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Renewable Energy Concept Development and Application in Shipping Industry

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ABSTRACT

Shipping industry contributes to global greenhouse gas emissions. As awareness of the impact of climate change grows, there is an urgent need to transition towards sustainable practices in the maritime sector. One solution is the adoption of renewable energy sources for ships, which can significantly reduce emissions and improve energy efficiency. This article explores various renewable energy sources that can be used on ships, such as solar and wind energy and carbon capture technology. The benefits and challenges of each energy source are discussed, along with their potential to support the shipping industry's sustainability goals. The article also examines the latest technological advancements and innovations in renewable energy for ships, such as hybrid propulsion systems and fuel cells. The present article concludes with a discussion of the regulatory framework and policies that can support the adoption of renewable energy sources in the shipping industry. The transition towards renewable energy sources for ships is an essential step towards achieving a more sustainable future for the shipping industry and the planet.

CITATION

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KEYWORDS

alternative energy sources, greenhouse gases, harmful emission, wind energy, solar energy, ecological safety of shipping, maritime transportation, carbon capture



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Introduction

In the dynamic field of maritime transportation, the pursuit of sustainability is becoming increasingly urgent. With the shipping industry facing the dual challenge of meeting growing demands and reducing environmental impact, the integration of renewable energy sources seems promising. This study builds on existing knowledge and tries to bridge the gaps in understanding the future development and application of renewable energy concepts in the shipping industry, aiming not only to shed light on the current state of knowledge, but also to identify areas where innovation and focused research are needed towards a more sustainable future of maritime transportation. In the last few years, the shipping industry has seen a creeping transformation toward alternative energy sources. These can be completely renewable or cleaner sources of energy for propelling ships, phasing out fossil fuels. Approximately 25 % of worldwide greenhouse gas emissions stem from the transportation sector, and within this domain, the maritime sector contributes around 3 % of these emissions (Onyshchenko & Melnyk, 2022). Given the changes in legislation and international goals to reduce environmental impact, maritime industry players are competing to decarbonize their assets and operations. While alternative fuels such as methanol, hydrogen and ammonia are promising in the long term, they are still in the technical development stage and largely unregulated. Alternatively, carbon capture, utilization, and storage (CCUS) technology can be

an effective solution. The study on modeling greenhouse gas emissions in the transportation sector provides insights into the environmental impact of transportation and the need for sustainable practices (Güzel & Alp, 2020). The IEA report offers a valuable overview of the status and progress in clean energy, providing a comprehensive background for understanding the global clean energy landscape (IEA, 2023). Modern research provides a comprehensive overview of the management of energy systems integrated with renewable energy sources throughout their life cycle and valuable perspectives on adapting sustainable energy solutions to meet the specific needs of this complex environment (Wang et al., 2021; Arruda et al., 2018). While literature on bidding behaviors in the energy sector and the optimization of energy systems provide insights into the challenges and opportunities in transitioning to renewable energy sources (Guo et al., 2022). The important aspect of the issue is the development of sustainable energy propulsion systems for sea transport in the alignments with United Nations sustainable development goals (Tay & Konovessis, 2023). The ship energy efficiency and initiatives in the maritime sector to reduce carbon emissions are also a part of the notion of sustainable shipping (Issa et al., 2022). The prioritizing alternative energy sources for sustainable shipping also involve an assessment of various energy options, considering factors such as efficiency, environmental impact, and feasibility in the context of maritime operations (Munim et al., 2023). According to von Malmborg (2023) advocacy coalitions play a vital role in policy change in the context of decarbonization of international shipping, specifically looking at the case of maritime FuelEU. Renewable energy has significant potential to decarbonize the shipping industry, which is responsible for a significant portion of global greenhouse gas emissions. The use of renewable energy in shipping can help reduce the industry's environmental footprint, improve energy efficiency, and enhance energy safety. Currently, renewable energy in shipping is used mainly for auxiliary needs and for shore power supply when ships are connected to the grid while docked in port. However, there is growing interest in using renewable energy sources such as wind, solar and hydrogen to power ship propulsion systems.

