International Journal of Environment and Geoinformatics 11(1):043-049 (2024)

Research Article

An Approach to Green Ports in Terms of Low-Carbon Energy and Sustainability

Omer Berkehan Inal[1,*], Caglar Dere[2]

[1]Istanbul Technical University, Maritime Faculty, Marine Engineering Department, Istanbul/Turkey.
[2]Izmir Katip Celebi University, Faculty of Naval Architecture and Maritime, Department of Marine Engineering, Izmir/Turkey.

* Corresponding author: O.B. Inal
E-mail: inalo@itu.edu.tr

Received: 08.01.2024
Accepted 13.03.2024

How to cite: Inal and Dere (2024). An Approach to Green Ports in Terms of Low-Carbon Energy and Sustainability, *International Journal of Environment and Geoinformatics (IJEGEO)*, 11(1): 043-049. doi. 10.30897/ijegeo.1416523

Abstract

Decarbonization compromise holds a significant place as a crucial topic in all industries worldwide today. The maritime sector is also getting its share from this carbon-neutral movement. Ports, being one of the vital areas in the maritime industry, are significantly affected by this decarbonization movement. In this context, a clear connection is observed between decarbonization compromise, green ports, and sustainable development goals in ports. For many years, the European Sea Ports Organization has been prioritizing environmental concerns, sustainable development goals, and the concept of green ports. This article focuses on prioritizing the elements that should be considered among sustainable development goals and green ports, taking into account the European Sea Ports Organization's environmental priorities over the last five years. Accordingly, an approach proposal about the low-carbon energy technologies has been put forward.

Keywords: Green Port, Decarbonization, SDGs, Sea Transportation

Introduction

Maritime transportation has served as a key driver of economic development for various countries, acting as a primary facilitator of trade between nations over the years. To be more precise, sea transportation accounts for a significant 80-90% share of global trade (Bayırhan and Gazioğlu, 2021; Inal and Deniz, 2021; Zincir, 2022b). The substantial utilization of shipping can be attributed to its energy efficiency when compared to road and air transportation. The maritime logistics chain comprises numerous distinct phases, with ports emerging as substantial links within this transportation network.

In recent years, the global maritime industry has experienced a paradigm shift towards sustainability, with increasing recognition of the deep impact it has on both environmental and climatic conditions. As the being the link between land and sea trade, ports play a crucial role in this transformation, serving as vital hubs for commerce while concurrently contributing to energy efficiency, emissions reduction and climate change. The urgency to mitigate these negative effects has given rise to the concept of "Green Ports," an innovative approach aimed to harmonize economic activities with environmental stewardship (Köseoğlu and Solmaz, 2019; Satir and Doğan-Sağlamtimur, 2018). The environmental footprint of traditional ports has been a cause for concern, primarily due to the emission of greenhouse gases, air pollutants, and the ecological disturbance caused by port infrastructure development (Gültepe Mataracı, 2016). The maritime industry, being a major contributor to global carbon emissions, has drawn increased attention from regulatory bodies, environmentalists, and the public alike (Lin et al., 2022). Acknowledging the necessity of confronting these challenges, the concept of green ports has arisen as a beacon of hope, promoting a dedication to sustainable practices, diminished emissions, and climate resilience (Gibbs et al., 2014).

Green ports represent a departure from the conventional model of port operations, integrating eco-friendly technologies, renewable energy sources, and innovative infrastructure designs. This transformation encompasses a wide spectrum of initiatives, from the adoption of electric and hybrid vehicles for cargo handling to the implementation of energy-efficient lighting systems (Kanellos et al., 2023). Moreover, green ports emphasize the reduction of air and water pollution, minimizing the impact of port activities on surrounding ecosystems and biodiversity. At the core of the green port initiative lies a profound commitment to cope with climate change. Climate variability and extreme weather events present substantial threats to port operations, demanding resilient infrastructure and adaptive strategies. Green ports harness climate-smart technologies to enhance their capacity to withstand and recover from the adverse impacts of climate change, thereby ensuring the continuity of maritime trade (Gonzalez-Aregall and Bergqvist, 2019; Lin et al., 2022). The European Sea Ports Organization (ESPO) has been at the forefront of advocating for sustainability and environmental responsibility within the maritime industry. Recognizing the pivotal role that ports play in the global supply chain and their impact on the surrounding ecosystems, ESPO has identified and prioritized ten key environmental objectives that underscore its commitment to fostering a greener and more sustainable future for maritime operations.

