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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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A B S T R A C T

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.

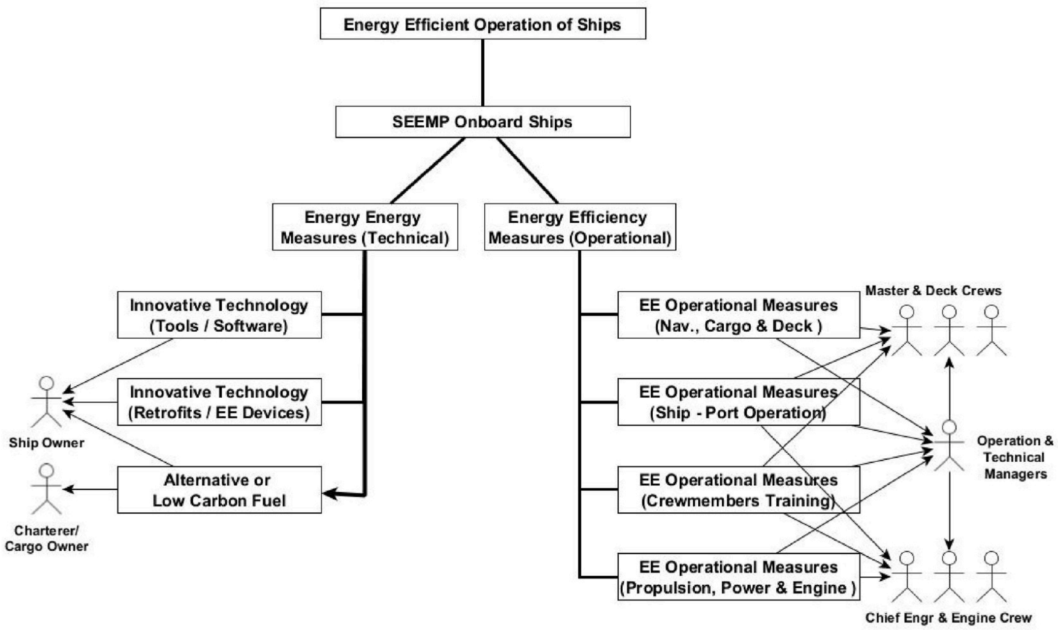

Fig. 1. Engagement map of shipowners, ship managers, and crewmembers on energy efficiency operations (Source: [65]).

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.

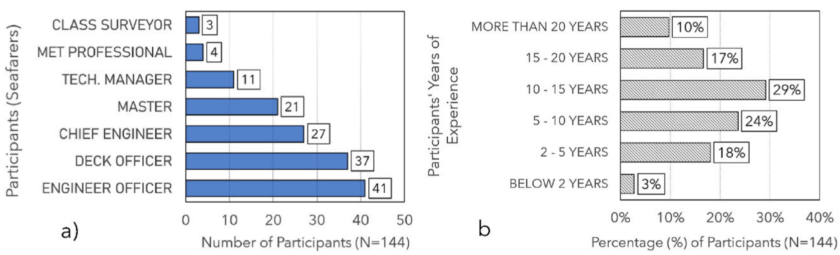

Fig. 2. (a): Number of Participants According to their Position in Shipping Companies; 2(b): Percentage (%) of Participants According to Years of Experience.

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.

