

A LITERATURE REVIEW ON GREEN PORT AND INCENTIVES

Hüseyin Gençer ^{1,*}, Kenan Tata ¹, Tutku Eker İşcioğlu ¹ and M. Taner Albayrak ¹

¹ Piri Reis University, Türkiye

Abstract: The idea of green ports emerged after various initiatives to reduce emissions from port activities. Green port refers to the incorporation of environmentally sustainable practices into a port's operations and management. One of the first issues that come to mind regarding the environmental impacts of ports is carbon emissions. Carbon emissions in ports mainly arise from three main factors: handling equipment, tugboats and ships. This study reveals prominent research on carbon emissions from these factors in ports. Studies in the literature have shown that the application of new technologies, improving fuel efficiency, and adopting alternative fuels are essential strategies to reduce these emissions and their related effects. Various incentives from both industry and governments are being implemented around the world to reduce emissions. Ports provide incentives to ships based on their type or size, such as discounts on port dues, tonnage tax, and registration fees. Given the decarbonization strategies of both the World Maritime Organization and the European Union, such initiatives will increase and become even more important in the future.

Keywords: Green port; Sustainability; GHG Emissions, Decarbonization

1. Introduction

As in many sectors, sustainability is one of the most current issues in the port industry. Port sustainability can be defined as the implementation of policies and actions that effectively address the present and future requirements of port stakeholders, while simultaneously safeguarding and preserving human and natural resources (AAPA, 2007). Although sustainability comes to mind when talking about green ports, green focuses only on environmental issues. In other words, green port takes into account just one aspect of sustainable ports. Because sustainability also considers social, economic and environmental issues.

Ports implement environmental management strategies to uphold their social license and worldwide competitiveness, while simultaneously reducing any negative impacts. Certain ports use these programs to ensure compliance with regulations, while others consider sustainability to be a fundamental aspect of their operational strategy. Starting from the early 2000s, Europe has established environmental management by fostering collaboration among ports, research institutions, and specialized organizations. A proficient port environmental management system (EMS) recognizes environmental concerns that may be alleviated. Researchers highlight the need of including stakeholders in order to determine the key environmental factors that should be measured to assess the performance of a port in terms of its environmental impact (Dinwoodie et al., 2012; Şakar and Çetin, 2012; Alzahrani et al. 2021).

The emissions sources at a port can be categorized into three aspects: handling equipment, tugboats and ships. Quay cranes, RTG (rubber tyred gantry) cranes, straddle carriers, reach stackers and yard tractors for in-port transportation can be given as examples of port handling equipment. Tugboats are motorized marine vehicles that help ships maneuver quickly and safely in port areas. Ships, on the other hand, are marine vehicles that provide both short-sea and deep-sea maritime transportation services and differ according to the cargo they carry, such as containers, tankers and dry cargo. Apart from their maneuvers in the port, ships also cause GHG emissions due to the operation of auxiliary machines while they are at the berth (Alamouch et al., 2022b).

This study, which is part of the initiative known as the “Green Port Alliances” project, specifically targets the in-port services sector, which has been overlooked in the European Union (EU) Green Deal goal to decarbonize the maritime industry. The project has received funding under Erasmus+ Partnerships for Innovation-Alliances (ERASMUS-EDU-2023-PI-ALL-INNO) and receives financial support from the European Commission. The second part of the study deals with studies on carbon emissions caused by port equipment. The third section presents prominent research on ship-related GHG emissions in ports. The fourth section discusses current studies on carbon emissions from tugboats in ports. The fifth section reveals the initiatives implemented in important ports

around the world regarding green ports. The final section concludes the study by suggesting future research directions.

2. Emissions arising from handling equipment

Port environmental research centers on examining energy usage and emissions inventory in order to apply specific actions aimed at reducing emissions. Compared to studies on emissions caused by ships, the number of studies on emissions from in-port handling equipment is less. However, the number of studies conducted in this field has been increasing recently.