Table 1: Top 10 environmental priorities of ESPO from 2013 and the last 5 years.

No	2013	2018	2019	2020	2022	2023
1	Air Quality	Air Quality	Air Quality	Air Quality	Climate Change	Climate Change
2	Port Waste	Energy Consumption	Energy Consumption	Climate Change	Air Quality	Air Quality
3	Energy Consumption	Noise	Climate Change	Energy Efficiency	Energy Efficiency	Energy Efficiency
4	Noise	Relation with Local Community	Noise	Noise	Noise	Noise
5	Ship Waste	Ship Waste	Relation with Local Community	Relation with Local Community	Water Quality	Water Quality
6	Relation with Local Community	Port Development (Land)	Ship Waste	Ship Waste	Relation with Local Community	Ship Waste
7	Dredging	Climate Change	Garbage	Water Quality	Ship Waste	Relation with Local Community
8	Dust	Water Quality	Port Development (Land)	Garbage	Garbage	Port Development (Land)
9	Port Development (Land)	Dredging	Dredging	Dredging	Port Development (Land)	Garbage
10	Water Quality	Garbage	Water Quality	Port Development (Land)	Dredging	Port Development (Sea)

Table 2: Impact on air of the maritime transportation and port activities.

Activities / Events	Local Air Pollution	Odor	Global Air Pollution
Maneuvering	x		x
Loading / Unloading at Terminals	x	x	x
Hoteling	x		x
Dredging	x		x
Land Traffic	x		x
Waste Disposal	x	x	x
Port Building, Maintenance / Infrastructure	x		x
Fuels Deposits		x	
Air Traffic	x		x
Bulk Handling	x		x
Industrial Activities	x		x
Spills		x	

As illustrated in Table 1, energy efficiency/consumption, air quality, and climate change stand as the top three environmental priorities for ESPO. Notably, the priority of climate change, highlighted in blue, has been on the rise over the past five years. Meanwhile, port area air quality and energy efficiency/consumption maintain their positions at the forefront of the ranking. This ranking unmistakably demonstrates the significance of port emissions and their impact on climate change and global warming, underscoring their non-negligible importance. In this context, when looking at alternative improvement methods that port operations can implement to reduce emissions, providing shore power (cold-ironing) to ships berthed at the port emerges as the most significant factor in improving air quality in ports. The transition from using fossil fuels to using alternative fuels or electricity while the ship is in port leads to an increase in air quality and a reduction in GHG emissions. However, the lack of international standards for electric connection systems poses a challenge to the use of this technology. The main difficulty arises from the use of different voltages and frequencies in the electrical supply systems of different countries.

As given in Table 2 (Velasquez and Martinez de Oses, 2013), the degradation of air quality in port areas is a focal point of current research. The convergence of multiple systems in the ports and energy domains, along with low-carbon methods and technologies for comprehensive green port energy systems, offers a comprehensive view of the development status of low-carbon technologies in ports. The focus is on various aspects, including electricity substitution, renewable energy generation, and applications of clean fuel.

In this scope the paper is structured as follows; the relation of green port concept and sustainable development goals are presented in sections 2 via summarizing the most common parameters. Section 3 discusses the methodologies for carbon-free energy sources such as electric energy, alternative fuels and renewable energy. At last, the concluding remarks with the future scope are highlighted in section 4.

Green Ports and Sustainable Development Goals

The United Nations' 2030 Agenda encompasses 17 Sustainable Development Goals (SDGs) accompanied by 169 diverse targets falling within these goals. Figure 1 illustrates the SDGs using distinct colors and symbols. These goals are integrated into three fundamental pillars: social equity, economic growth, and environmental protection (Zincir, 2022a).

Fig. 1. Impact on air of the maritime transportation and port activities.

Green ports play a pivotal role in the framework of Sustainable Development Goals (SDGs), highlighting environmental sustainability and responsible resource management (UN, n.d.). An analysis of the correlation between Sustainable Development Goals (SDGs) and green ports has been conducted and consolidated in Table 3. This table provides a comprehensive overview, outlining the names and descriptions of all seventeen SDGs, along with their corresponding relevance and connections to green ports (Carpenter et al., 2021).