1. General Approach to the Introduction of Renewable Energy in Shipping Industry

The prospects for developing and applying the concept of renewable energy in shipping are in line with the IMO Strategy for Reducing Greenhouse Gas Emissions from Ships 2023, which emphasizes the need to shift to sustainable and low-carbon fuels to reduce greenhouse gas emissions from the shipping industry. Specific elements of the strategy emphasize the development of alternative low/zero carbon fuels, the importance of research and development in achieving emission reduction targets, and the role of innovation and technology in making zero-emission ships more attractive. Highlighting IMO's focus on biofuels, alternative fuels and innovative technologies complements the discussion on the prospects for renewable energy in shipping. In addition, the life cycle assessment (LCA) methodology mentioned in the IMO strategy is consistent with the consideration of the environmental footprint of various renewable energy options.

The concept of renewable energy in the shipping industry is also closely linked to recent developments in reducing greenhouse gas (GHG) emissions from the shipping sector. The extension of the EU Emissions Trading System (ETS) to CO₂ emissions from large ships calling at EU ports is in line with the concept of renewable energy, incentivizing the use of cleaner fuels. The system covers: a) 50 % of emissions from voyages starting or ending outside of the EU (allowing the third country to decide on appropriate action for the remaining share of emissions); b) 100 % of emissions that occur between two EU ports and when ships are within EU ports (European Commission, n.d.).

In addition, the important role played by the FuelEU (establishment of a maximum limit on the greenhouse gas content of energy used by ships calling at European ports) maritime regulation, which sets a maximum limit on the greenhouse gas content of energy used by ships also emphasizes the wider implications of EU commitments to reduce greenhouse gas emissions, especially through measures such as the inclusion of maritime emissions in the EU ETS. The EU's financial contribution to the EC-IMO energy efficiency project emphasizes the practical implementation of renewable energy concepts. Therefore, examining how this support contributes to the deployment of low-carbon technologies and renewable energy in maritime transportation adds a real dimension to the prospects for renewable energy in the shipping industry.

The issue of decarbonization in the maritime industry is urgent and pressing. In 2023, the International Energy Agency announced that an average annual improvement of +4 % would be needed to put the shipping industry on the right track toward zero emissions by 2030 (IEA, 2023). The industry needs more than just fuel and technology development to succeed. A fundamental change in thinking is needed. This change starts with adopting a holistic approach to maritime business, where marine conservation is a key objective, and it is the protection of marine ecosystems that is understood as an integral part of human progress. What changes this can lead to in the coming decades through what it takes to achieve the goal of reducing harmful emissions is the topic of this article.

To make the maritime industry more competitive in the global marketplace, innovative materials are needed to improve vessel performance and environmental friendliness. In recent years, other industries have made significant progress in this area. However, the maritime sector is lagging in introducing advanced materials that have a lower environmental impact, are cheaper and easier to maintain. The main obstacles to eco-friendly shipping are technological ignorance and an oversupply of fossil fuels which reduce the extent of financial investment in the development of potentially attractive alternative and renewable energy solutions for the maritime industry (Yeremenko, 2022, p. 44).

Soon, marine renewable energy will make up a more significant part of the global energy portfolio. In this vision, floating wind farms, wave and tidal power plants provide a significant share of renewable energy in the onshore grid. The enormous power of tides and wind will be harnessed to create green energy. Improvements in design mean that tomorrow's tidal and wind turbines will be able to produce much more energy than their counterparts today. Energy storage solutions are an important part of this equation. They help to combat the problem of fluctuations in wind power compared to grid needs. In floating offshore wind farms, the electrolysis process uses seawater to convert excess energy into hydrogen. The hydrogen is then stored on the seabed to be converted back into energy during periods of low wind. Renewable energy sources are becoming increasingly important in shipping as the sector seeks to reduce greenhouse gas emissions. Renewable energy can be a viable solution to reduce greenhouse gas emissions in the maritime transport sector. However, there are several prerequisites that need to be considered for the development of renewable energy in maritime transport. These include technological and infrastructure development, regulatory framework, public-private partnership, market demand and investment (Figure 1).

