training (CPTT)	Knowledge (1)	0.799	0.798	0.035	23.156	0.638	0.880	0.918	0.737
	Understanding (2)	0.876	0.876	0.019	45.185	0.767			
	Proficiency (3)	0.891	0.890	0.019	46.684	0.794			
	Satisfaction (4)	0.864	0.863	0.023	36.883	0.746			
3. Inhouse Training (IHT)	Knowledge (1)	0.799	0.794	0.046	17.446	0.638	0.641	0.807	0.586
	Understanding (2)	0.852	0.854	0.026	32.362	0.726			
	Proficiency (3)	0.628	0.621	0.076	8.208	0.400			
4. IMO E-Learning (IMOEL)	Knowledge (1)	0.786	0.779	0.105	7.516	0.618	0.796	0.868	0.623
	Understanding (2)	0.882	0.875	0.111	7.974	0.778			
	Proficiency (3)	0.754	0.745	0.112	6.752	0.569			
	Satisfaction (4)	0.726	0.718	0.100	7.282	0.527			
5. IMO Train the Trainer (IMOTTT)	Knowledge (1)	0.851	0.606	0.058	14.650	0.724	0.821	0.881	0.651
	Understanding (2)	0.689	0.468	0.052	13.360	0.475			
	Proficiency (3)	0.815	0.563	0.058	13.990	0.664			
	Satisfaction (4)	0.859	0.604	0.060	14.410	0.738			
6. MET Institute Training (METIT)	Knowledge (1)	0.861	0.637	0.045	19.090	0.741	0.727	0.830	0.620
	Proficiency (3)	0.788	0.530	0.054	14.570	0.621			
	Satisfaction (4)	0.695	0.404	0.061	11.350	0.483			
7. Onboard Training (OBT)	Understanding (2)	0.883	0.884	0.017	50.756	0.780	0.773	0.868	0.687
	Proficiency (3)	0.843	0.842	0.033	25.646	0.711			
	Satisfaction (4)	0.755	0.744	0.073	10.355	0.570			
8. Pre-sea & Post-sea Training (PSPST)	Knowledge (1)	0.823	0.819	0.052	15.958	0.677	0.903	0.932	0.776
	Understanding (2)	0.912	0.911	0.019	48.029	0.832			
	Proficiency (3)	0.889	0.888	0.023	38.539	0.790			
	Satisfaction (4)	0.897	0.896	0.019	47.212	0.805			
9. Ship Energy Efficiency Management Plan (SEEMP)	Knowledge (1)	0.687	0.687	0.070	9.850	0.472	0.782	0.870	0.693
	Understanding (2)	0.893	0.892	0.016	56.297	0.797			
	Proficiency (3)	0.900	0.898	0.019	47.526	0.810			
10. Maritime Energy Management System program (MariEMSP)	Knowledge (1)	0.844	0.842	0.030	28.285	0.712	0.838	0.892	0.674
	Understanding (2)	0.876	0.874	0.029	30.568	0.767			
	Proficiency (3)	0.827	0.825	0.038	21.725	0.684			
	Satisfaction (4)	0.729	0.731	0.033	22.272	0.531			
11. World Maritime University Program (WMUP)	Knowledge (1)	0.923	0.922	0.020	46.575	0.852	0.876	0.924	0.802
	Understanding (2)	0.879	0.877	0.025	35.121	0.773			
	Proficiency (3)	0.883	0.882	0.032	27.948	0.780			

SM=Sample Mean, SD=Standand Deviation, IR= Indicator Reliability, CA=Cronbach's Alpha, CR=Composite Reliability, AVE = Average variance extracted (Source: SmartPLS 3.2.9).

The Average Variance Extracted (AVE), Cronbach's Alpha (CA), and Composite Reliability (CR) results, calculated in Table 2, are displayed to determine the validity and reliability of the research model. AVE values of all latent variables or model constructs exceed 0.50. The values for CSBT, CPTT, IHT, IMOEL, IMOTTT, METIT, OBT, PSPST, SEEMP, MariEMSP, and WMUP are (0.534, 0.737, 0.586, 0.623, 0.651, 0.620, 0.687, 0.776, 0.693, 0.674, and 0.802), respectively, since all constructs have AVE values greater than 0.50,

Table 3
Reliability Indexes and criteria.

Reliability Indexes	Criteria	Reference
Average Variance Extracted (AVE)	>0.50	[118,120,121]
Composite Reliability (CR)	>0.80	[122]
Cronbach's Alpha (CA)	>0.60	[123]
Indicator Loading Value (ILV)	0.60 to 0.70	[118,120,121,124]

which is acceptable.

CR values for all model constructs are greater than 0.80 (0.820, 0.918, 0.807, 0.868, 0.881, 0.830, 0.868, 0.932, 0.870, 0.892, and 0.924). It is acceptable as long as the CR value exceeds or equals 0.80. The internal reliability of the model structures was determined using Cronbach's alpha. The results of Cronbach's alpha are shown in Table 2, which are all greater than 0.60. As can be seen in Table 3, there is a strong correlation between the indicators of the model constructions. Additionally [118], recommends examining the loading values of all model constructs to determine whether they are convergence-valid. Each construct should have loading values greater than 0.60 for each indicator of the latent variable, as specified in the study of [119]. Five items were eliminated because they had values below 0.60. When the aforementioned indicators were removed, loading values ranged from 0.64 to 0.84, which all exceeded 0.60. Thus, these findings support the research model's convergence validity, indicating a high correlation between all construct indicators (see Table 2).

4.1.2. Discriminant validity

According to the Fornell-Larker criteria [119], the square root of the AVE of each latent construct must be greater than the correlation of the construct with each other latent variable to determine discriminant validity. In the correlation matrix and diagonal, the square roots of the AVE coefficients must be confirmed [120]. In Table 4, the discriminant validity shows that correlations between the AVE root square values and any other model components are greater than correlations between latent variables.

4.1.3. Common method bias test

It is common for Variance Inflation Factors (VIFs) to range from 1 to 10 and upward. Using the VIF, we can determine what percentage of variance has been inflated for each coefficient. Generally, the VIF 1 represents no correlation, 1 to 5 moderate correlation, and greater than 5 highly correlated [125]. VIFs were calculated to examine multicollinearity among the variables, and their maximum value was 2.477 (Table 6), within [125]'s recommended range. These factors don't exhibit any multicollinearity problems. VIFs greater than 3.3 indicate pathological collinearity and a potential bias due to common methods. Our model (Table 5) is considered free of common method bias as the values of all VIFs are equal to or lower than 3.3 [126].

4.1.4. Heterotrait-monotrait ratio (HTMT)

To determine the convergent validity of the constructs, the HTMT value should be compared to a predefined threshold (commonly set at 0.85 or 0.90). An HTMT value below the designated threshold signifies robust convergent validity, signifying that the constructs exhibit the anticipated interrelationships (Table 5). Conversely, if the HTMT value surpasses the threshold, it warrants scrutiny for potential concerns regarding convergent validity, possibly indicating overlap or multicollinearity between the constructs. Notably, the current study reveals no evidence of multicollinearity among the constructs.

4.1.5. Structural model

The following five constructs were examined using a multivariate analysis technique (variance-based structural equation modeling) to identify significant relationships: (i) IMO Training, (ii) Institutional Training, (iii) Shipping Company Training, and (iv) Specialized Training, and (v) SEEMP. It has been demonstrated in Table 6 that IMO Training and Shipping Company Training have significant relationships with SEEMP ($\beta = 0.196$, $t = 2.180$, $p < 0.05$), and ($\beta = 0.478$, $t = 4.831$, $p < 0.05$ respectively). As a result, hypotheses H1 and H3 were supported. On the other hand, SEEMP does not show significant relationships with Institutional Training and Specialized Training ($\beta = 0.028$, $t = 0.262$, $p > 0.05$) and ($\beta = 0.044$, $t = 0.464$, $p > 0.05$ respectively). Therefore, hypotheses H2 and H4 were not supported.