A more detailed explanation of the Table 3 is as follows: SDG 3 focusing on good health and well-being, can be exemplified through initiatives that prioritize the health and safety of port communities, workers, and the overall environmental well-being. Capacity-building programs within green ports partially contribute to SDG 4, centered on quality education, by enhancing skills and knowledge related to sustainable practices within the maritime industry. SDG 6, talks about clean water, and ports are working to keep water clean, use it wisely, and make sure port activities don't harm the environment. The integration of renewable energy sources into port operations emerges as a strategic cornerstone for contributing to SDG 7, which focuses on ensuring universal access to affordable, reliable, sustainable, and modern energy. Moreover, SDG 8, addressing decent work and economic growth, is actively tackled through green port initiatives that create employment opportunities within the renewable energy sector and sustainable logistics. SDG 9, centered on industry, innovation, and infrastructure, finds support in the practices of green ports that emphasize efficiency, innovation, and the development of sustainable infrastructure. The commitment of green ports also advances SDG 11, focused on sustainable cities and communities, by fostering sustainable urban development through eco-friendly port operations and logistics. The adoption of circular economy principles within port management not only supports SDG 12, about using resources responsibly and creating less waste, which is exactly what green ports do by following circular economy principles. Green ports also contribute to SDG 13 by taking action against climate change, reducing carbon emissions, and preparing for climate impacts. Protecting life below water, as mentioned in Goal 14, is another goal that green ports work on by implementing measures to keep marine ecosystems safe and prevent pollution. Lastly, for Goal 17, green ports believe in working together and forming partnerships to make these goals happen and promote sustainable development globally.

The remaining SDGs do not have a direct relevance with green ports. This shows that 8/17 of the SDGs are directly relevant to green port concept, while the 4/17 are partially and 5/17 are non-relevant. It is obvious that ensuring green ports is essential for the SDGs in the maritime industry.

Discussion

Electrification of Port Equipment

In shipping, when a ship arrives at a port, marine diesel generator is used to provide power for communication, lighting, ventilation, and/or cargo handling. Unfortunately, the marine diesel generators use fuel oil or marine diesel oil, resulting high air pollutant emissions. To address these issues during berthing, shore power technology can be employed. This technology enables the vessel to connect to the power system on the port instead of relying on onboard auxiliary engines. This approach, known as shore power, achieves electrification from the shore to the ship and has proven to be highly effective in reducing emissions. Research suggests that the implementation of shore power technology can lead to a 10% reduction in global port emissions (Zis et al., 2014).

Table 3: SDGs relevancy with green ports.

No	SDGs	Description	Relevancy
1	No poverty	End poverty in all its forms everywhere	None
2	Zero hunger	End hunger, achieve food security and improved nutrition and promote sustainable agriculture	None
3	Good health and well-being	Ensure healthy lives and promote well-being for all at all ages	Partially/Directly
4	Quality education	Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all	Partially
5	Gender equality	Achieve gender equality and empower all woman and girls	None
6	Clean water and sanitation	Ensure availability and sustainable management of water and sanitation for all	Directly
7	Affordable and clean energy	Ensure access to affordable, reliable, sustainable and modern energy for all	Directly
8	Decent work and economic growth	Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all	Directly
9	Industry, innovation and infrastructure	Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation	Partially
10	Reduced inequalities	Reduce inequality within and among countries	None
11	Sustainable cities and communities	Make cities and human settlements inclusive, safe, resilient and sustainable	Partially
12	Responsible consumption and production	Ensure sustainable consumption and production patterns	Directly
13	Climate action	Take urgent action to combat climate change and its impacts	Directly
14	Life below water	Conserve and sustainably use the oceans, seas and marine resources for sustainable development	Directly
15	Life on land	Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss	Partially
16	Peace, justice and strong institutions	Promote peaceful and inclusive societies for sustainable development, provide access to justice for all and build effective, accountable and inclusive institutions at all levels	None
17	Partnerships for the goals	Strengthen the means of implementation and revitalize the global partnership for sustainable development	Directly

However, despite the considerable emission reduction advantages offered by shore power technology, its widespread adoption encounters challenges, including technological issues related to power quality, system stability, safety, and synchronization.