Appropriate infrastructure is needed to deploy renewable energy technologies in the maritime sector. Among other things, this includes the installation of wind turbines, solar panels and hydrogen refueling stations. A legal and regulatory framework that supports the development and deployment of renewable energy technologies in the maritime sector is crucial. Policies such as renewable energy incentives, carbon pricing and emission standards are essential. Cooperation between the public and private sectors is essential for the

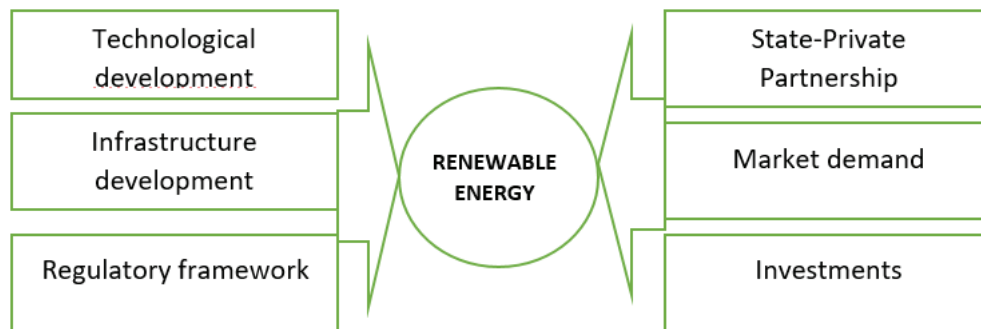


Figure 1. Prerequisites for the development of renewable energy in maritime transport (Authors)

development of renewable energy in maritime transport. Public-private partnerships can help mobilize funding, share knowledge and expertise, and support the deployment of renewable energy technologies. Market demand for renewable energy in the maritime sector is needed. This includes both demand from shipping companies for renewable energy technologies and demand from consumers for environmentally friendly shipping services. Significant investments are required to develop and deploy renewable energy technologies in the maritime sector. Investments in research and development, infrastructure, and public-private partnerships are needed.

In general, the development of renewable energy in maritime transport requires a multifaceted approach that considers technological, infrastructure, regulatory and market factors. By addressing these challenges, the maritime sector can contribute to global efforts to reduce greenhouse gas emissions and promote sustainable development. The shipping industry has significant potential for renewable energy development. Currently, it relies heavily on fossil fuels for energy transportation and production, which not only contributes to greenhouse gas emissions but also poses risks to the marine environment. The use of renewable energy sources in the maritime sector can help reduce emissions, increase energy security, and promote sustainable development. There are several major renewable energy technologies that can be used in the maritime sector, such as wind power, solar power, and carbon capture, use and storage (CCUS).

2. Additional Initiatives on the Use of Renewable Energy Sources in Shipping

There are also various initiatives aimed at increasing the use of renewable energy in shipping, such as the International Maritime Organization's (IMO) goal of reducing greenhouse gas emissions from shipping by at least 50% by 2050 compared to 2008 levels (2023 IMO Strategy on Reduction of GHG Emissions from Ships). Wave and tidal energy converters can be used to generate electricity from the movement of waves and tides. These technologies are particularly well suited for coastal regions with strong tidal currents.

Biofuels made from organic matter, such as algae or waste, can be used to power ships. Biofuels can be blended with traditional fuels or used in special engines. Biofuels made from sustainable sources can be used in marine engines to reduce greenhouse gas emissions. Such fuels can be produced from a variety of sources, including algae, used cooking oil, and even agricultural waste.

Hydrogen is another promising source of renewable energy for the shipping industry. Hydrogen fuel cells can be used to power ships and provide electricity for onboard systems. They can be used to generate electricity for onboard systems or to power electric propulsion

systems and produce no emissions other than water. Several companies are developing hydrogen fuel cells that convert hydrogen into electricity to power propulsion systems. However, the infrastructure for hydrogen production, transportation, and storage is still in the early stages of development, limiting its widespread adoption.

Ship fuel cells are a type of cell that can be used to power ships. Fuel cells are electrochemical devices that convert the chemical energy of a fuel into electrical energy through a reaction between the fuel and an oxidant. They typically use hydrogen as the fuel and oxygen from the air as the oxidant. The advantage of using fuel cells in ships is that they produce electricity without emitting harmful pollutants, such as nitrogen oxides or sulfur dioxide, which are commonly emitted by conventional marine engines. In addition, fuel cells have a higher efficiency than conventional engines, meaning that they can convert more of the energy in the fuel into useful work. However, there are some challenges associated with the use of ship fuel cells, including the need for large amounts of hydrogen to be stored onboard the ship, which requires significant infrastructure and safety measures. Additionally, the cost of fuel cells is currently higher than conventional engines, although this is expected to decrease as the technology becomes more widespread.