The researcher [127] has recommended R^2 values ranging between 0.02 and 0.12 as weak, 0.13 to 0.25 as moderate, and 0.26 or higher as large in scholarly research on marketing issues. Based on the results of this study, the R^2 value of SEEMP is 0.408, as seen in Fig. 5. In other words, the four factors we identified as (i) IMO Training, (ii) Institutional Training, (iii) Shipping Company Training, and (iv) Specialized Training accounted for 40.8 % of effective training of seafarers for successful implementation of SEEMP in the global shipping industry. It is important to notice, however, that that the sample is quite small which can have an influence on the

Table 4
Model discriminant validity.

	CSBT	CPTT	IHT	IMO EL	IMO TTT	METIT	OBT	PSPST	SEEMP	Mari EMSP	WMUP
CSBT	0.731										
CPTT	0.635	0.858									
IHT	0.673	0.683	0.766								
IMOEL	0.595	0.637	0.530	0.789							
IMOTTT	0.084	−0.067	−0.069	0.049	0.807						
METIT	0.593	0.694	0.577	0.721	−0.020	0.788					
OBT	0.642	0.573	0.485	0.613	−0.024	0.586	0.829				
PSPST	−0.089	0.155	0.088	−0.018	−0.598	0.125	0.027	0.881			
SEEMP	−0.023	0.106	0.013	0.035	−0.794	0.051	0.023	0.438	0.821		
MariEMSP	0.502	0.593	0.463	0.549	0.016	0.458	0.522	0.061	0.035	0.832	
WMUP	−0.017	0.192	0.099	0.012	−0.575	0.175	0.005	0.686	0.511	0.056	0.895

(Source: SmartPLS 3.2.9)

Table 5
HTMT ratio.

	CPTT	CSBT	IHT	IMOEL	IMOTTT	METIT	MariEMSP	OBT	PSPST	SEEMP	WMUP
CPTT											
CSBT	0.789										
IHT	0.79	0.67									
IMOEL	0.778	0.769	0.72								
IMOTTT	0.1	0.147	0.149	0.108							
METIT	0.781	0.834	0.816	0.81	0.119						
MariEMSP	0.137	0.128	0.094	0.083	0.748	0.078					
OBT	0.68	0.824	0.65	0.773	0.071	0.813	0.068				
PSPST	0.173	0.149	0.172	0.106	0.723	0.146	0.477	0.049			
SEEMP	0.684	0.643	0.605	0.657	0.088	0.611	0.1	0.621	0.107		
WMUP	0.218	0.089	0.154	0.113	0.728	0.185	0.547	0.053	0.783	0.075	

(Source: SmartPLS 3.2.9)

Table 6
Path model.

Hypotheses	Beta (β)	SM	SD	LL	UL	t Statistics	p Values	Comment	VIF
IMO Training - > SEEMP	0.196	0.200	0.090	−0.057	0.399	2.180	0.038	Supported	2.285
Institutional Training - > SEEMP	0.028	0.036	0.107	−0.194	0.227	0.262	0.794	Not Supported	2.027
Shipping Company Training - > SEEMP	0.478	0.494	0.099	0.248	0.647	4.831	0.000	Supported	2.278
Specialized Training - > SEEMP	0.044	0.026	0.094	−0.128	0.241	0.464	0.643	Not Supported	2.108
R2	0.408								
Q2	0.405								

SM=Sample Mean, SD=Standand Deviation, LL = Lower Limit, UL=Upper Limit, Variance Inflation Factor = VIF, R^2=Coefficient of determination, Q2 = Predicted Relevance (Source: SmartPLS 3.2.9).

results, which creates some uncertainty. According to Ref. [128], the model is predictively relevant when Q^2 is greater than 0, whereas the model is not predictively relevant when Q^2 is less than 0. A further point to consider is that the guidelines for evaluating the Q^2 value indicate that, for each endogenous latent variable of interest, the values of 0.02, 0.15, and 0.35 represent small, medium, and large relevance, respectively [128]. As shown in Table 6, the Q^2 value for SEEMP is 0.405, which represents a high level of relevance for the endogenous construct.

4.2. Seafarers' knowledge, understanding and proficiency (KUP) in SEEMP

Ship crews are responsible for operating the vessel, navigating it at sea, and transporting cargo from port to port. To improve energy efficiency, crew members implement various technical and operational measures as part of the SEEMP during ship operations. Part 3 of

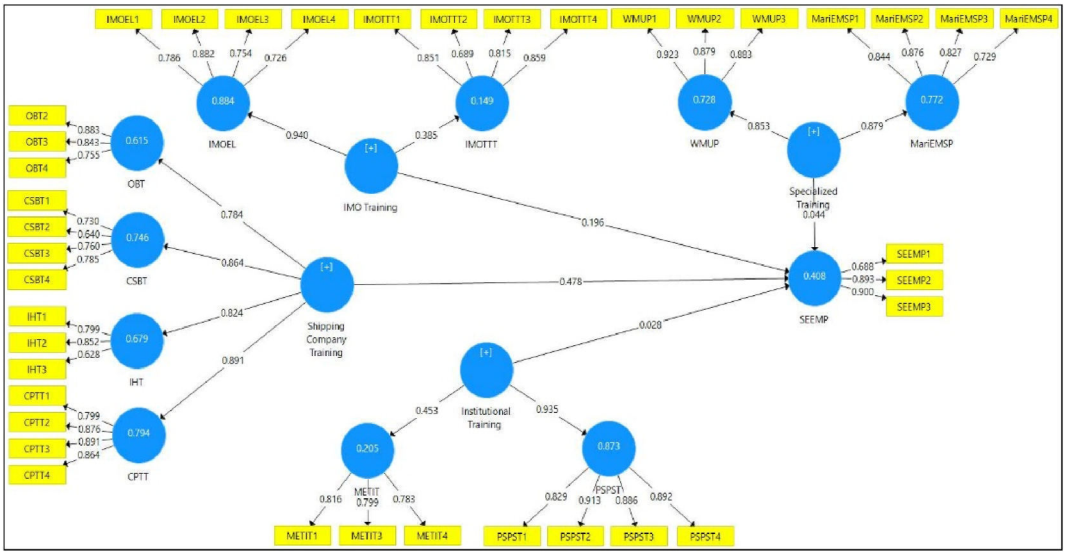

Fig. 5. Path model (Source: SmartPLS 3.2.9).

the questionnaires consisted of three questions designed to measure crew members' knowledge, understanding, and proficiency in implementing SEEMP onboard ship. Based on the analysis of survey data, Fig. 6(a) indicates that 55 % of participants are very knowledgeable or knowledgeable, Fig. 6(b) shows that 53 % of participants understand or understand well, and Fig. 6(c) illustrates that 58 % of participants are very proficient or proficient in implementing SEEMP onboard ships. In summary, almost 50 % of seafarers working onboard ships and ashore offices have the necessary knowledge, understanding, and proficiency in energy efficiency regulations, operational and technical energy efficiency measures, and their implementation procedures onboard ships.

5. Discussions

This study evaluated the effectiveness of different training programs for seafarers in implementing SEEMP in the global shipping industry. The results revealed that IMO Training, Institutional Training, Shipping Company Training, and Specialized Training programs accounted for 40.8 % of effective training for seafarers in implementing SEEMP, with an R^2 value of 0.408. It is important to notice, however, that that the sample is quite small which can have an influence on the results, which creates some uncertainty. Furthermore, Section 4.2 findings indicate that 55 % of participants are knowledgeable, 53 % understand well, and 58 % are proficient in SEEMP implementation onboard ships. Overall, nearly 50 % of current seafarers, both onboard and ashore, possess requisite knowledge, understanding, and proficiency in energy efficiency regulations, operational measures, and their execution procedures aboard ships, which are supported by Dewan and Godina [129]. According to their recent study, 39 % of seafarers have excellent or good technical knowledge about maritime energy efficiency standards and carbon emissions practices onboard ships.

