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Environmental solutions for maritime ships: challenges and needs

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Abstract

The manuscript focuses on the subject of environmental solutions for maritime ships. With the increasing volume of cargo transported by sea, it is crucial to minimise its environmental impact. The International Maritime Organization (IMO) has introduced new regulations in recent years to limit environmental damage. IMO's initial strategy for reducing GHG emissions from ships aims to reduce GHG emissions from vessels by 50% by 2050 and CO_2 emissions by 70% compared to 2008 (Resolution MEPC.304 (72), 2018). This has prompted ship owners to seek solutions to reduce fossil fuel consumption. The study aims to determine the feasibility of using eco-friendly solutions in maritime shipping to meet the challenges and needs of sustainable maritime fleet. Own contribution includes expert findings, which evaluate individual solutions and their potential uses in global maritime fleet. The publication also highlights the current usage of eco-friendly solutions on ships as well as crew and ship owner attitudes towards their future use and presents conceptual solutions. It should be noted that the subject-matter addressed in this paper is topical and very important in view of the limitations being introduced in respect of environmental standards.

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1. Introduction

The growth rate of cargo transported by sea observed globally in the recent years results in a parallel increase of environmental hazards. According to estimates, maritime shipping contributes 13.5% to the total GHG emissions from transport in the European Union. In 2019, for ships above 5,000 GT (gross tonnage) operating in the EU region, SO_2 emissions amounted to 1.63 million tonnes, or approx. 18% of the global sulphur dioxide emissions from international shipping, whereas CO_2 emissions in 2018 totalled 140 million tonnes. It should be noted that approx. 40% of harmful emissions were generated by vessels operating between EU ports, and the remaining 60% were produced during voyages into and out of Community ports. The ever-increasing ship traffic, and especially container ships, which produce around one-third of EU fleet's total CO_2 emissions (European Maritime Transport…, 2021), pose a broad range of environmental hazards, also at seaports. It is appropriate to note that seaports are an active link of logistics chains meant to integrate different activities and to provide effective end-to-end services to ships as well as other transport modes. Contemporary marine vessels fitted with state-of-the-art technologies are still imperfect and unreliable, posing a direct threat to water ecosystems (Deja et al., 2021a). Scrubbers are a popular environmental system which is now fitted in 20% of the global fleet, while 25% of all vessels can be termed 'eco modern' (Enabling global trade…, 2021).

2. Research background

In recent years, the IMO imposed a number of restrictions to reduce the harmful emissions from maritime transport. Since 2015, sulphur dioxide emission limits have been in place for the North Sea and Baltic Sea areas, which have effectively reduced concentrations by up to 60 percent (European Maritime Transport…, 2021). SO_x emission limits of 0.10% m/m were imposed in the sulphur emission control area (SECA)

(Prevention of Air Pollution…; Wymagania IMO dotyczące… 2018). Since 2021, ships operating in this area are required to apply certain measures to prevent, reduce and control air pollution, also with respect to NO_x pollution (Resolution MEPC.328(76), 2021).

Along with the development of the maritime transport sector (in early 2022, the global merchant fleet totalled 102,899 vessels) (Review of maritime… 2022) and newly implemented international regulations, the need to minimise the adverse environmental impact of ships has increased, in particular with respect to reducing emissions of harmful substances to air. The ships built (or rebuilt) today must be designed in consideration of EEDI (Energy Efficiency Design Index). This parameter relates fuel consumption to emissions of harmful substances and CO_2 into the atmosphere (Przepisy Nadzoru Konwencyjnego…, 2022).

Pursuant to the current international legislation on monitoring of emissions of harmful substances, operating ships are required to submit SEEMPs (Ship Energy Efficiency Management Plans). This measure is aimed at improving the energy efficiency of ships and reducing marine fuel consumption. Operating parameters of vessels in this respect are monitored using the EEOI (Energy Efficiency Operational Indicator) (Wysocki 2017, Resolution MEPC.1/Circ.684 17, 2009).