Yang and Cheng (2013) compared RTG cranes and electric RTGs for energy savings and carbon emission reduction in container terminals. Their results showed that electric RTGs offer significant performance improvements, achieving 86.60% energy savings and 67.79% carbon emission reduction. A study conducted by Yu et al. (2017) has indicated a strong correlation between emissions from yard tractors and the placement of export containers. Sim et al. (2018) evaluated the carbon emissions of five operations at a container terminal in South Korea, including ship maneuvering, ship at berth, container loading and unloading, container transportation, container receiving and delivery, using the system dynamics method. Yun et al. (2018) proposed a simulation model to address complex stochastic processes in container terminals. Simulation experiments show that reduced speed in waterway channels can reduce emissions by 48.4% and 32.9%, while LNG use can reduce emissions by 11% for ships and 8% for total emissions. The study conducted by Martinez-Moya et al. (2019) presented crucial data on the actual energy usage and carbon emissions of Port of Valencia, Spain. According to the findings, yard terminal tractors and RTGs are the primary contributors to emissions, making up 68.1% of the total carbon emissions from the terminal. Okşaş (2023) estimated the total carbon emissions produced by container handling equipment at Ambarlı container port, which handles 30% of Türkiye's total container volume. The study revealed that yard tractors caused the most carbon emissions in the port.

In recent literature reviews, there are also studies on the effect of the use of alternative fuel, renewable energy and new technologies on reducing greenhouse gases in ports. Alzahrani et al. (2021) reviewed existing research on digital technologies for decarbonizing seaports, focusing on carbon reduction, renewable energy use, cost-performance optimization, smart control technologies, and green port practices. Hoang et al. (2022) examined advanced renewable energy technologies, clean fuels, and smart grid strategies for port-to-ship interactions. In their study, Fadiga et al. (2024) highlighted the necessity of technological innovations, regulatory structures, and cooperation among stakeholders in order to attain viable marine ports.

In the literature, when port handling equipment is mentioned, the first thing that comes to mind is the optimization of the operations in which these equipment are used. Planning port inland operations, berth assignment to ships and optimization of crane scheduling problems can be given as examples. Thanks to mathematical models developed to solve such problems, energy savings can be achieved in port operations optimization and therefore carbon emissions can be reduced. However, in many cases, too much equipment movement occurs in both shore operations and yard area operations to reduce the time that ships stay in port, resulting in excess energy consumption and carbon emissions. In this regard, it will become more important to develop multi-purpose mathematical models that, on the one hand, maximize the service quality and speed for ships and, on the other hand, minimize GHG emissions.

3. Emissions arising from ships

The activities of numerous ships are a significant source of GHG emissions at ports. Ships release GHGs during docking and departure maneuvers. Additionally, the process of idling while waiting for docking or departure permission further causes emissions. While in port, ships frequently utilize auxiliary engines and boilers to provide electricity for various aboard systems, including lighting, air conditioning, and cargo handling equipment. Typically, these engines combust marine diesel oil or heavy fuel oil, emitting carbon dioxide (CO₂), nitrogen oxides (NO_x), sulfur oxides (SO_x), and particulate matter (Alzahrani et al., 2021).

There are various studies in the literature on ship-related emissions in ports. Winnes et al. (2015) investigated potential reductions in ships' GHG emissions from ports' efforts. The researchers calculated emissions in various scenarios, including alternative fuel, ship design, and operation. The study found that emissions from ships in the port area are projected to increase by 40% to 2030. Styhre et al. (2017) analyzed GHG emissions from ships in

using data from Gothenburg, Long Beach, Osaka, and Sydney ports. The model calculates the aggregate greenhouse gas (GHG) emissions for each port to be 150,000, 240,000, 97,000, and 95,000 tonnes of carbon dioxide equivalents per year for each port. The study discussed four measures aimed at reducing emissions: decreased speed in fairway channels, on-shore power supply, decreased turnaround time at berth, and the use of alternative fuels. The extent to which emissions may be reduced is contingent upon the frequency of ship visits, with ships that make 10 or fewer calls making a substantial contribution.