The study highlighted that IMO Training and Shipping Company Training have significant positive relationships with SEEMP implementation onboard ships. Specifically, training provided by the International Maritime Organization (IMO), such as IMO E-Learning (IMOEL) and IMO Train the Trainer (IMOTTT), and training activities conducted by shipping companies for seafarers on EEOS, such as onboard training (OBT), computer/simulator-based training (CSBT), in-house training (IHT), and company project team training (CPTT), were found to be effective in enhancing seafarers' knowledge and awareness of ship energy efficiency measures. Though most seafarers regularly attended onboard training (OBT) on ships and gained a good understanding and proficiency in implementing SEEMP, they did not gain the required knowledge from the OBT. On the other hand, computer or simulator-based training (CSBT) was very effective for seafarers in gaining the required KUP. Our findings are also supported by the researchers [19,62,82,102,105].

However, the study did not find significant relationships between SEEMP and Institutional Training and Specialized Training programs. This suggests that institutional training courses for seafarers, such as MET institute training (METIT) and pre-sea and post-sea training (PSPST), and specialized training programs on EEOS, such as WMU Program (WMUP) and MariEMS Program (MariEMSP), may not be as effective in enhancing SEEMP implementation onboard ships. A previous study by Ref. [19] has criticized the training course module developed by IMO and WMU in 2012 for MET institutes for not addressing the need for training to increase seafarers' awareness and to enhance their current competence, knowledge, and motivation levels. In Ref. [65], the authors highlighted the training requirements and challenges of energy-efficient ship operation and recommended simulator-based training to increase the knowledge, understanding, and proficiency of seafarers for the adoption of SEEMP onboard ships.

These findings, therefore, provide valuable insights for shipping companies and training institutions in designing and delivering training programs to enhance the successful implementation of SEEMP in the global shipping industry. Previous studies have recommended simulator-based training and computer-based gamification tools to improve seafarers' awareness of energy efficiency measures. The IMO and WMU have also developed a "Train the Trainer (TTT)" course package on EEOS to equip administrators and trainers with the necessary skills to support the IMO capacity-building initiatives.

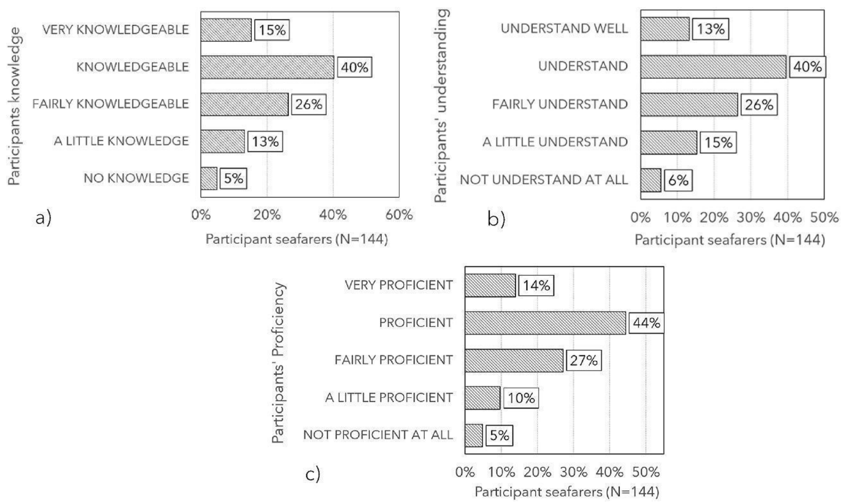

Fig. 6. (a): Participants' knowledge; 6(b): Participants' understanding, and 6(c): Participants' proficiency in implementing SEEMP onboard ships.

6. Training framework for enhancing seafarers' competence in energy-efficient ship operations

Technological advancements and the use of digital technologies are revolutionizing the maritime industry and changing the conventional duties played by seafarers. To improve energy-efficient ship operation to achieve net-zero emission targets, seafarers must transition into digital operators, necessitating an effective education and training framework to continuously update their knowledge and skills. Digital technologies make operations more efficient, help with the switch to alternate fuels, and provide useful information toward the goal of reaching the net-zero carbon emissions target by 2050. DNV Maritime Forecast estimates that 1.8 million seafarers will need decarbonization training by 2050 [97]. According to a recent study [129], a significant proportion of seafarers, specifically 47 %, demonstrated a substantial commitment to enhancing energy-efficient ship operations by leveraging their technical expertise during their tenure on board vessels. Human perception, skill, and decision-making are still essential to ensure the efficacy and safety of vessels, according to a recent safety report from DNV and Lloyd's List Intelligence [130]. To ensure effective implementation of SEEMP measures onboard ships to enhance energy-efficient ship operation, crewmembers onboard ships and ship managers ashore must receive effective training. The study [129] indicates that 84 % of seafarers are extremely or very interested in learning about low-carbon emission measures and energy-efficiency regulations. Based on the mapping of various energy efficiency training courses/programs adapted from the study in Ref. [65] and our findings from this study, in Fig. 7, the green color has been used for effective and light brown color has been used for less effective training programs/activities. The blue color has been used for deck officers, including masters, and the red color has been used for engineering officers, including chief engineers, as their involvement in adopting energy efficiency operational measures varies according to their different shipboard responsibilities. To implement the SEEMP successfully and achieve energy efficiency goals on ships, a training framework must be tailored to the requirements and responsibilities of seafarers.

The following recommendations are proposed, as shown in Fig. 8, for shaping a strategic training framework for seafarers in energy-efficient ship operations.

(1) **IMO Introductory Training:** All ship crews, including masters and chief engineers working onboard ships, and technical and operation managers based ashore, along with company energy efficiency project teams, should attend the IMO E-Learning (IMOEL) course on Energy-Efficient Operation of Ships (EEOS) as introductory training.

IMO Trainer Programs: Ship masters, chief engineers, ship managers, and company project teams are advised to participate in

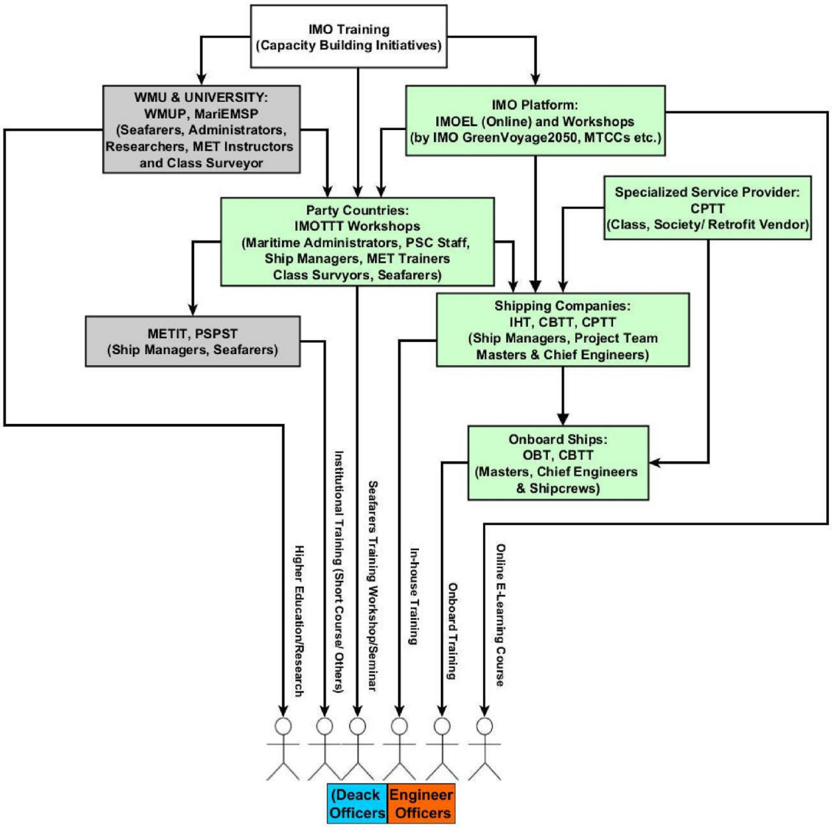

Fig. 7. Mapping of maritime energy efficiency training programs and activities for Stakeholders (Source: adapted from Ref. [65]).