According to EU guidance, ships should be designed and built with three main considerations in mind: reducing adverse environmental impact, improving the economic efficiency of ship operation (*inter alia* by reducing the use of fossil fuels) and enhancing the safety level of vessels (Przepisy Nadzoru Konwencyjnego …, 2022).

Common solutions used in seagoing vessels that meet the aforesaid environmental requirements include the LNG (Liquefied Natural Gas) propulsion. LNG is gaining ground in transport and has a global share of around 25% (Łęgosz et al.). The availability of this fuel on the Polish market has increased following the opening of the regasification terminal in Świnoujście for unloading of LNG in liquid phase (Deja et al., 2021b). LNG achieves a reduction of GHG emissions by 9% to 15% compared to low-sulphur fuels (i.e., marine gas oil, MGO) (Lindstad, 2020; European Maritime Transport…, 2021). Depending on the technical parameters of the main engine, LNG is capable of reducing NOx emissions by 85% to 90%, almost completely eliminating SOx and particulate matter (PM) emissions as compared to fuels containing up to 1% sulphur (Det Norske Veritas 2010; Pawlak 2013). This technology has been successfully used in gas tankers, i.e., ships designed to carry LNG, for years (Maruszczak et al., 2016). Interest in LNG as an alternative vessel fuel is due to a number of reasons, such as technical considerations (since it can be combusted in marine boilers, gas turbines and dual- or tri-fuel engines) (Herdzik, 2013). TT-Line is a ferry operator providing services in the area of the Baltic Sea which has recently focused on green ships. Their 230-metre long, LNG-fuelled vessels are capable of carrying up to 800 passengers and 200 freight units (Nasze nowe Zielone …). Scrubbers are another popular solution with shipping companies operating in emission control areas (ECAs). The installation is connected with the main engine system, and it controls SO_x and NO_x emissions. Its key role is to reduce SO_x, while the reduction of NO_x is insignificant, which rules out comparisons against LNG systems (Panasiuk et al. 2015)

Rotor sails are an environmental technology that has been gaining foothold in the recent years. These devices were used in their original form almost 100 years ago on the rotor ship Buckau (length: 52 metres, capacity: 455 GRT). Their function is to support the main propulsion of a seagoing vessel. The core part of the rotor sail is made of cylindrical structures that rotate on the deck during navigation. When the ship is on a favourable course, the installation harnesses wind and optimises the performance of the main engine (Szymonowicz, 2022a.; Szymonowicz et al., 2022b). With its continued monitoring of wind speeds, it reduces fuel consumption by 5% to 20% (Kuuskoski, 2017). The eSAIL solution employs a similar technology that is based on a structure resembling an oblong elliptical cylinder, sucking in part of the airflow around it (Rigid sails…). According to estimates, the use of solutions such as Wind Propulsion (WP) & Wind Assist Shipping Projects (WASP) in global fleet by 2030 should reduce the total CO_2 emissions from maritime transport to 3.5-7.5 million tonnes (CE Delft, 2016). Wind power technologies retrofitted onto already operated ships can generate fuel savings of 5% to 25%, while in the case of new ships, the savings can be above 30% (European Maritime Transport…, 2021). A company named Wallenius Wilhelmsen has decided to invest in conceptual solutions that employ sails on seagoing vessels. Currently, they are implementing the Orcelle Wind project, which involves building a Ro-Ro ship with a capacity to carry 7,000 cars (scheduled for launch in 2026). The vessel will be 220 m long and 40 m wide. In accordance with the technical assumptions, the innovative solution is expected to reduce emissions of harmful substances by as much as 90% compared to currently used propulsion systems (Orcelle Wind – introducing…, 2021; Szymonowicz et al., 2022b).

Air Lubrication System is another environmental system that helps optimise the environmental parameters of a travelling ship. In technical terms, the purpose of the system is to maintain a layer of air bubbles under the bottom of the ship, with a direct effect of optimising the hydrodynamic performance of the vessel during navigation. This technology improves the ship's Energy Efficiency Design Index (EEDI) (Giernalczyk et al., 2021).