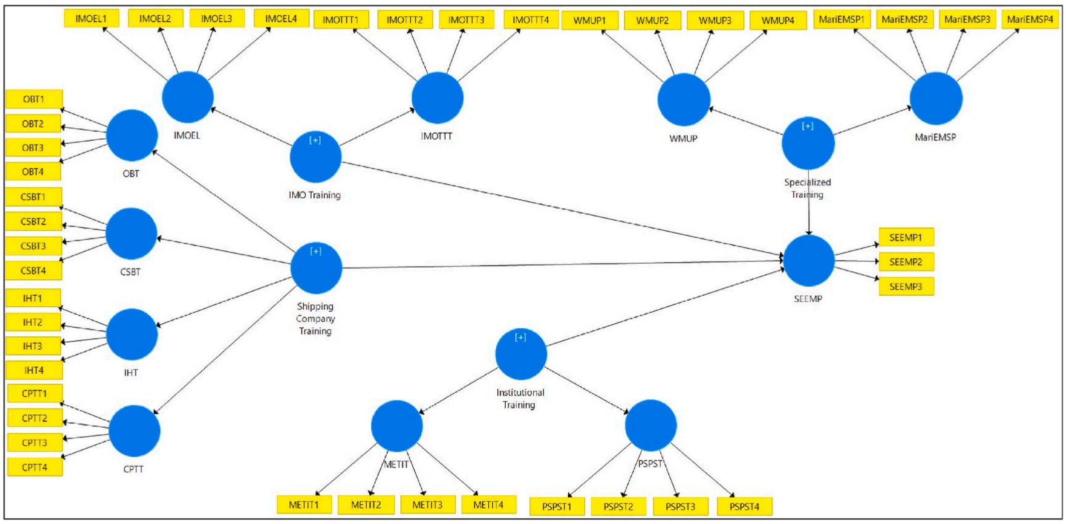

Fig. 3. Conceptual model (Source: SmartPLS 3.2.9).

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

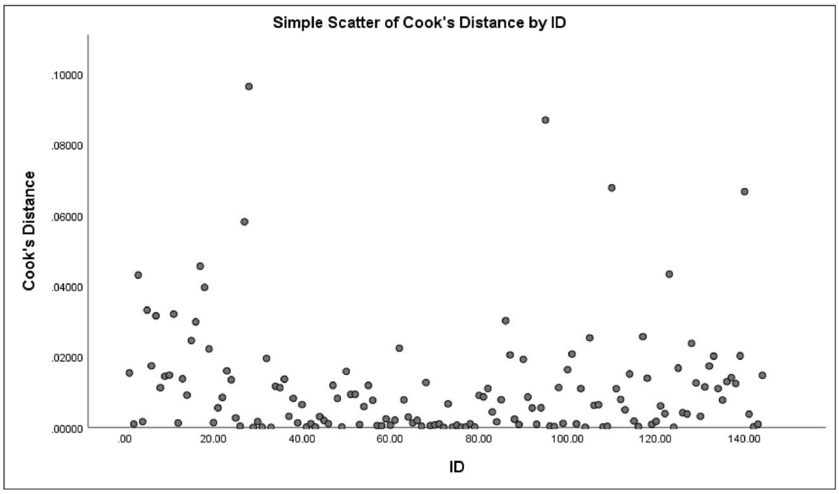

Fig. 4. Multivariate normality (Source: SPSS 26).

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

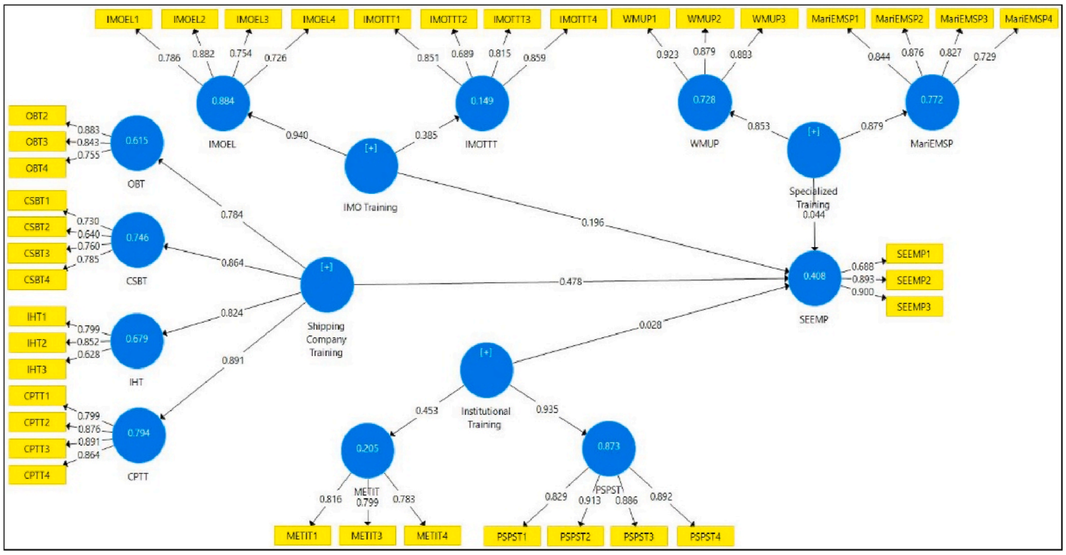

Fig. 5. Path model (Source: SmartPLS 3.2.9).