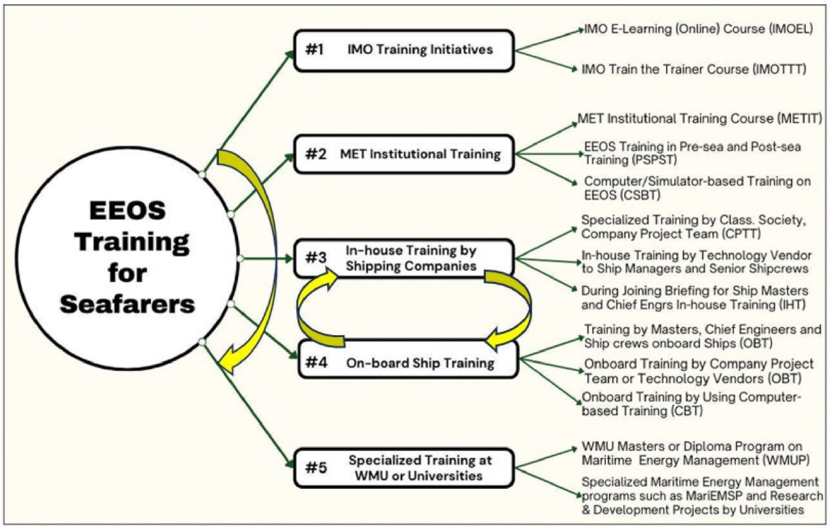

Fig. 8. A strategic training framework for seafarers and trainers in energy-efficient ship operations.

IMO Train the Trainer (IMOTTT) programs. This will enhance their knowledge and awareness of ship energy efficiency measures, enabling them to serve as trainers for ship crews onboard ships.

(2) **Formal Institutional Training:** All deck officers and engineers onboard ships are recommended to undergo MET Institutional Training (METIT) for comprehensive knowledge and understanding. This formal institutional training featuring computer-based or simulator-based training (CSBT) by professional MET instructors ensures a solid foundation of knowledge and understanding and enhances proficiency in implementing energy efficiency measures onboard ships.
(3) **In-House Training:** Following institutional training, ship managers, company project teams, masters, and chief engineers are encouraged to undergo in-house training at shipping company offices regularly. This training, conducted by classification societies, retrofit vendors, and training service providers using simulators, is crucial for effective knowledge transfer and practical insights.
(4) **Onboard Training:** All crew members, including deck officers and engineers, should undergo regular onboard training (OBT) facilitated by masters, chief engineers, or company energy efficiency project teams regularly. Introducing computer-based training (CBT) or modern gamification software onboard, supervised by masters and chief engineers, ensures effective training and improves skills.
(5) **Specialized Education:** Individual seafarers, ship managers, or stakeholders seeking specialized education can consider postgraduate programs at WMU or attending the EU-funded MariEMS program arranged by specialized training providers. These avenues are recommended for achieving higher education, fostering further research and development in maritime energy management, and making valuable contributions to the field.

Finally, implementing computer and simulator-based training (CSBT) into conventional methodologies by MET Institutes is advocated to foster comprehensive skill acquisition among seafarers. To ensure efficient training delivery, trainers and instructors affiliated with MET Institutes must engage in the IMO Train the Trainer (IMOTTT) program or workshops facilitated by member state administrations or the IMO. Masters, chief engineers, and technical managers engaged in onboard training (OBT) should participate in the IMOTTT program or workshops to enhance training effectiveness. Upon completing institutional training programs for EEOS, participants' knowledge, understanding, and performance (KUP) must be assessed through a competency assessment system. Additionally, MET institutions need to gather feedback from seafarers so that training programs can be upgraded to meet the updated demands of the shipping industry. Furthermore, onboard training (OBT) and in-house training (IHT) for crew members directly responsible for implementing the SEEMP are strongly recommended, as they will promote continuous professional development.

Assessment and Feedback of EEOS Education and Training Programs: A training, assessment, feedback, and update cycle of EEOS training programs is proposed, as seen in Fig. 9. Participants' competence in energy-efficient practices must be assessed in EEOS training programs, including IMO Training Initiatives (IMOEL and IMOTTT) and MET Institutional Training Programs (METIT, PSPST, and CSBT). IMO's web-based assessment system or maritime administrations of member states facilitate this assessment, evaluating knowledge, understanding, and performance (KUP). Successful candidates receive a Proficiency Certificate in EEOS. Maritime stakeholder feedback on energy-efficient practices during ship operations is critical to refining operational measures and implementation procedures, addressing complexities as they arise during ship operations. Training programs at MET institutions must be updated regularly to meet evolving industry demands. Feedback from seafarers serves as a guide. To ensure comprehensive knowledge transfer, shipping company in-house (IHT & CPTT) and onboard ship (OBT) trainers must complete IMOTTT courses as well as hold

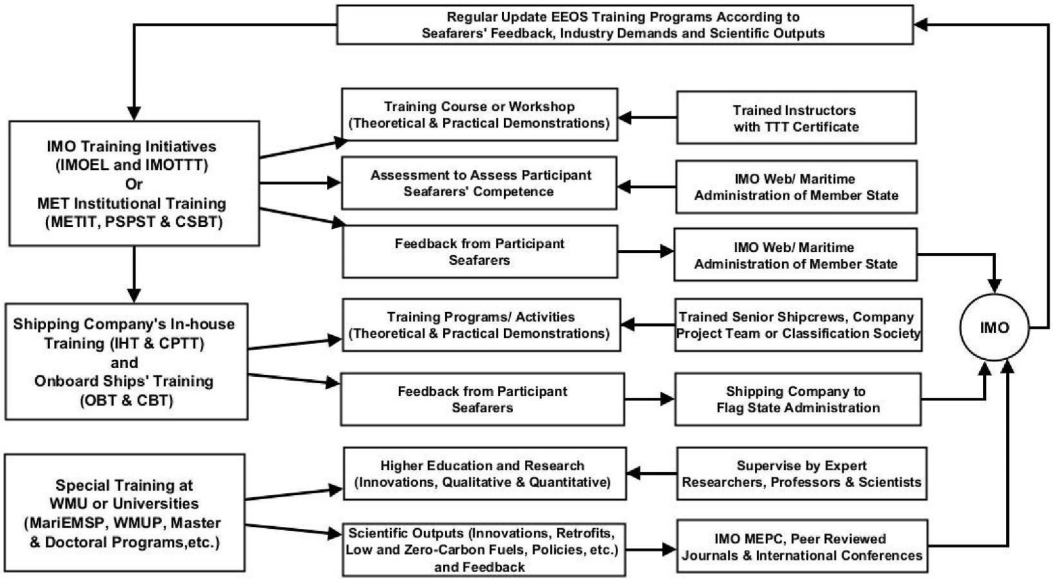

Fig. 9. Training, assessment, feedback, and update cycle of EEOS training programs.

Train-the-Trainer (TTT) certificates. Following each tenure, onboard officers and engineers, including masters and chief engineers, must provide feedback to shipping companies about challenges encountered, best practices for implementing SEEMP to meet the targeted goal, and suggestions for improving onboard training activities, which in turn helps the company to update onboard training activities periodically. Higher education and research in maritime energy management, whether at WMU or other universities, is crucial for fostering innovative technologies, low-carbon fuels, and efficiency measures. Conducting qualitative and quantitative surveys among industry stakeholders is vital for policy development. Regularly providing feedback to IMO MEPC, publishing articles in peer-reviewed journals, and engaging in international conferences are essential for progressing towards the net-zero emissions target by 2050. IMO must review all feedback, shipping industry demands, and scientific outputs to improve standards, create policies, and provide guidelines to update EEOS training programs regularly.

7. Conclusions

The maritime sector relies heavily on its workforce, particularly seafarers, who manage daily ship operations. Recent research emphasizes that employee engagement has a critical role in organizational effectiveness and is often linked with satisfaction, commitment, and involvement [131]. In preparation for the IMO's ambitious goal of achieving net-zero emissions by 2050, the maritime industry requires extensive education and training programs for enhancing seafarers' competence. The maritime industry needs competent seafarers equipped with proficiency in digitalization, information technology (IT), artificial intelligence (AI), and technical expertise to navigate the challenges of a decarbonized future. Digitalization makes operations more efficient and helps transition to alternative fuels to achieve 2050's net-zero emissions target. By 2050, DNV Maritime Forecast predicts that 1.8 million sailors will need decarbonization training [97]. This study highlights the importance of effective training programs for seafarers to enhance energy-efficient ship operations to achieve net-zero emissions targets by 2050. Almost half of seafarers have the necessary knowledge and proficiency in energy efficiency measures. IMO Training and Shipping Company Training were found to be effective programs for enhancing seafarers' knowledge and awareness of ship energy efficiency measures. A computer and simulator training program for energy-efficient ship operations proved more effective than onboard training by masters and chief engineers. However, Institutional Training and Specialized Training programs were found to be less effective in this regard.