The climate change observed in the recent years and depleting fossil fuel resources translate into an immediate need to look for solutions that will relieve us of these energy sources. Therefore, it is crucial that we look for propulsion methods with an appropriate energy efficiency, minimising the emission levels of harmful substances (Davydenko et al., 2022). Electric propulsion is the single best choice among the presented solutions, as far as reduction of harmful emissions into the environment is concerned. It enables a complete elimination of harmful emissions and has been used in global fleet for a long time. In larger vessels, it has an auxiliary function (for instance, it can be used for operational activities in ports). Its biggest constraint is the travel range. The solution is popular in Scandinavia and is used mostly in ferry shipping. The Stena Line shipping company is currently developing its fleet in this respect. They own several hybrid ships, but they intend to fit their ferries with all-electric motors (Szymonowicz et al., 2022b; Stena Elektra – from …, ABB rozszerza …).

3. Methodology

The study aims to determine the feasibility of using eco-friendly solutions in maritime shipping to meet the challenges and needs of sustainable maritime fleet. This paper is a continuation of research on environmental solutions minimising harmful emissions used in seagoing vessels which was carried out for the purpose of the engineering thesis "Ocena wybranych technicznych rozwiązań na statkach morskich w kontekście zrównoważonego rozwoju transportu" (Evaluation of selected technical solutions on seagoing vessels in the context of sustainable transport development) (Szymonowicz, 2022a) and the publication "Ocena wybranych technicznych rozwiązań na statkach morskich w kontekście ochrony klimatu" (Evaluation of selected technical solutions on seagoing vessels in the context of climate protection) (Szymonowicz et al., 2022b). The research is being conducted in order to assess the proposed environmental solutions in maritime shipping to meet the challenges and needs of sustainable maritime fleet, with a particular focus on the Baltic Sea region. The research findings presented herein made it possible to evaluate the understanding of innovative technologies used on ships among marine industry employees. The subject matter addressed in this paper is topical and very important in view of environmental constraints concerning the reduction of harmful emissions imposed by the IMO on seagoing vessels until 2050.

Figure 1 presents the successive steps of the research carried out to achieve the main objective of the study.

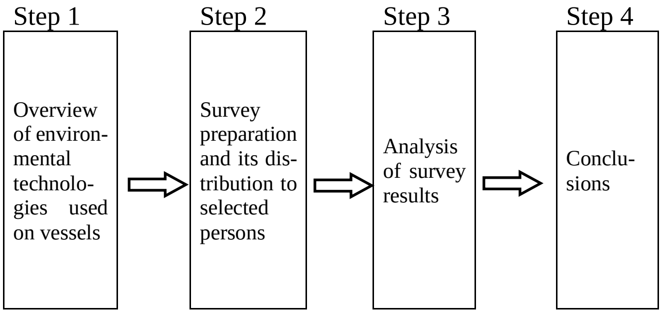

Fig. 1. Research framework

The first step involved, inter alia, an overview of environmental technologies used on vessels. Based on the research background, expert opinions and the most recent trends in the marine industry, individual environmental systems were selected, described, and evaluated. The overview of environmental solutions was carried out relying on a range of sources, such as manufacturer websites, publications of classification societies, and IMO guidelines.

In the third step, the survey results were analysed (Table 1). Finally, conclusions were presented.