At the port operations side, various types of logistics equipment to facilitate cargo handling and management play a crucial role (Carlo et al., 2014). This equipment comprises quay cranes (QC) designed for cargo or container loading and unloading from the ship's side, yard cranes (YC) including rail-mounted gantry (RMG), automated guided vehicles (AGVs), and rubber-tire gantry (RTG) for container handling and stacking in the yard. Additionally, there are conveyor belts dedicated to bulk cargo handling and transfer vehicles like reach stackers (RS), straddle carriers (SC), and lift trucks (LT) for container and cargo lifting and transfer (Huang et al., 2023). Although this equipment is manually driven some automated RTG and RMG are improved to enhance efficiency and reduce labor costs (Gharehgozli et al., 2014). Another study in the literature compares the performance of four types of cargo handling equipment in a Taiwan port shows that automatic rail and electric tire transtainers are advantageous in energy efficiency, and carbon reduction (Yang and Lin, 2013). Another study shows that battery powered AVGs are more profitable compared to standard AVGs are more profitable according to net present costs (Schmidt et al., 2015). Consequently, integrating electrification with energy storage systems facilitates the transfer of the quay crane's (QC) peak load, leading to enhanced energy utilization efficiency. In particular, a study, successfully integrated energy storage systems, resulting in a substantial reduction of QC's peak load from 1500 to 150 kW (Parise and Honorati, 2015).

Renewable Energy

In the aim of sustainable and green maritime transportation, renewable energy sources become crucial to power the ports. Harnessing the energy from renewable energy sources like the sun, wind, waves, and geothermal heat are important in reducing carbon footprint (Acciaro et al., 2014). Unlike fossil fuels, renewable energy doesn't release greenhouse effect harmful gases (Inal, Zincir, et al., 2022). However, differing from traditional energy sources, integration renewable energy resources like photovoltaic and wind power poses a challenge to grid management due to the variable nature of their power supply. Additionally, due to the high level of fluctuation, the generated energy may exceed the energy demand of the port. Therefore, the implementation of an energy storage system becomes necessary to manage and store the surplus energy efficiently (Ustun et al., 2012).

Wind turbines are predominantly situated in the vicinity of port areas, harnessing the power of the wind, while solar panels find their placement on the roofs of suitable buildings within ports. Successful examples of wind energy implementation can be observed in ports such as Hamburg, Venice, and Genoa. For instance, more than 20 wind turbines with over 25 MW capacity have installed in Hamburg Port (Port of Hamburg Magazine, 2018). On the other hand, Jurong Port in Singapore use solar panels on the roof of warehouses to reach zero-carbon with a capacity of over 12 thousand MWh (Song and Poh, 2017).

Nevertheless, there is still a need for comprehensive studies on the planning and arrangement of renewable energy in ports. Taking photovoltaic and wind power as prime examples, the location for installing photovoltaic arrays necessitates adequate solar radiation. A preference for rooftop photovoltaics arises, requiring consideration of load requirements for distributed photovoltaic power systems on the roofs of large warehouses and other structures in newly developed port areas. In the case of installing wind turbines within ports, multiple factors must be taken into account. These include variations in sea conditions, how deep the entry channels, safety distances between anchorages and navigation channels and wind farm boundaries. As the scale of the port is adjusted, the layout of renewable energy power stations within ports must also be adapted, necessitating an urgently required plan that is safe, efficient, and economically viable.

Alternative Fuels

The maritime industry, ships and ports, currently relies heavily on fossil fuels as its primary energy source (Zincir, 2022c, 2023). Shifting towards low or zero-carbon fuels is a crucial pathway to achieve decarbonization in shipping (Inal, Charpentier, et al., 2022). Currently, liquefied natural gas (Schinas and Butler, 2016), biomass fuels (Sevim and Zincir, 2022, 2023), and hydrogen energy (Inal, 2023) are emerging as promising clean alternatives for the maritime sector. The electric generation onboard ship is based on diesel generators, and this causes an increase in GHG emissions. Besides the ship-based measures, port based alternative fuels would be an important contributor to the decarbonization of the maritime industry. To cope with this issue, alternative fuels driven onshore power supply is an important solution. As mentioned in (Sadiq et al., 2021) Siemens has successfully constructed Germany's largest shore power system at the port of Kiel. This system, with a capacity of 16 megavolt amperes, can simultaneously supply two ships, contributing to an annual reduction of over 8000 tons of CO_2 emissions. Another EU funded project “The Green Crane” assessed equipment powered by liquefied natural gas, such as terminal tractors.