A hybrid propulsion system for ships typically involves combining two or more power sources to provide propulsion. This can help reduce emissions and improve efficiency compared to traditional single-source propulsion systems. One common approach is to combine a traditional diesel engine with an electric motor and battery system. The diesel engine can be used for high-power operations, such as cruising at high speeds or maneuvering in tight spaces, while the electric motor can be used for low-power operations, such as maintaining a slow speed or docking. The battery system can provide additional power during peak demand periods or be charged using excess energy from the diesel engine. Another approach is to use a combination of different fuel sources, such as diesel and liquefied natural gas (LNG), to power the ship. This can help reduce emissions and improve fuel efficiency, as LNG produces lower emissions compared to diesel.

Hybrid propulsion systems can also include other technologies, such as energy recovery systems that capture waste heat or kinetic energy and use it to power the ship. Overall, hybrid propulsion systems offer a promising way to reduce the environmental impact of ships and improve their efficiency.

3. Algorithms of the Implementation of Renewable Energy in Shipping

The integration of renewable energy into maritime transportation appears to be a promising direction with multifaceted benefits. Switching to renewable energy sources, such as wind, solar and hydrogen, will enable maritime transportation to significantly reduce carbon dioxide emissions, in line with global efforts to mitigate climate change. In addition to environmental benefits, there are economic benefits to switching to renewable energy sources: in the long term, it can be more cost-effective than the use of traditional fossil fuels. This economic viability allows shipping companies to reduce operating costs, ensuring sustainable competitiveness. In addition, renewable energy improves energy security by reducing the impact of price volatility and geopolitical risks associated with fossil fuels. A critical outcome of this transition is improved air quality, as renewables produce minimal or zero emissions, reducing the health and environmental risks associated with fossil fuel combustion emissions. These findings highlight the transformational potential of renewable energy deployment in maritime transport, laying the foundation for a sustainable and resilient industry in the face of changing global challenges (Figure 2).

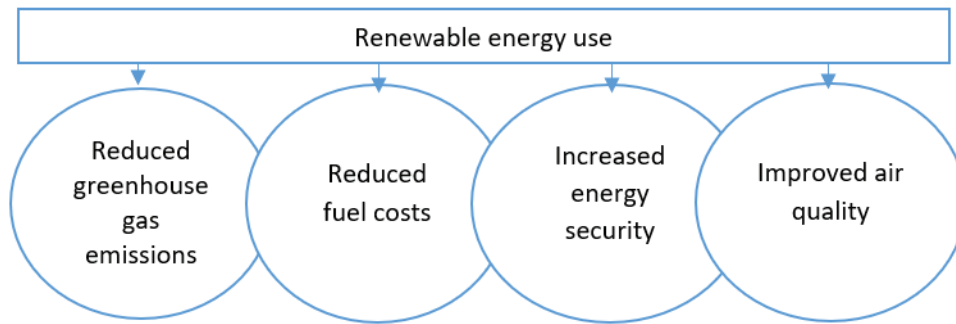


Figure 2. Advantages of renewable energy use (Authors)

Renewable energy is an important factor for the maritime sector, which relies heavily on fossil fuels for its operations. Below are the steps of the algorithm for the use of renewable energy in the maritime sector (Figure 3):