Table 1. Survey results

Question	Answers [%]		
1. How long have you been working in the maritime sector?	< 5 years	6 to 10 years	> 10 years
	25	14	38
2. In which maritime subsector do you work?	Vessels	Maritime companies	Universities
	52	15	10
3. How would you describe your understanding of environmental technologies used on seagoing vessels?	Good	Moderate	Poor
	30	40	7
4. Do you know (from the practical side) the environmental solutions presented in the survey? You can choose more than one answer.	Rotor Sail	WINGSAIL	eSail
	20	18	3
	Scrubber	Air Lubrication System	LNG propulsion
	41	12	55
	Electric propulsion	None of the above	
	55	8	
5. According to you, which of these environmental technologies stand a chance of being widely adopted in the future?	Rotor Sail	WINGSAIL	eSail
	12	12	7
	Scrubber	Air Lubrication System	LNG propulsion
	19	7	48
	Electric propulsion	None of the above	I don't know any
	33	5	6
6. Does the company you work for make or intend to make a practical use of these environmental solutions on its ships?	Yes	No	Don't know
	59	10	8
7. Do you believe that the currently proposed environmental technologies for seagoing vessels will prove successful and their future use will significantly contribute to the reduction of emissions of sulphur oxides, nitrogen oxides and carbon dioxide into the atmosphere?	Yes	No	Don't know
	59	10	8
8. Do you believe that introduction of environmental technologies on ships could pose a threat to:	Yes	No	Don't know
Environment	18.7	62.7	18.7
Ship crew	29.7	57.7	12.5
Ship structure	27.4	50	12.5
9. Do you believe that introduction of environmental technologies on ships could result in economic benefits for shipping companies?	Yes	No	Don't know
	43	27	7
10. Does your current employer intend to provide (or have they already provided) staff training on the implementation of environmental technologies in seagoing vessels?	Yes	No	Don't know
	12	37	28

4. Evaluation of selected environmental solutions in seagoing vessels in the context of sustainable development

Table 2 presents a brief characterisation of selected environmental solutions (Appendix A)

5. Results

In August and September 2022, an anonymous survey was sent directly to over a hundred maritime sector employees, mostly to international seagoing vessel crews. The form was also published on industry social media sites. The focus of the survey was mostly on acquiring opinion from practitioners on environmental technologies for seagoing vessel. Most respondents were direct ship crew members (68%), followed by maritime company employees (19%), and representatives of maritime universities (13%). It should be noted that the students participating in the study were in the middle of maritime apprenticeships or had just completed them.

Table 2 presents the results of the survey, which obtained opinions on innovative solutions used on seagoing vessels. The first question was about professional experience in the maritime sector. The largest group of respondents were persons with 10+ years of experience (49%), followed by those with less than 5 years of experience (32%) and 6 to 10 years of experience (18%). The purpose of the next question was to verify the respondents' understanding of the environmental solutions which are used on seagoing vessels today. More than half of the respondents (52%) stated they had a moderate level of knowledge, 39% said they had a good understanding of the subject-matter, and 9% had little knowledge in this field. Subsequently, the respondents directly addressed the specific technologies presented in the survey, as they were asked about the practical knowledge of these solutions. Based on the answers, the best known environmental solutions are the electric propulsion (55%) and LNG propulsion (55%), followed by Scrubbers (41%), Rotor Sail (20%), Wingsail (18%), Air Lubrication System (12%), and eSAIL (3%). 8% of the respondents did not have any practical knowledge of the technologies concerned.

The respondent's answers to the next question, concerning the possibilities of future use and development of each solution, were directly associated with their understanding of the technologies. According to them, the greatest potential for large-scale use in global fleet lies in the LNG propulsion (48%) and electric propulsion (33%), followed by Scrubbers (19%), Rotor Sail (12%), Wingsail (12%), and eSAIL (7%).

The respondents were also asked for their opinion on the potential hazards to the marine environment, ship crews, and ship structure posed by the technologies.

a) Most respondents (62.7%) stated that they did not perceive the innovative solutions as a hazard to the marine environment, while 18.7% of them saw them as a hazard or did not know how to answer this question.
b) In terms of ship crew safety, more than half of the respondents (57.8%) did not perceive any issues in this respect, 29.7% saw a threat, and 12.5% could not formulate any opinion.
c) Half of the respondents do not perceive any potential hazards to ship structure, 27.4% see them as an issue, and 22.6% did not choose any specific answer.

More than half of the respondents (59%) stated that environmental technologies would significantly contribute to the reduction of harmful emissions of sulphur oxides, nitrogen oxides and carbon dioxide into the atmosphere. Only 10% answered the opposite, and 8% were unable to give any specific answer.