A limitation of this study lies in the sample bias towards seafarers who predominantly engaged in energy-efficient ship operations training provided by shipping companies and the IMO E-Learning online course. While these avenues are widely accessed due to their convenience and endorsement by companies, the study received fewer responses from seafarers who attended EEOS courses conducted by maritime training institutes or specialized programs by institutions like the World Maritime University (WMU) or EU-funded MariEMS program. Additionally, self-assessment data from seafarers were used to determine their knowledge, understanding, and proficiency (KUP) regarding SEEMP implementation, which may be considered a limitation of this study. Another limitation is the small sample size used in this paper, which can influence the results, leading to some uncertainty.

The shipping industry has to undergo significant challenges in transitioning to net-zero emissions by adapting zero-carbon energy sources and innovations, necessitating comprehensive training for seafarers. Inadequate monitoring of seafarers' training and progress by IMO may slow down the process. Increasing energy efficiency requires both technological adoption and skilled seafarers. Meeting ambitious net-zero emission targets by 2050 requires proper training and assessment of seafarers. However, based on our study findings, a recommended effective training framework has been proposed for seafarers to enhance their competence to successfully implement SEEMP onboard ships. Future research should focus on a comprehensive assessment mechanism, evaluating the long-term impact of training programs on SEEMP implementation and energy efficiency performance onboard ships. Additionally, the development of more effective immersive and non-immersive simulators for training seafarers and ship managers should be explored. Furthermore, the effectiveness of alternative training methods, such as gamification and virtual reality, could also be investigated. Additionally, further research could explore the effectiveness of specialized training programs and institutional training courses for seafarers on SEEMP implementation. Considering the limitation of this study, further study is needed for broader participation to ensure a comprehensive understanding of seafarers' perspectives on energy-efficient ship operations training across various educational platforms. Finally, more studies could focus on the long-term effects of training programs and their impact on energy efficiency and emissions reduction in the shipping industry.

Data availability statement

The data and calculations presented in this study come from software directly. So, there is no other data available to share.

CRediT authorship contribution statement

Mohammud Hanif Dewan: Writing – review & editing, Writing – original draft, Validation, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Mohitul Ameen Ahmed Mustafi:** Writing – review & editing, Investigation. **Florinda Matos:** Writing – review & editing, Supervision, Project administration. **Radu Godina:** Writing – review & editing, Writing – original draft, Supervision, Project administration, Funding acquisition, Conceptualization.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:The corresponding author declares her interest as an Associate Editor for Heliyon.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.heliyon.2024.e36505.

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B

Survey Questionnaires

In Appendix B, we have included survey questionnaires that we utilized in our studies.

B.1 Survey Questionnaire 1

This survey questionnaire was utilized to achieve objectives RO1: To identify roles and challenges faced by seafarers as they implement operational energy efficiency measures in ships; and RO2: To investigate how seafarers embrace new work cultures associated with the energy-efficient operation of ships.

The survey questionnaire 1 has been attached to the next page.

Identifying Seafarers' Roles and Challenges for the Adoption of Energy Efficiency Operational Measures onboard Ships

Dear Seafarers,
We cordially invite you to participate in our PhD research survey, "Identifying Seafarers' Roles and Challenges for the Adoption of Energy Efficiency Operational Measures onboard Ships." Energy efficiency is paramount for modern ship operations, but its implementation affects seafarers directly. Many energy efficiency measures, such as SEEMP and CII, pose challenges to seafarers due to technical knowledge requirements, increased operational efforts, and additional documentation tasks, impacting their working culture. Your valuable response will help in understanding these challenges better, enabling us to formulate guidelines and suggestions for shipping companies, the IMO, and other regulatory bodies. Through your participation, we aim to foster a positive working environment for seafarers while ensuring effective implementation of energy efficiency measures onboard ships.

We deeply appreciate your unwavering commitment to advancing the maritime sector towards greater efficiency and environmental sustainability. Your data will be handled with the utmost confidentiality, stored securely, and used solely for research purposes.

Sincerely yours,

Mohammud Hanif Dewan
PhD Student ID # 61154
PhD Researcher, FCT NOVA, UNL - Portugal

Participants Profile:

* Indicates required question

1. Email *

____

2. Position on board Ship or shipping company *

Check all that apply.

- [ ] Ship Manager/ Tech. Super/ Marine Super
- [ ] Master
- [ ] C/O
- [ ] 2/O
- [ ] Chief Engineer
- [ ] 2/E
- [ ] 3/E
- [ ] Onboard Environmental Officer
- [ ] Onshore Environment Compliance Manager
- [ ] Experienced Master/Ch. Engr in Other Maritime Professions (left the sea after 2013)

3. Experience in Present Position *

Mark only one oval.

- ( ) Below 2 years
- ( ) 2 - 5 Years
- ( ) 5 - 10 years
- ( ) 10 - 15 Years
- ( ) 15 - 20 years
- ( ) More than 20 Years

4. Department *

Mark only one oval.

- ( ) Engine
- ( ) Deck
- ( ) Ship Operation (Superintendent / ship manager)

5. In Which Country is your shipping company Located? *

____

6. In which types of vessels are you working or managing? *

Check all that apply.

- [ ] Tanker (oil/Chemical/Crude)
- [ ] Bulk Carrier / General Cargo
- [ ] Car Carrier
- [ ] Container ship
- [ ] Passenger ship
- [ ] Gas Tanker
- [ ] Offshore Vessel/DP/AHT/Ro-Ro/Ferry/Others

Implementation of operational measures of SEEMP (Ship Energy Efficiency Management Plan) and CII (Carbon Intensity Indicator) for Energy Efficiency Improvement onboard ships

7. As an onboard seafarer or onshore manager, are you facing any challenges in implementation of SEEMP measures onboard ships? [1=yes. 2=no, 3] *

Mark only one oval.

- ( ) 1
- ( ) 2
- ( ) 3

8. If yes, please select from below options which challenges are applicable for you *

Check all that apply.

- [ ] Traditional work culture has been changed a lot
- [ ] Work-load has been increased
- [ ] Normal rest hours are hampered
- [ ] Increased technical difficulties
- [ ] Experiencing mental stress
- [ ] Increased paper works
- [ ] Need to work beyond normal working hours
- [ ] Experiencing additional inspection by the PSC or 3rd Party
- [ ] Attending at lots of training onboard ships or during vacation
- [ ] Increased planned maintenance works
- [ ] It is just an additional workload with my responsibilities as ashore Manager/Tech Super/Marine Super
- [ ] "No Comments" in case your answer is "No" in question no. 1
- [ ] Other: ______________________

9. Do you support to put an additional manpower such as "Environmental Officer" onboard your ship for implementation Energy Efficiency as well as environmental regulations imposed by the IMO or Other national/International regulatory bodies? *

Mark only one oval.

- ( ) Strongly Agree
- ( ) Agree
- ( ) Neutral
- ( ) Disagree
- ( ) Strongly disagree

10. Do you agree on the opinion that Energy Efficient Operation of Ships has changed the traditional normal working culture of Seafarers onboard ships in recent days? *

Mark only one oval.

- ( ) Strongly agree
- ( ) Agree
- ( ) Neutral
- ( ) Disgree
- ( ) Strongly disagree

11. In your opinion, what the changes of working cultures are you observed onboard ships: *

Check all that apply.