Despite being a cleaner version of traditional fossil fuels, liquefied natural gas and biomass fuels fall short of achieving zero emissions, making hydrogen energy a more viable long-term solution (Singh et al., 2015). Hydrogen energy, being a zero-carbon fuel, offers high energy density and efficient long-term storage (Andersson and Grönkvist, 2019). Hydrogen production through electrolysis, especially in renewable energy-intensive port areas with abundant water resources, provides a pollution-free and zero-emission solution. Direct current electricity can be generated by fuel cells efficiently with lower noise and vibration without emitting any greenhouse gas compared to diesel generators (Inal and Deniz, 2020). Hydrogen energy applications in ports extend to various scenarios, including commuting, transportation vehicles, and loading/unloading machinery. Hydrogen fuel cells, efficiently converting hydrogen energy into stable electricity, have been implemented in ports like Valencia. The biggest challenges for wide application of hydrogen are strict storage conditions, and technology maturity, serving as crucial areas for future research.

Conclusion

Ports are significant energy consumers, and due to the fossil fuel-based energy generation, they emit greenhouse gases. The greenhouse gas emissions released by ports have a significant impact on global warming, and different approaches should be developed to address this issue. In this context, the concept of green ports and the Sustainable Development Goals presented by the United Nations serve as catalysts for the greener resolution of energy needs in ports. However, there is currently insufficient guidance for achieving carbon-neutral transportation in ports, necessitating the exploration of different alternatives. This article aims to put light on the diverse challenges faced by ports, proposing alternative energy measures, and exploring the application of emerging technologies.

Firstly, an overview of the challenges encountered in ports is focused. Subsequently, green port concept is discussed by matching the related SDGs. The article focuses onto emerging technological trends, including electrification, renewable energy, and alternative fuels. Unfortunately, while regulatory policies hold promise in decarbonizing the port sector and improving efficiency, their practical implementation is currently constrained. Moreover, the article highlights the significance of modern port infrastructure, such as powering the port equipment with hydrogen fuel cell systems while these elements are deemed essential in reducing GHG emissions and enhancing energy efficiency. In future studies, it is recommended to conduct port-specific case analyses of hydrogen fuel cell-based energy production and storage systems, examining them from both financial and environmental perspectives. Since the energy expenditures of each port vary, determining which option would yield more efficient results in terms of sustainable development goals can only be possible through a port-specific analysis. This article presents potential solutions within the perspective of sustainable development goals under the general green port framework.

Authors Contribution

All persons who meet authorship criteria are listed as authors, and all authors certify that they have participated sufficiently in the work to take public responsibility for the content, including participation in the concept, design, analysis, and writing of the manuscript.

Competing Interests

The authors declare that they have no competing interests.

Acknowledgment

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

References

Acciaro, M., Vanelslander, T., Sys, C., Ferrari, C., Roumboutsos, A., Giuliano, G., Lam, J. S. L., Kapros, S. (2014). Environmental sustainability in seaports: a framework for successful innovation. *Maritime Policy & Management,* 41(5), 480–500. doi.org/10.1080/03088839.2014.932926

Andersson, J., Grönkvist, S. (2019). Large-scale storage of hydrogen. *International Journal of Hydrogen Energy*, 44(23), 11901–11919. doi.org/10.1016/j.ijhydene.2019.03.063

Bayirhan, İ., Gazioğlu, C. (2021). New Maritime Trade Routes in the Arctic Region: one of the Strongest Alternative to the Suez Canal. *International Journal of Environment and Geoinformatics,* 8(3), 397-401. doi.org/10.30897/ijegeo.911179

Carlo, H. J., Vis, I. F. A., Roodbergen, K. J. (2014). Storage yard operations in container terminals: Literature overview, trends, and research directions. *European Journal of Operational Research,* 235(2), 412–430. doi.org/10.1016/J.EJOR.2013.10.054