The next survey question focused on economic considerations. Almost half of the respondents (43%) stated that a large-scale introduction of environmental technologies in marine fleet would result in economic benefits for shipping companies, 27% were of the opposite opinion, and 7% could not answer this question.

The purpose of the next group of questions was to gather views on the environmental solutions in the context of the current employer.

a) The first question addressed the use and practical implementation of environmental solutions on ships owned by the shipping companies employing the respondents. Based on the answers, most respondents (36%) work or have worked for a shipping company which implements environmental solutions on ships, 21% of survey participants are not employed by any such company, and the others (19%) were unable to tell whether the shipping company they worked for intended to introduce environmental technologies on its ships.
b) In the second question in this part, respondents were asked whether the company they worked for planned to provide staff training on environmental technologies for ships currently or in the near future. Most respondents (37%) stated that their employer did not intend to provide such training, 12% confirmed that this was the case, while 28% did not know whether such training was planned.

6. Conclusion

Maritime shipping is a vital part of global trade, transporting more than 80% of goods by volume. Despite its importance, the shipping industry also contributes to a significant amount of pollution, particularly in the form of air emissions, oil spills, and waste discharge. In recent years, the need to reduce the environmental impact of shipping has become a topical issue, with the maritime sector facing increasing regulatory pressure to adopt environmentally sustainable practices. One of the main challenges faced by the shipping industry is reducing air emissions. Shipping is a significant source of air pollutants, including greenhouse gases (GHGs), nitrogen oxides (NO_x), and sulphur oxides (SO_x). These emissions contribute to air pollution, which has a detrimental effect on human health and drives climate change. To tackle this problem, the International Maritime Organization (IMO) has set targets to reduce GHG emissions from ships, including reduction in sulphur content of bunker fuel and implementation of energy efficiency measures. In conclusion, the shipping industry faces numerous environmental challenges, including reducing air emissions, minimising the risk of oil spills, and improving waste management practices. To address these challenges, the industry needs to invest in new technologies and implement effective regulatory measures. The transition to a more sustainable shipping industry will require cooperation between ship owners, governments, and the wider maritime community. With the right investment and commitment, the shipping industry can become more environmentally sustainable, reducing its impact on the planet and ensuring a healthy future for the planet and its inhabitants.

The introduction of stringent international regulations on emissions of harmful substances enhances the need to modernise fleet operating in certain regions of the world. It should be noted that proper ship operation supported by efficient and environmentally-friendly technologies results in a reduction of the ship's energy requirements. It is clear that there is a need for the widespread adoption of ecological solutions on seagoing ships to reduce their impact on the environment. The use of technologies such as electric and LNG propulsion, rotor sail, Wingsail, air lubrication systems, scrubbers and eSails are among the most promising in this regard. However, their use is limited due to insufficient knowledge and experience, the need for specialised training courses, and the lack of investment in new technologies. Nevertheless, with the increasing environmental awareness and stricter regulations, the future should see an increased adoption of these solutions on seagoing ships, providing a more sustainable and eco-friendly way of transporting goods across the world's oceans.

On the basis of the study, it has been concluded that:

- The environmental technologies best known to the respondents are electric propulsion (71%) and LNG propulsion (71%), while the least known one is eSail (3%).
- Persons with more than 10 years of industry experience demonstrate the best knowledge of environmental solutions on seagoing vessels.
- The respondents are aware that the introduction of innovative technologies on seagoing vessels results in the reduction of harmful emissions and that these technologies are particularly relevant for ships navigating in special areas.
- The answers provided show that currently few shipping companies (16%) intend to provide specialist staff training on environmental solutions used on their ships.
- According to 47% of the respondents, their current employers intend to deploy environmental solutions on their ships in the coming years.

The research method is constrained by the number of survey participants, but it should be noted that the study has a pilot character. It should be stressed that some environmental systems presented in this paper are still being introduced or retrofitted, so they can be used in global fleet on a wider scale in the future. Furthermore, there are many solutions on the global market today which are still in the conceptual stage, and as a result, their understanding by ship crews and maritime company employees participating in the survey could be limited.