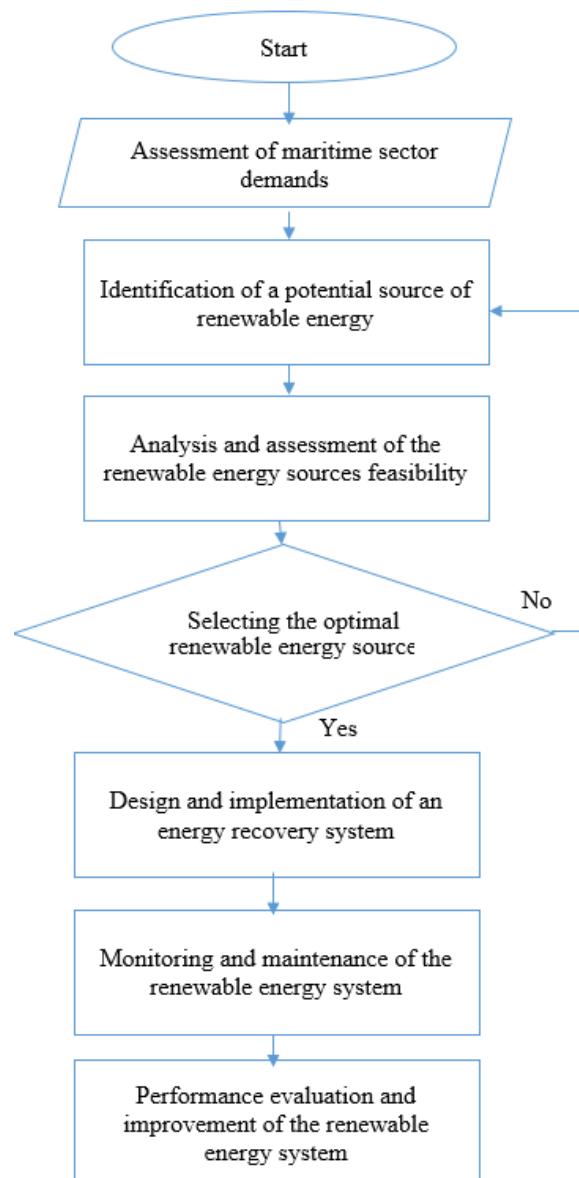


Figure 3. Algorithm model of renewable energy implementation (Authors)

The first step is to assess the energy needs of the maritime sector, including shipping, fishing and other activities. This information will help determine the type and capacity of renewable energy systems needed. The next step is to identify potential renewable energy sources that can be utilized in the maritime sector, such as wind, solar, tidal, and wave energy. Once potential sources have been identified, the feasibility of using each source must be assessed based on factors such as availability, reliability, cost, and environmental impact. Based on the feasibility study, select the most appropriate renewable energy source for the maritime sector. After selecting the renewable energy source, develop a renewable energy system that will meet the energy needs of the maritime sector. The implementation of the renewable energy system is based on the installation of the necessary equipment and infrastructure. Monitor and maintain the renewable energy system to ensure that it operates at maximum efficiency and to identify any issues that need to be addressed. Regularly evaluate the performance of the renewable energy system to determine its effectiveness in meeting the energy needs of the maritime sector. Make necessary improvements: Based on the assessment, make necessary improvements to the renewable energy system to optimize its performance and efficiency. Promote the use of renewable energy in the maritime sector. Promote the use of renewable energy in the maritime sector to encourage other stakeholders to adopt sustainable practices.

The development of renewable energy can help make maritime transportation more sustainable, efficient, and environmentally friendly. In the future of the maritime industry, we see technologies that either already exist or are emerging today, technologies scaled and streamlined into a holistic ecosystem that forms a better maritime industry for both people and the planet's ecosystem. In addition, by using renewable energy, shipping companies can improve their brand reputation and attract environmentally conscious customers. At the same time, the development of renewable energy in the marine sector faces several challenges, including high upfront costs, limited infrastructure and technical barriers. However, with the right policies and investments, the sector has the potential to make significant progress toward a more sustainable and resilient future.

In response to the urgent need to incorporate environmentally friendly practices into maritime operations, several shipping companies are actively introducing innovative renewable energy concepts. These practical implementations not only demonstrate a commitment to reducing carbon footprints, but also represent an important step towards greener shipping. A few highlights of how these companies have integrated renewable energy solutions into their fleets, presented in Table 1.

These examples illustrate how shipping companies are actively exploring and implementing renewable energy concepts to meet environmental goals and regulatory requirements. The maritime industry continues to innovate, looking for ways to integrate sustainable technologies and reduce overall environmental impact.

As these shipping companies adopt innovative renewable energy concepts, it is critical to implement robust cybersecurity measures to ensure the safety and reliability of these technologies. Cybersecurity protocols must protect Flettner rotors, solar panels, hybrid battery systems and wind propulsion systems from potential cyber threats, protecting not only the vessels, but also the interconnected digital infrastructure that supports these green initiatives. In an era of digital transformation, prioritizing cybersecurity becomes paramount to safely navigating the waters of sustainable development (Melnyk et al., 2023).