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.

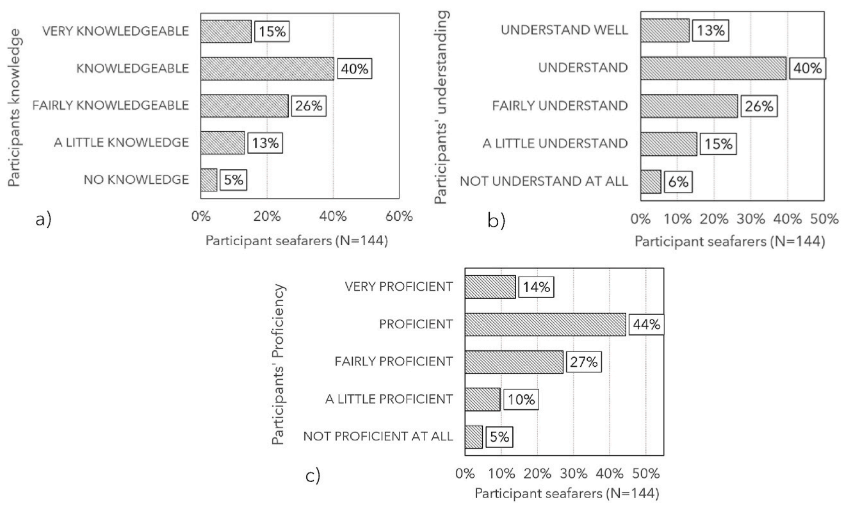

Fig. 6. (a): Participants' knowledge; 6(b): Participants' understanding, and 6(c): Participants' proficiency in implementing SEEMP onboard ships.

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

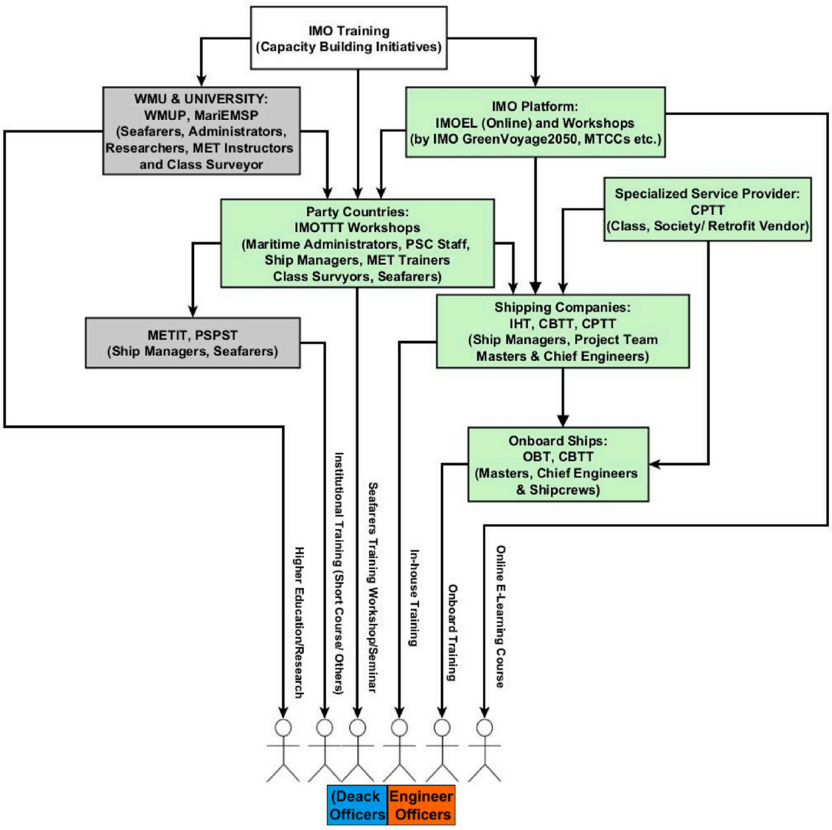

Fig. 7. Mapping of maritime energy efficiency training programs and activities for Stakeholders (Source: adapted from Ref. [65]).