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Appendix A

Table 2. Selected environmental solutions used on ships

No.	Name	Solution description	Environment impact (advantages and disadvantages)
1.	Rotor Sail	Supports the main propulsion of a seagoing vessel. Developed by Norsepower, relies on the Magnus effect (which involves the production of a force perpendicular to the direction of the airstream acting on a spinning body that rotates and moves in relation to a fluid). The core part is made of special cylindrical structures that rotate on the deck during navigation if an appropriate course is chosen relative to the wind direction.	<u>Advantages:</u> 1. Fuel savings: Rotor Sail can significantly reduce fuel consumption and emissions by harnessing wind energy to supplement the ship's engine. 2. Cost-effective: The installation and maintenance costs of a Rotor Sail are relatively low compared to other energy-saving technologies, making it an attractive option for ship owners. 3. Easy to operate: Rotor Sails are easy to install and operate, with no need for additional crew training or certification. 4. Environmentally friendly: By reducing the ship's fuel consumption (up to 20% reduction of fuel usage), Rotor Sails help to reduce greenhouse gas emissions and lower the environmental impact of shipping. <u>Disadvantages</u>: 1. Weather dependent: The effectiveness of Rotor Sail depends on wind conditions, and its efficiency may be reduced in calm or unfavourable weather conditions. 2. Limited availability: Rotor Sail technology is still in its early stages of development, and not all ships are equipped to use it. 3. Space requirements: Rotor Sails are large, and ships must have enough deck space to accommodate them. 4. Technical limitations: The performance of Rotor Sail depends on factors such as the ship's speed and wind direction, which can limit its effectiveness in certain situations.

2.	eSAIL	A solution developed by Bound4blue based on a structure resembling an oblong elliptical cylinder. eSAIL's working principle relies on sucking in a part of airflow around the sail which, in an appropriate configuration, re-adheres the airflow to its surface, generating up to seven times more lift than a conventional sail.	Advantages: 1. Improved fuel efficiency: eSAIL technology can improve fuel efficiency by up to 20% by reducing wind resistance. This leads to lower fuel consumption and emissions, which is beneficial for both the environment and the ship's operating costs. 2. Lower maintenance costs: eSAIL technology does not require complex maintenance and can be installed and maintained with ease. 3. Increased cargo capacity: With the reduced fuel consumption, ships can carry more cargo, which increases their earning potential. 4. They are relatively easy to operate (vessel crew training is sufficient). Disadvantages: 1. High initial cost: Installing eSAIL technology can be expensive for ship owners, which can be a barrier for its widespread adoption. 2. Limited to specific ship types: eSAIL technology is most effective on vessels that have a large surface area, such as cargo ships and ferries. It is less effective on smaller ships and ships with a different design. 3. Dependence on wind conditions: The effectiveness of eSAIL technology depends on the wind conditions, and it may not be effective in areas with low wind speeds.
3.	Wingsail	The sail was designed to work based on aerodynamics principles analogous to airplane wings. Technically, a low-pressure region is created on the leeward side of the sail, along with a high-pressure region on the windward side.	Advantages: 1. Increased efficiency: Wingsails can generate lift similar to an airplane wing, which can provide additional propulsion to the ship. This reduces fuel consumption and emissions, making the ship more environmentally friendly. 2. Flexibility: Wingsails can be adjusted in real-time to respond to changes in wind conditions, providing more control over the ship's speed and direction. 3. Reduced crew requirements: Wingsails can be automated, reducing the number of crew members required to operate the ship, making the ship more cost-effective to run. 5. They are relatively easy to operate (vessel crew training is sufficient). Disadvantages: 1. High cost: Installing Wingsails on a ship is an expensive process, requiring significant investment upfront. 2. Maintenance requirements: Wingsails require regular maintenance to ensure they are in good working order, which can be time-consuming and expensive. 3. Complexity: The technology behind Wingsails is complex, requiring a high level of technical expertise to operate and maintain the system. 4. Limited availability: Wingsails are not widely available and can be difficult to source, making them less accessible to many ship operators.
4.	Air Lubrication System	A system lubricating a ship's hull with compressed air is a technical solution maintaining a layer of air bubbles under the bottom of the ship. Its function relies on reducing hydrodynamic resistance during navigation, which lowers the requirement for main engine power, thus saving fuel. The proprietary system was designed by Silverstream Technologies. Despite these limitations, the ALS technology is an innovative solution for reducing emissions from maritime shipping and has the potential to play a significant role in addressing the environmental impact of this sector. As the shipping industry continues to grow and regulations become more stringent, the use of this technology is likely to become more widespread in the future.	Advantages: 1.Fuel efficiency: The ALS technology can reduce fuel consumption and emissions by up to 10%, leading to lower costs and reduced environmental impact. 2.Improved speed: The reduced friction between the hull and water can lead to an increase in speed, which is important for commercial shipping operations that rely on fast, reliable delivery times. 3.Easy to retrofit: The ALS technology is easy to retrofit onto existing ships, which makes it a cost-effective solution for reducing emissions from the existing fleet. Disadvantages: 1.High cost: The initial investment required to install the ALS technology can be significant, which may be a barrier for smaller shipping companies or older ships. 2.Maintenance: Regular maintenance is required to keep the system working properly, which can increase operating costs. 3.Weather dependence: The effectiveness of the ALS technology can be impacted by weather conditions, such as strong winds or rough seas, which can reduce its efficiency.