Carpenter, A., Skinner, J. A., and Johansson, T. M. (2021). Conclusions: Connecting Sustainable Development Goals to the Maritime Domain (pp. 489–507). Springer, Cham. doi.org/10.1007/978-3-030-69325-1_22

Gharehgozli, A. H., Roy, D., de Koster, M. B. M. (2014). Sea Container Terminals: New Technologies, OR Models, and Emerging Research Areas. *SSRN Electronic Journal.* doi.org/10.2139/SSRN.2469175

Gibbs, D., Rigot-Muller, P., Mangan, J., Lalwani, C. (2014). The role of sea ports in end-to-end maritime transport chain emissions. *Energy Policy,* 64, 337–348. doi.org/10.1016/J.ENPOL.2013.09.024

Gonzalez-Aregall, M., Bergqvist, R. (2019). Green port initiatives for a more sustainable port-city interaction: The case study of Barcelona. *In Maritime Transport and Regional Sustainability* 109–132. Elsevier. doi.org/10.1016/B978-0-12-819134-7.00007-1

Gültepe Mataracı, G. D. (2016). *Yeşil Liman Yaklaşımı ve Liman İşletmelerinde Sürdürülebilirlik.* Istanbul Technical University.

Huang, W., Yu, M., Li, H., Tai, N. (2023). Energy Management of Integrated Energy System in Large Ports (Vol. 18). Springer Nature Singapore. doi.org/10.1007/978-981-99-8795-5

Inal, O. B. (2023). Legislative Approach to Fuel Cells in the Turkish Maritime Industry. *IHTEC 2023 - International Hydrogen Technologies Congress,* 236(4). doi.org/10.1177/14750902221074191

Inal, O. B., Charpentier, J. F., Deniz, C. (2022). Hybrid power and propulsion systems for ships: Current status and future challenges. *Renewable and*

Sustainable Energy Reviews, 156. doi.org/10.1016/j.rser.2021.111965

Inal, O. B., Deniz, C. (2020). Assessment of fuel cell types for ships: Based on multi-criteria decision analysis. *Journal of Cleaner Production*, 265, 121734. doi.org/10.1016/j.jclepro.2020.121734

Inal, O. B., Deniz, C. (2021). Emission Analysis of LNG Fuelled Molten Carbonate Fuel Cell System for a Chemical Tanker Ship: A Case Study. *Marine Science and Technology Bulletin*, 10, 118–133. doi.org/10.33714/masteb.827195

Inal, O. B., Zincir, B., Dere, C. (2022). Hydrogen as Maritime Transportation Fuel: A Pathway for Decarbonization. In A. K. Agarwal and H. Valera (Eds.), *Greener and Scalable E-fuels for Decarbonization of Transport* 67–110. Springer Singapore. doi.org/10.1007/978-981-16-8344-2_4

Kanellos, F. D., Tsekouras, G. J., Nikolaidis, V. C., Prousalidis, J. M. (2023). Toward Smart Green Seaports: What should be done to transform seaports into intelligent and environment-friendly energy systems? *IEEE Electrification Magazine*, 11(1), 33–42. doi.org/10.1109/MELE.2022.3232980

Köseoğlu, M. C., Solmaz, M. S. (2019). Yeşil Liman Yaklaşımı: Türkiye ve Dünya Yeşil Liman Ölçütlerinin Karşılaştırılmalı Bir Değerlendirmesi. *IV. Ulusal Liman Kongresi*, 41–60. doi.org/10.18872/0.2019.2

Lin, C. Y., Dai, G. L., Wang, S., Fu, X. M. (2022). The Evolution of Green Port Research: A Knowledge Mapping Analysis. *Sustainability* (Switzerland), 14(19). doi.org/10.3390/su141911857

Parise, G., Honorati, A. (2015). Port cranes with energy balanced drive. 2014 AEIT Annual Conference - From Research to Industry: The Need for a More Effective Technology Transfer, *AEIT 2014*. doi.org/10.1109/AEIT.2014.7002047