Table 1. Practical implementation of renewable energy concepts in the shipping companies – after (Petković et al., 2021; NYK, 2021; Scandlines, 2023; International Windship Association, 2023)

Shipping Company	Renewable Concept	Application
Maersk Line	Flettner Rotors	Tested and implemented Flettner rotors on some container ships. Large rotating cylinders on the deck harness wind power for auxiliary propulsion, reducing fuel consumption.
NYK Line	Solar Panels	Integrated solar panels into some vessels, converting sunlight into electricity for auxiliary power. Contributes to powering onboard systems, reducing reliance on conventional power.
Scandlines	Battery Hybrid System	Introduced battery hybrid systems on certain ferries. Stores electrical energy for peak demand, enabling the vessel to operate on cleaner electric power, reducing emissions.
Windship Technology	Wind Propulsion Systems	Offers retrofit solutions with advanced wind propulsion systems like Flettner rotors or rigid sails. Aims to significantly reduce fuel consumption and emissions during vessel operations.
Eco Marine Power	Aquarius Marine Solar Power	Provides solutions like the Aquarius Marine Solar Power, integrating solar panels into rigid sails. Tested on various vessels to harness solar energy for auxiliary power.

Conclusions

As the shipping industry seeks to move away from fossil fuels and reduce its carbon footprint, renewable energy sources are becoming increasingly important. In this article, various perspectives on the development and application of renewable energy concepts in the shipping industry were examined. Against the backdrop of a discussion of the current state of the industry and the challenges it faces in transitioning to renewable energy, several renewable energy technologies that are being developed and deployed on ships were reviewed, including wind, solar, power, hydrogen, and fuel cells. The article also discusses the economic and regulatory factors contributing to the implementation of renewable energy in the shipping industry, as well as the challenges yet to be overcome. These challenges include technological limitations, infrastructure limitations, and cost considerations. Despite the progress in the development of renewable energy systems for shipping, there is still a long way to go before these technologies are widely deployed. Further research, investment and policy support are needed to accelerate the adoption of renewable energy in shipping and help the industry meet its emissions reduction targets. In summary, the article concludes that renewable energy has significant potential to play a key role in the future of the shipping industry. However, achieving this goal will require continued innovation and

investment in new technologies, as well as a concerted effort to address the regulatory and economic challenges that currently stand in the way of widespread adoption.