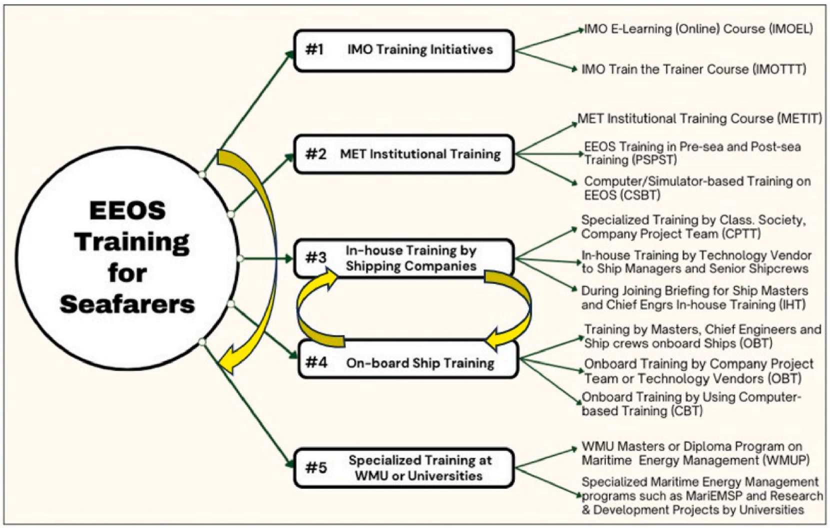

Fig. 8. A strategic training framework for seafarers and trainers in energy-efficient ship operations.

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

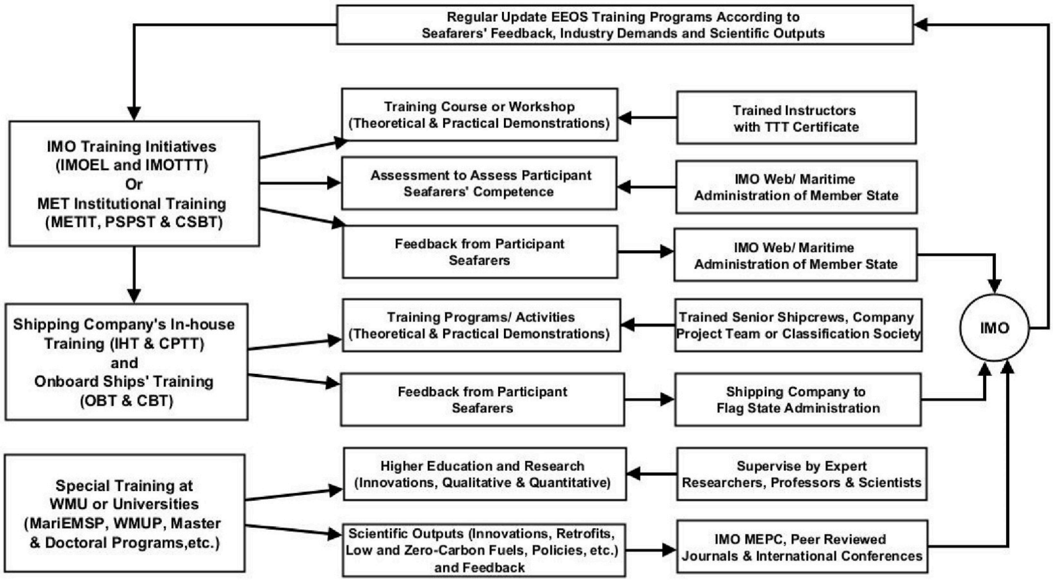

Fig. 9. Training, assessment, feedback, and update cycle of EEOS training programs.

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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