- [ ] Careful fuel consumption recording and Reporting
- [ ] Strict adherence to Planned Maintenance System (PMS)
- [ ] Ships always ready for PSC inspections
- [ ] Crew practices SEEMP energy-saving measures
- [ ] Well-maintained main and auxiliary engines
- [ ] Actions to save energy and fuels taken promptly
- [ ] Strictly maintaining of EE documents
- [ ] Optimized power usage and machinery operation
- [ ] Adherence to company/charterer instructions for just-in-time arrival
- [ ] Optimized voyage planning and weather routines
- [ ] Regular onboard SEEMP training by master/chief engineer
- [ ] Efficient lighting and fan usage
- [ ] Crews aware of EE and carbon emissions
- [ ] Implementation of slow steaming to save fuels
- [ ] Zero compromise on excess power consumption
- [ ] Other: ________________

12. To implement the SEEMP measures onboard ships, you are directly involved with which operational energy efficiency measures (select multiples if applicable) *

Check all that apply.

- [ ] Speed Optimization
- [ ] Voyage execution
- [ ] Weather routing
- [ ] Just-in-time Arrival
- [ ] Trim and Ballast Optimization
- [ ] Hull Efficiency Monitoring
- [ ] Propeller Efficiency Monitoring
- [ ] Main Engine Performance Monitoring
- [ ] Auxiliary Engine Performance Monitoring
- [ ] Waste Heat Recovery
- [ ] Ship's Power Optimization
- [ ] Retrofit/ Variable Frequency Drive for Pumps and Fans
- [ ] Port Operation Optimization
- [ ] Slow Steaming
- [ ] Awareness and Training of Ship Crews
- [ ] Other: ______________________

13. Can your ship as well as your company get financial benefits and contribute to the environment by improving energy efficiency and reducing fuel consumption? *

Mark only one oval.

- ( ) Yes
- ( ) No
- ( ) May be (No Idea)

14. If you have received any incentive or recognition or appreciation for effective implementation of SEEMP measures to meet the pre-set goal of your company, please select from below as appropriate *

Mark only one oval.

- Financial Incentive
- Annual Bonus
- Appreciation Certificate
- Formal Recognition/Gift/Trophy
- Nothing/No Appreciation/No Financial Benefits

15. Has the Shipping Company or Maritime Administration or IMO Representative ever asked your feedback or suggestions (as an onshore or onboard Personnel) for effective implementation of Energy Efficiency Measures onboard Ships? *

Mark only one oval.

- Yes
- No

16. Do you think that it is very important get your feedback or suggestions (as an onshore or onboard Personnel) for effective implementation of Energy Efficiency Measures onboard Ships? *

Mark only one oval.

- Yes
- No
- May be

17. As a well-experienced seafarer, do you have any suggestions for the effective implementation of Energy Efficiency Operational Measures onboard ships? Please specify

B.2 Survey Questionnaire 2

This survey questionnaire was utilized to achieve objective RO3: To evaluate the awareness and knowledge level of seafarers regarding energy-efficient and low-carbon shipping practices following a decade of IMO regulation enforcement.

The survey questionnaire 2 has been attached to the next page.

Seafarers' Current Level of Awareness and Knowledge on Maritime Energy Efficiency Regulations and Measures

Dear Seafarers,
We invite you to participate in our study on *"Seafarers' Current Level of Awareness and Knowledge on Maritime Energy Efficiency Regulations and Measures*." As key contributors to the maritime industry, your insights are crucial in understanding the impact of energy efficiency regulations and measures on seafarers. The International Maritime Organization (IMO) and other regulatory bodies have implemented initiatives to reduce carbon emissions and enhance energy efficiency, directly affecting your work and operations at sea. By participating in this survey, you will help identify knowledge gaps and areas where training can be improved, ultimately shaping sustainable practices and a greener future for the industry.

We extend our heartfelt appreciation for your unwavering commitment to advancing the maritime sector towards greater efficiency and environmental sustainability. In the context of our research, we kindly seek your consent to utilize your data. Please be assured that we will handle your valuable information with the utmost confidentiality, storing it securely and employing it solely as anonymized data in our study.

Sincerely yours.

Mohammud Hanif Dewan
PhD Student ID # 61154
PhD Researcher, FCT NOVA, UNL - Portugal.

* Indicates required question

1. Email *

____

2. **<u>A. Profile of the participants</u>** *
Gender

Mark only one oval.

- ( ) Male
- ( ) Female

3. ***Age*** *

Mark only one oval.

- ( ) Under 25
- ( ) 25-34
- ( ) 35-44
- ( ) 45-54
- ( ) 55 and above

4. ***Present Job Role or Rank onboard Ship or Company*** *

Mark only one oval.

- ( ) Cadet/Student
- ( ) Deck officer (3/O or 2/O)
- ( ) Engine officer (4/E or 3/E)
- ( ) Deck officer (Master or C/O)
- ( ) Engine officer (C/E or 2/E)
- ( ) Ship Manager
- ( ) Other: ____________________ (Open-ended)

5. ***Years of experience at sea or sea + Office*** *

Mark only one oval.

- 1 year
- 1-2 years
- 1-5 years
- 6-10 years
- 11-15 years
- More than 15 years

6. ***Types of vessels participants currently work or manage*** *

Mark only one oval.

- Container ships
- Oil/Chemical Tankers
- Gas Carrier
- Bulk carriers
- Passenger ships
- Offshore vessels
- MET Institute - Bangladesh

7. ***In which country, your company is located?*** *

____

B. Participant's Awareness and Knowledge on Maritime Energy Efficiency Regulation and Measures

8. *Your* **awareness of the effects of CO2 and GHG emissions on our planet. (1. Not aware, 2. Somewhat aware, 3. Moderately aware, 4. Very aware, 5. Extremely aware)** *

Mark only one oval.

	1	2	3	4	5
	◯	◯	◯	◯	◯

9. *Your* **knowledge of the effects of CO2 and GHG emissions on our world**. ***(1. Very limited knowledge, 2. Limited knowledge, 3. Moderate knowledge, 4. Good knowledge, 5. Excellent knowledge)*** *

Mark only one oval.

	1	2	3	4	5
	◯	◯	◯	◯	◯

10. **Your efforts to improve EE and LC shipping based on their level of technical knowledge.**
(1. Not at all, 2. Very little, 3. Moderately, 4. Quite a bit, 5. Extensively) *

Mark only one oval.

	1	2	3	4	5
	◯	◯	◯	◯	◯

11. ***How you acquire the knowledge regarding effects that CO2 and GHG emissions to our world or Global Warming, Climate Change etc.*** *

Check all that apply.

- [ ] TV News/ Documentaries
- [ ] Radio
- [ ] Social Media (Facebook, LinkedIn etc.)
- [ ] Newspapers/Magazines
- [ ] Books and Publications
- [ ] Discussions with the people/colleagues
- [ ] Educational Courses/Programs
- [ ] Maritime Training Course(s)
- [ ] Part of Pre-sea/Post Sea Syllabus
- [ ] Onboard Ship Training
- [ ] Other: ______________________

12. **Training received by you for awareness and knowledge in EE and LC Shipping Practices** *

Check all that apply.

- [ ] IMO Training Programs (E-Learning course on MEE, IMO workshop on MEE etc.)
- [ ] Institutional Training on EEOS (Energy-Efficient Operation of Ships-EEOS Course, Pre-sea & Post-sea Course)
- [ ] Shipping Company Training Activities (Onboard Training, CBT/Simulator, Inhouse Training)
- [ ] Specialized Training on EEOS and SEEMP (WMU Programs, EU's MariEMS Program)
- [ ] None
- [ ] Other: ______________ (Open-ended)

13. **Areas need the most improvement to enhance EE and LC ship operations according to your perception** *

Mark only one oval.

- Innovative technical measures
- Energy efficiency operational measures
- Regulatory frameworks and policy formulation
- Knowledge and training of ship crews and other stakeholders
- Other: _______________ (Open-ended)

14. **Your level of technical knowledge on EE and LC shipping.** ***(1. Very limited knowledge, 2. Limited knowledge, 3. Moderate knowledge, 4. Good knowledge, 5. Excellent knowledge)*** *

Mark only one oval.

1	2	3	4	5

15. **How important you believe it is possible to reduce carbon emissions from shipping.** ***(1. Not important 2. Somewhat important 3. Moderately important 4. Very important 5. Extremely important)*** *

Mark only one oval.