REFERENCES

- 2023 IMO Strategy on Reduction of GHG Emissions from Ships. *International Maritime Organization*. <https://www.imo.org/en/OurWork/Environment/Pages/2023-IMO-Strategy-on-Reduction-of-GHG-Emissions-from-Ships.aspx>
- Arruda, G. M., Arruda, F. M., & Hogenson, J. M. (2018). Renewable Energy for the Arctic: New Perspectives. In *Renewable Energy for the Arctic: New Perspectives*. Routledge. (pp. 27–42).
- European Commission. (n.d.). *Climate Action. Reducing emissions from the shipping sector*. https://climate.ec.europa.eu/eu-action/transport/reducing-emissions-shipping-sector_en
- Guo, H., Chen, Q., Shahidehpour, M., Xia, Q., & Kang, C. (2022). Bidding behaviors of GENCOs under bounded rationality with renewable energy. *Energy*, 250, 123793. <https://doi.org/10.1016/j.energy.2022.123793>
- Güzel, T. D., & Alp, K. (2020). Modeling of greenhouse gas emissions from the transportation sector in Istanbul by 2050. *Atmospheric Pollution Research*, 11(12), 2190–2201. <https://doi.org/10.1016/j.apr.2020.08.034>
- IEA. (2023). *Tracking Clean Energy Progress 2023*. <https://www.iea.org/reports/tracking-clean-energy-progress-2023>
- International Windship Association. (2023). *Wind Propulsion (WP) & Wind Assist Shipping Projects (WASP)*. <https://www.wind-ship.org/en/wind-propulsion-wp-wind-assist-shipping-projects-wasp/>
- Issa, M., Ilinca, A., & Martini, F. (2022). Ship Energy Efficiency and Maritime Sector Initiatives to Reduce Carbon Emissions. *Energies*, 15, 7910. <https://doi.org/10.3390/en15217910>
- Melnyk O., Onyshchenko S., Onishchenko O., Lohinov O., & Ocheretna V. (2023). Integral Approach to Vulnerability Assessment of Ship's Critical Equipment and Systems. *Transactions on Maritime Science*, 12(1). <https://doi.org/10.7225/toms.v12.n01.002>
- Munim, Z., Chowdhury, M., Tusher, H., & Notteboom, T. (2023). Towards a prioritization of alternative energy sources for sustainable shipping. *Marine Policy*, 152, 105579. <https://doi.org/10.1016/j.marpol.2023.105579>
- NYK. (2021). *Implementation of sustainable, clean power Initiatives at green Ro-Ro terminal*. <https://www.nyk.com/english/esg/envi/renewable/>
- Onyshchenko, S., & Melnyk, O. (2022). Efficiency of Ship Operation in Transportation of Oversized and Heavy Cargo by Optimizing the Speed Mode Considering the Impact of Weather Conditions. *Transport and Telecommunication*, 23(1), 73–80. <https://doi.org/10.2478/ttj-2022-0007>
- Petković, M., Zubčić, M., Krcum, M., & Pavić, I. (2021). Wind Assisted Ship Propulsion Technologies – Can they Help in Emissions Reduction? *Naše More*, 68, 102–109. <https://doi.org/10.17818/NM/2021/2.6>
- Scandlines. (2023). *A fleet of hybrid ferries*. <https://www.scandlines.com/about-us/our-green-agenda/a-fleet-of-hybrid-ferries/>
- Tay, Z. Y., & Konovessis, D. (2023). Sustainable energy propulsion system for sea transport to achieve United Nations sustainable development goals: a review. *Discover Sustainability*, 4(20). <https://doi.org/10.1007/s43621-023-00132-y>
- von Malmborg, F. (2023). Advocacy coalitions and policy change for decarbonization of international maritime transport: The case of FuelEU maritime. *Maritime Transport Research*, 4, 100091. <https://doi.org/10.1016/j.martra.2023.100091>
- Wang, K., Li, Y., Wang, X., Zhao, Z., Yang, N., Yu, S., Wang, Y., Huang, Z., & Tao, Yu. T. (2021). Full Life Cycle Management of Power System Integrated With Renewable Energy: Concepts, Developments and Perspectives. *Frontiers in Energy Research*, 9. <https://doi.org/10.3389/fenrg.2021.680355>
- Yeremenko, K. (2022). International Maritime Organization and Decarbonization of Maritime Industry: Mandate and Instruments. *Lex Portus*, 8(3), 30–57. <https://doi.org/10.26886/2524-101X.8.3.2022.2>

Мельник О., Онищенко О., Онищенко С. Розвиток та застосування концепції відновлюваної енергії у судноплаванні. – Стаття.

Судноплавання сприяє глобальним викидам парникових газів. Оскільки усвідомлення впливу зміни клімату дедалі зростає, існує нагальна потреба переходу до сталих практик у морському секторі. Одним із рішень є застосування відновлюваних джерел енергії для суден, що може значно зменшити викиди та підвищити енергоефективність. У цій статті розглядаються різні відновлювані джерела енергії, що можуть бути використані на суднах, наприклад, сонячна і вітрова енергія, а також технології уловлювання вуглецю. Обговорюються переваги та проблеми кожного джерела енергії, а також їхній потенціал для підтримки цілей сталого розвитку судноплавної галузі. У статті також розглядаються останні технологічні досягнення та інновації у сфері використання відновлюваних джерел енергії для суден, зокрема гібридні силові установки та паливні елементи. Стаття завершується аналізом нормативно-правової бази та політики, які можуть підтримати впровадження відновлюваних джерел енергії у судноплаванні. Перехід на відновлювані джерела енергії для суден є важливим кроком до досягнення більш сталого майбутнього для судноплавної галузі та планети.

Ключові слова: мастильні матеріали, альтернативні джерела енергії, парникові гази, шкідливі викиди, енергія вітру, сонячна енергія, екологічна безпека судноплавання, морські перевезення, уловлювання вуглецю.