5.	Scrubber	The Scrubber (exhaust gas scrubber) is a special installation connected with the main engine system of a ship which controls SO_x and NO_x emissions arising in the process of marine fuel combustion. Currently, three types of wet scrubbers are used in seagoing vessels: closed-loop or open loop systems and hybrid systems.	Advantages: 1. Improved fuel efficiency: By reducing drag on the ship's hull, scrubbers can significantly improve fuel efficiency and reduce the ship's carbon footprint (NO_x and SO_x reduction). 2. Cost-effective: Scrubbers are relatively low-cost compared to other solutions such as hull optimisation or adding a wind-assisted propulsion system, making them accessible to smaller ships and operators. 3. Easy to Install: Scrubbers are relatively easy to install and can be retrofitted to existing ships, making them a fast and low-cost solution to improve fuel efficiency and reduce emissions.
5.	Scrubber	Despite their limitations, scrubbers represent a promising step towards improving the environmental impact of ships, and it is likely that this technology will continue to be developed and improved in the future.	Disadvantages: 1. Maintenance: Scrubbers require regular maintenance to keep them functioning properly, which can be an additional cost for ship operators. 2. The close loop uses fresh water mixed with caustic soda moreover it cannot be operated in restricted water outlet criteria. 3. Retrofitting into operating ships is difficult. The equipment requires sufficient space below deck. When installation is not planned in advance, this will be at the expense of cargo space.
6.	LNG propulsion	The composition of LNG fuel is very different from the parameters of heavy marine fuels, as it contains only slight amounts of heavy elements. Liquefied Natural Gas is a clear, colourless fuel with no toxic properties that does not promote corrosion, which is very important from the perspective of maritime transport.	Advantages: 1. Reduced emissions: LNG combustion releases lower levels of greenhouse gas emissions, i.e., 15-20% less carbon dioxide (CO_2,) around 100% less sulphur oxides (SO_x), and about 85-90% less nitrogen oxides (NO_x) compared to traditional fossil fuels. 2. Cleaner energy: LNG is a cleaner fuel than diesel and heavy fuel oil, reducing the environmental impact of shipping operations. 3. Increased energy efficiency: LNG is stored at a lower pressure than traditional fuels, meaning less energy is lost in the fuel storage and distribution process. 4. Improved engine performance: LNG provides a more consistent and stable fuel supply to engines, improving performance and reliability. Disadvantages: 1. High initial cost: LNG-powered ships are more expensive (10-15% more) to build and operate compared to conventional vessels, which can be a barrier for some ship owners. 2. Limited availability: LNG is not widely available as a fuel source, especially in remote or isolated regions, making it difficult for some ships to refuel. 3. Complex refuelling infrastructure: LNG requires a complex infrastructure, including specialized fuel storage and distribution systems, which can be difficult to install and maintain. 4. Cold energy loss: LNG requires refrigeration to maintain its low temperature, meaning that some energy is lost in the process, which can impact fuel efficiency.
7.	Electric propulsion	Mostly used as auxiliary propulsion (for auxiliary processes in ports). Currently used in ferry shipping, usually as a hybrid system. More and more ferry operators are contemplating the introduction of this propulsion system as the primary unit, due to its zero-emission performance. For environmental reasons, the need for electric propulsion on merchant ships is also on the rise. Another advantage offered by this solution is that it saves ship space and enables the use of surplus energy to operate auxiliary systems.	Advantages: 1. Fuel efficiency: Electric propulsion systems are more energy-efficient than traditional diesel engines and can reduce fuel consumption by up to 30%. This leads to lower operating costs and reduced greenhouse gas emissions. 2. Lower emissions: Electric propulsion systems do not emit harmful pollutants such as nitrogen oxides (NO_x), particulate matter, and sulphur oxides (SO_x). This makes them a more environmentally friendly option compared to traditional diesel engines. 3. Quieter operation: Electric propulsion systems are much quieter than traditional diesel engines, making them ideal for use in areas where noise pollution is a concern. 4. Flexibility: Electric propulsion systems can be easily scaled to meet the specific needs of a ship, and they can be used in a variety of applications, including cargo ships, cruise ships, and research vessels.