Port of Hamburg Magazine. (2018). www.mediaserver.hamburg.de/Nicole

Satir, T., Doğan-Sağlamtimur, N. (2018). The protection of marine aquatic life: Green Port (EcoPort) model inspired by Green Port concept in selected ports from Turkey, Europe and the USA. Periodicals of *Engineering and Natural Sciences*, 6(1), 120–129. doi.org/10.21533/pen.v6i1.149

Schinas, O., Butler, M. (2016). Feasibility and commercial considerations of LNG-fueled ships. *Ocean Engineering*, 122, 84–96. doi.org/10.1016/j.oceaneng.2016.04.031

Schmidt, J., Meyer-Barlag, C., Eisel, M., Kolbe, L. M., Appelrath, H. J. (2015). Using battery-electric AGVs in container terminals — Assessing the potential and optimizing the economic viability. *Research in Transportation Business & Management*, 17, 99–111. doi.org/10.1016/J.RTBM.2015.09.002

Sevim, C., Zincir, B. (2022). Biodiesel and Renewable Diesel as a Drop-in Fuel for Decarbonized Maritime Transportation. In: Agarwal, A.K., Valera, H. (eds) Potential and Challenges of Low Carbon Fuels for *Sustainable Transport. Energy, Environment, and Sustainability*. Springer, Singapore. doi.org/10.1007/978-981-16-8414-2_10

Sevim, C., Zincir, B. (2023). *Lifecycle Emissions of Fossil Fuels and Biofuels for Maritime Transportation: A Requirement Analysis. Energy, Environment, and Sustainability*, 27–44. doi.org/10.1007/978-981-99-1677-1_3/COVER

Singh, S., Jain, S., Ps, V., Tiwari, A. K., Nouni, M. R., Pandey, J. K., Goel, S. (2015). Hydrogen: A sustainable fuel for future of the transport sector. *In Renewable and Sustainable Energy Reviews* (Vol. 51). doi.org/10.1016/j.rser.2015.06.040

Song, S., and Poh, K. L. (2017). Solar PV leasing in Singapore: enhancing return on investments with options. *IOP Conference Series: Earth and Environmental Science*, 67(1), 012020. doi.org/10.1088/1755-1315/67/1/012020

UN. (n.d.). THE 17 GOALS | Sustainable Development. Retrieved January 4, 2024, from sdgs.un.org/goals

Ustun, T. S., Ozansoy, C., Zayegh, A. (2012). Modeling of a centralized microgrid protection system and distributed energy resources according to IEC 61850-7-420. *IEEE Transactions on Power Systems*, 27(3), 1560–1567. doi.org/10.1109/TPWRS. 2012.2185072

Velasquez, S., and Martinez de Oses, F. X. (2013). SHIPPOL, Towards an Automatic Green House Effect Gases Tracing and Accounting System in Harbor Areas by Using AIS Technology. *Journal of Maritime Research*, X(3), 37–46.

Yang, Y. C., Lin, C. L. (2013). Performance analysis of cargo-handling equipment from a green container terminal perspective. *Transportation Research Part D: Transport and Environment*, 23, 9–11. doi.org/10.1016/J.TRD.2013.03.009

Zincir, B. (2022a). Analyzing marine engineering curriculum from the perspective of the sustainable development goals. *Marine Science and Technology Bulletin*, 11(2), 158–168. doi.org/10.33714/ masteb.1079480

Zincir, B. (2022b). Environmental and economic evaluation of ammonia as a fuel for short-sea shipping: A case study. *International Journal of Hydrogen Energy*, 47(41), 18148–18168. doi.org/10.1016/J.IJHYDENE.2022.03.281

Zincir, B. (2022c). Environmental and economic evaluation of ammonia as a fuel for short-sea shipping: A case study. *International Journal of Hydrogen Energy*. doi.org/10.1016/j.ijhydene. 2022.03.281

Zincir, B. (2023). Slow steaming application for short-sea shipping to comply with the CII regulation. *Brodogradnja*, 74(2), 21–38. doi.org/10.21278/ brod74202

Zis, T., North, R. J., Angeloudis, P., Ochieng, W. Y., Bell, M. G. H. (2014). Evaluation of cold ironing and speed reduction policies to reduce ship emissions near and at ports. *Maritime Economics and Logistics*, 16(4), 371–398. doi.org/10.1057/ MEL.2014.6/FIGURES/9