1	2	3	4	5

16. **How you believe it is possible to reduce carbon emissions from shipping.** ***(1. Not possible 2. Somewhat possible 3. Moderately possible 4. Very possible 5. Extremely possible)*** *

Mark only one oval.

	1	2	3	4	5	
	◯	◯	◯	◯	◯	

17. **How you believe it is possible for ship crews to reduce carbon emissions from ships.** ***(1. Not possible 2. Somewhat possible 3. Moderately possible 4. Very possible 5. Extremely possible)*** *

Mark only one oval.

	1	2	3	4	5	
	◯	◯	◯	◯	◯	

18. **Your interest in learning EE and LC ship operations.** ***(1. Not interested 2. Somewhat interested 3. Moderately interested 4. Very interested 5. Extremely interested)*** *

Mark only one oval.

	1	2	3	4	5	
	◯	◯	◯	◯	◯	

19. **How you believe incentives (financial rewards or recognition) can motivate ship crews for EE and LC ship operations. (1. Not at all 2. Very little 3. Moderately 4. Quite a bit 5. A significant amount)** *

Mark only one oval.

	1	2	3	4	5
	◯	◯	◯	◯	◯

B.3 Survey Questionnaire 3

This survey questionnaire was utilized to achieve objective RO5: To propose a strategic training framework for seafarers that would enhance their proficiency and effectiveness in executing energy-efficient ship operations.

The survey questionnaire 3 has been attached to the next page.

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To Identify Effective Training Programs for Seafarers on Energy-Efficient Operation of Ships (EEOS)

Dear Seafarers,

I hope this letter finds you well. I am currently pursuing my Ph.D. at FCT NOVA, UNL, Portugal, and I am conducting a research survey on identifying effective training programs for the Energy-Efficient Operation of Ships (EEOS). By attending this survey, you are giving me consent to use your response in my study research.

As you know, in the IMO's Standards of Training, Certification, and Watchkeeping for Seafarers (STCW) 2010, the knowledge, understanding, and proficiency requirements are three basic elements such as knowledge, understand and proficiency (KUP) that participants should gain from various STCW courses. Available EEOS Training Programs/Activities for Seafarers:

- Onboard Training (OBT) on EEOS by Technical managers or Master & Chief Engr
- Computer and Simulator-Based Training (CSBT) on EEOS Course
- Inhouse Training (IHT) on EEOS by Shipping Companies
- MET Institutes' Training (METIT) on EEOS
- IMO E-Learning Training (IMOEL) by GreenVoyage2050
- Classification Society and Project Team Training
- EEOS Training integrated with Pre-sea and Post-sea training (PSPST)
- WMU Program (WMUP) on Maritime Energy Management
- IMO or Administration's "Train the Trainer (TTT)" Workshop (IMOTTT)
- MariEMS Program, (MariEMSP) Funded by EU

This survey aims to evaluate the EEOS training programs' effectiveness and identify improvement areas. To achieve this, I kindly request your participation in my survey, which will take only 5-10 minutes of your time. The survey includes four questions that rate your knowledge, understanding, proficiency, and satisfaction with each EEOS course you have attended.

Your participation in this survey is essential to provide insight into the effectiveness of EEOS training programs. Your responses will be kept anonymous and confidential.

Thank you for your valuable feedback and time. If you have any questions or concerns, please do not hesitate to contact me on WhatsApp at # 351965459322.

Sincerely yours.

Mohammud Hanif Dewan
PhD Student ID # 61154
FCT NOVA, UNL, Portugal.

Part 1: Background Information of the Participant Seafarers

A. Where do you work?*
   - Deck Department
   - Engine Department
   - Ashore Office in Shipping Company
   - MET Institute
   - Other: ______________________________

B. In Which position you work at present?*
   - Master
   - Deck Officer (C/O, 2/O, 3/O)
   - Chief Engineer
   - Engineer (2/E, 3/E, 4/E)
   - Ship Manager (Tech. Super/Marine Super/Operation Manager)
   - MET Instructor/ Faculty Member
   - Other: _____________________________

C. In Which country, your company is located?

   Answer: _________________________________

Part 2: Participant's Knowledge, Understanding, Proficiency, and Satisfaction Gained from the EEOS Training Courses/Programs

1. Onboard Training (OBT) on EEOS by Technical managers or Master and Chief Engineer

It is standard practice for the master or chief engineer to train ship crews on EE operational measures and implementation procedures per the company's SEEMP guidelines.

Have you attended the "Onboard Training on EEOS by Technical managers or Master and Chief Engineer"?*

- o Yes
- o No

A. Level of knowledge about energy efficiency regulations, technical and operational measures that can be applied on board ships

Strongly disagree 1 2 3 4 5 Strongly agree

B. B. Level of understanding in implementing SEEMP (energy efficiency regulations, various technical and operational measures) onboard ships

Strongly disagree 1 2 3 4 5 Strongly agree

C. C. I am confident in my ability to apply energy efficiency regulations and implement operational measures onboard ships

Strongly disagree 1 2 3 4 5 Strongly agree

D. D. I am satisfied with the course content or learning activities, and outcomes in relation to energy-efficient operation of ships

Strongly disagree 1 2 3 4 5 Strongly agree

2. Computer-and Simulator-Based Training (CSBT) on EEOS Course

The computer-and Simulator-based training programs use animations or game-based e-learning tools and simulation technology where seafarers make choices in realistic situations. The course covers various scenarios that help seafarers gain practical knowledge and skills in reducing emissions and optimizing vessel performance.

Have you attended the "Computer-and Simulator-Based Training (CBT) on EEOS Course"?*

- Yes
- No

A. I gained new knowledge about energy efficiency regulations, technical and operational measures that can be applied on board ships

Strongly disagree 1 2 3 4 5 Strongly agree

B. I have achieved a good understanding of how to implement energy efficiency regulations, various technical and operational measures onboard ships

Strongly disagree 1 2 3 4 5 Strongly agree

C. I am confident in my ability to apply energy efficiency regulations and implement operational measures onboard ships

Strongly disagree 1 2 3 4 5 Strongly agree

D. I am satisfied with the course content or learning activities, and outcomes in relation to energy-efficient operation of ships

Strongly disagree 1 2 3 4 5 Strongly agree

3. Inhouse Training (IHT) on EEOS by Shipping Companies

During the pre-joining briefing, the shipping company provides masters and chief engineers some in-house training on SEEMP measures and how they can be implemented effectively on ships by technical managers ashore.

Have you attended in the "Inhouse Training on EEOS by Shipping Companies"?*

- Yes
- No

A. I gained new knowledge about energy efficiency regulations, technical and operational measures that can be applied on board ships

Strongly disagree 1 2 3 4 5 Strongly agree

B. I have achieved a good understanding of how to implement energy efficiency regulations, various technical and operational measures onboard ships

Strongly disagree   1   2   3   4   5   Strongly agree

C. I am confident in my ability to apply energy efficiency regulations and implement operational measures onboard ships

Strongly disagree   1   2   3   4   5   Strongly agree

D. I am satisfied with the course content or learning activities, and outcomes in relation to energy-efficient operation of ships

Strongly disagree   1   2   3   4   5   Strongly agree

4. MET Institutes or Training (METIT) Service Providers Course on EEOS

Together with World Maritime University (WMU), IMO has prepared the "Energy Efficient Operation of Ships (EEOS) - IMO Model Course No. 4.05" on the implementation of SEEMP measures to promote energy-efficient ship operation. It covers GHG emissions, climate change, and IMO regulations and activities. It integrates operational and technical components into a realistic training program to encourage energy-efficient shipping operations.