		5. Improved performance: Electric propulsion systems can provide improved performance in terms of speed, acceleration, and manoeuvrability compared to traditional diesel engines.
8.	Electric propulsion	Disadvantages: 1. High initial cost: Electric propulsion systems can be significantly more expensive to install and maintain compared to traditional diesel engines. 2. Limited range: Electric propulsion systems have a limited range compared to traditional diesel engines, which can make them less practical for long voyages. 3. Dependence on electrical supply: Electric propulsion systems require a reliable electrical supply, which may not be available in remote locations. 4. Limited battery technology: Currently available battery technology is limited in terms of energy density and power, which can limit the application of electric propulsion systems in larger ships. 5. Maintenance challenges: Electric propulsion systems can be complex and require specialised maintenance and support, which may not be available in all ports.

Source: Adapted from: (Szymonowicz et al., 2022b; www.norsepower.com; www.wartsila.com; www.bound4blue.com, www.wind-ship.org, www.stenaline.com Det Norske Veritas, 2010; Perational Vessels. 2022, Chłopińska et al. 2017, Pawlak 2013; Giernalczyk et al. 2021; Panasiuk et al., 2015; Understanding exhaust gas treatment systems 2012; Forkiewicz et al. 2018; Endres et al. 2018; Kuś P. 2015; Almqvist, 2021, Maliszewski, 2022, Nowicki, et al. 2016).

海运船舶的环境解决方案：挑战和需求

關鍵詞
海洋环境
环境技术
海洋运输
海洋可持续性

摘要
本文重点关注船舶环保解决方案。随着海上货物运输量的增加，最大限度地减少其环境影响至关重要。国际海事组织（IMO）近年来引入了新的法规以限制环境破坏。IMO的初步战略旨在到2050年将船舶温室气体排放减少50%，二氧化碳排放量比2008年减少70%（MEPC.304（72）决议，2018年）。这促使船东寻求解决方案以减少化石燃料的消耗。本研究旨在确定在海运中使用环保解决方案以满足可持续船队的挑战和需求的可行性。本研究包括专家调查结果，评估个别解决方案及其在全球海事船队中的潜在使用。本文还突出了目前船舶使用环保解决方案的情况，以及船员和船东对未来使用的态度，并提出了概念解决方案。值得注意的是，本文所涉及的主题非常重要，考虑到环境标准的限制。