Have you attended in the "EEOS Course by MET Institutes or Consultancy Farms"?*

- Yes
- No

A. I gained new knowledge about energy efficiency regulations, technical and operational measures that can be applied on board ships

Strongly disagree   1   2   3   4   5   Strongly agree

B. I have achieved a good understanding of how to implement energy efficiency regulations, various technical and operational measures onboard ships

Strongly disagree 1 2 3 4 5 Strongly agree

C. I am confident in my ability to apply energy efficiency regulations and implement operational measures onboard ships

Strongly disagree 1 2 3 4 5 Strongly agree

D. I am satisfied with the course content or learning activities, and outcomes in relation to energy-efficient operation of ships

Strongly disagree 1 2 3 4 5 Strongly agree

5. IMO E-Learning (IMOEL) Online Course on EEOS by GreenVoyage2050

The EEOS E-Learning (Online) Course by the project "GreenVoyage2050" is a comprehensive training program designed to enhance seafarers' knowledge and skills in energy-efficient operation of ships. The course covers topics such as ship design, machinery and equipment, and operational procedures to optimize vessel performance and reduce emissions.

Have you attended in the "IMO E-Learning (IMOEL) Online EEOS Course by GreenVoyage2050"?*

- Yes
- No

A. I gained new knowledge about energy efficiency regulations, technical and operational measures that can be applied on board ships

Strongly disagree 1 2 3 4 5 Strongly agree

B. I have achieved a good understanding of how to implement energy efficiency regulations, various technical and operational measures onboard ships

Strongly disagree 1 2 3 4 5 Strongly agree

C. I am confident in my ability to apply energy efficiency regulations and implement operational measures onboard ships

Strongly disagree 1 2 3 4 5 Strongly agree

D. I am satisfied with the course content or learning activities, and outcomes in relation to energy-efficient operation of ships

Strongly disagree 1 2 3 4 5 Strongly agree

6. Classification Society or Company Project Team Training (CPTT) on EEOS

Classification Society, project team of the shipping company or retrofit providers/vendors offer specialized training to ship crews on the implementation of a particular EE method on board ships on occasion.

Have you attended in the "Classification Society or Company Project Team Training (CPTT)'' on EEOS? *

- Yes
- No

A. I gained new knowledge about energy efficiency regulations, technical and operational measures that can be applied on board ships

Strongly disagree 1 2 3 4 5 Strongly agree

B. I have achieved a good understanding of how to implement energy efficiency regulations, and various technical and operational measures onboard ships

Strongly disagree 1 2 3 4 5 Strongly agree

C. I am confident in my ability to apply energy efficiency regulations and implement operational measures onboard ships

Strongly disagree 1 2 3 4 5 Strongly agree

D. I am satisfied with the course content or learning activities, and outcomes in relation to energy-efficient operation of ships

Strongly disagree 1 2 3 4 5 Strongly agree

7. EEOS Training embedded with Pre-sea/Post-sea training (PSPST) Curriculum

The program aims to equip seafarers with knowledge and skills in energy-efficient ship operation from the beginning of their training. By integrating energy efficiency training into pre-sea/post-sea training, seafarers are prepared to adopt sustainable practices throughout their careers and contribute to reducing emissions from the shipping industry.

Have you attended in the EEOS Training embedded with the "Pre-sea/Post-sea training (PSPST) Curriculum"?*

- Yes
- No

A. I gained new knowledge about energy efficiency regulations, technical and operational measures that can be applied on board ships

Strongly disagree 1 2 3 4 5 Strongly agree

B. I have achieved a good understanding of how to implement energy efficiency regulations, various technical and operational measures onboard ships

Strongly disagree 1 2 3 4 5 Strongly agree

C. I am confident in my ability to apply energy efficiency regulations and implement operational measures onboard ships

Strongly disagree 1 2 3 4 5 Strongly agree

D. I am satisfied with the course content or learning activities, and outcomes in relation to energy-efficient operation of ships

Strongly disagree 1 2 3 4 5 Strongly agree

8. Maritime Energy Management Masters' Program at WMU (WMUP)

A specialized course designed to provide advanced knowledge and skills in energy management for the maritime industry. The program covers topics such as energy efficiency, renewable energy, and emission reduction strategies, preparing graduates for leadership roles in sustainable maritime operations. The curriculum is based on international standards and focuses on practical solutions to real-world challenges in the maritime industry.

Have you attended in the "Maritime Energy Management Masters' Program at WMU (WMUP)"?*

- Yes
- No

A. I gained new knowledge about energy efficiency regulations, technical and operational measures that can be applied on board ships

Strongly disagree 1 2 3 4 5 Strongly agree

B. I have achieved a good understanding of how to implement energy efficiency regulations, and various technical and operational measures onboard ships

Strongly disagree 1 2 3 4 5 Strongly agree

C. I am confident in my ability to apply energy efficiency regulations and implement operational measures onboard ships

Strongly disagree 1 2 3 4 5 Strongly agree

D. I am satisfied with the course content or learning activities, and outcomes in relation to energy-efficient operation of ships

Strongly disagree 1 2 3 4 5 Strongly agree

9. “IMO or Administration's Train the Trainer (IMOTTT)" Workshop on EEOS

IMO's Train the Trainer Course on "Energy Efficient Ship Operation" arranged by party country administrators helps training providers improve their energy efficiency training courses. It promotes seafarers' awareness and knowledge of MARPOL Annex VI, Chapter 4 regulations, and best practices for energy-efficient ship operation. The goal is to reduce GHG emissions from the shipping industry.

Have you attended in the “IMO or Administration's Train the Trainer (IMOTTT)" Workshop on EEOS?*

- Yes
- No

A. I gained new knowledge about energy efficiency regulations, technical and operational measures that can be applied on board ships

Strongly disagree 1 2 3 4 5 Strongly agree

B. I have achieved a good understanding of how to implement energy efficiency regulations, and various technical and operational measures onboard ships.

Strongly disagree 1 2 3 4 5 Strongly agree

C. I am confident in my ability to apply energy efficiency regulations and implement operational measures onboard ships.

Strongly disagree 1 2 3 4 5 Strongly agree

D. I am satisfied with the course content or learning activities, and outcomes in relation to energy-efficient operation of ships.

Strongly disagree 1 2 3 4 5 Strongly agree

10. MeriEMS Program (MeriEMSP) of EU

The Ship Energy Management Team (SEMT) was developed under the MeriEMS project, which received funding from the European Union (EU). The SEMT is a group of individuals responsible for monitoring and improving a ship's energy performance. Its goal is to promote energy-efficient operation and reduce emissions from the shipping industry, in line with EU environmental regulations.

Have you attended in "MeriEMS Program (MeriEMSP) of EU"?*

- Yes
- No

A. I gained new knowledge about energy efficiency regulations, technical and operational measures that can be applied on board ships.

Strongly disagree 1 2 3 4 5 Strongly agree

B. I have achieved a good understanding of how to implement energy efficiency regulations, and various technical and operational measures onboard ships.

Strongly disagree 1 2 3 4 5 Strongly agree

C. I am confident in my ability to apply energy efficiency regulations and implement operational measures onboard ships.

Strongly disagree 1 2 3 4 5 Strongly agree

D. I am satisfied with the course content or learning activities and outcomes in relation to the energy-efficient operation of ships.

Strongly disagree 1 2 3 4 5 Strongly agree

Part 3: Participants' knowledge, understanding, and proficiency in implementing SEEMP Onboard Ships

1. Implementation of Shipboard Energy Efficiency Management Plan (SEEMP) regulations and measures onboard ships

A. I have clear knowledge of SEEMP regulations and various technical and operational measures*

Strongly disagree 1 2 3 4 5 Strongly agree

B. I have a good understanding of SEEMP regulations and implementation procedures of various technical and operational measures *

Strongly disagree 1 2 3 4 5 Strongly agree

C. I am confident in my ability to apply the SEEMP regulations and operational measures onboard ships*

Strongly disagree 1 2 3 4 5 Strongly agree

Part 4: Feedback from the Participant Seafarer

1. For effective implementation of SEEMP onboard ships, what is more important do you think as a seafarer?

   Answer:
   ……………………………………………………………………………………………
   ……………………………………………………………………………………………
   ……………………………………………………………………………………………
   ……………………………………………………………………………………………
   …………………………………………………………………………………………

2024

MOAMMUD HANIF DEWAN

EXPLORING THE ENGAGEMENT, KNOWLEDGE AND EFFECTIVE TRAINING OF SEAFARERS IN ENERGY-EFFICIENT SHIP OPERATIONS

UNIVERSIDADE NOVA DE LISBOA