Alamouh et al. (2020) classified the technical and operational steps implemented by ports to decrease GHG emissions and enhance energy efficiency. After analyzing 214 papers, researchers found a total of 7 primary categories and 19 subcategories. The findings indicate a lack of adequate investigation into the development of ports in developing countries. It is also evident that implementing a single strategy may not be sufficient to achieve decarbonization of ports, since the potential for reducing emissions, the complexity of the task, and the associated costs vary significantly. Paulauskas et al. developed an approach (2020) to evaluate the potential reduction of ship emissions in ports, taking into account the effect of human factors. The research findings indicate that the expertise and qualifications of port pilots and ship masters have a substantial impact on the execution of ship maneuvers, which in turn affects the number of emissions produced by ships. Lohuh et al. (2023) revealed that ship activities in the anchorage zone contribute significantly to air pollution in the Busan Port area. This is particularly true for emissions such as NO_x (8.78%) and volatile organic compounds (7.52%), which form secondary aerosols when they react with oxidized substances.

Barone et al. (2024) analyzed the impact of electrical energy storage systems on the energy system of ships providing short-sea shipping services and therefore the environmental footprint during port stays. The authors developed a dynamic modeling tool to assess the viability of charging these devices during navigation and utilizing them as substitutes for conventional diesel generators. The findings indicate that the utilization of lithium-ion batteries and supercapacitors leads to a substantial decrease in the release of pollutants, hence resulting in a notable reduction in both fuel consumption and carbon dioxide emissions. Their study also emphasizes the importance of reducing emissions from ships during maneuvering in port areas, highlighting the need for appropriate education and training to improve decision-makers' qualifications. Qi et al. (2024) proposed a multidimensional approach to analyze carbon emissions from ships at port, utilizing AIS data, constructing a three-dimensional tensor, and decomposing it for feature extraction. Validated using Tianjin Port data, this method offers valuable insights for energy-saving and emission reduction strategies. The approach in that study, validated using Tianjin Port data, provides valuable information for energy saving and emission reduction strategies.

4. Emissions arising from tugboats

Although reducing GHG emissions is one of the most popular topics in the maritime industry, the impact of tugboats has been little researched in the literature. Tugboats play a vital role in maritime operations and significantly contribute to port emissions through the release of engine exhaust gasses. The emissions are principally caused by the burning of diesel fuel, resulting in the production of a variety of GHG. Currently, there are more than 21,000 tugboats in operation worldwide, which collectively release 40 million metric tons of carbon dioxide annually. Despite its apparent insignificance, it is worth noting that this accounts for just 4% of the overall shipping emissions (Jameson, 2022). The EU ETS System, which entered into force on January 1, 2024, will initially be applied to ships carrying cargo and passengers with a gross tonnage of 5000 and above. Therefore, tugboats are exempt from this for now due to their small size (EU Climate Action, 2024). Currently, 40% of the tugboats in the worldwide fleet are 15 years old or younger. Since tugboats may work for more than 30 years, retrofitting will be necessary to reduce carbon emissions from the whole fleet of tugboats (Jameson, 2022).

There is an increasing concern regarding port emissions, likely due to the fact that major commercial ports are situated in densely populated cities. It is crucial to understand the impact of port activities on the health of citizens and its global ramifications. This issue is of utmost importance to the public. Ortega et al. (2022) made a study to determine GHG emissions caused by the Spanish tugboat fleet from 2004 to 2017 and their impact on the country's shipping sector. The methodology used by the International Maritime Organization and Gini concentration index was applied to the fleet. Results showed that emissions concentration increased by region and decreased by age and size, indicating that tugboat activity varied by region but evolved more homogeneously with age and size. Ergüven et al. (2023) analyzed GHG emissions of tugboats in İzmit Bay, Türkiye. Their study shows that tugboat emissions account for an average of 10% of all ship emissions for port areas.

The operation of tugboats is a crucial component of port operations, and effective scheduling and planning of tugboat operations have a direct and substantial influence on the timely arrival and departure of vessels at the port. Moreover, effective planning of tugboats reduces unnecessary maneuvers, thus reducing energy consumption and therefore carbon emissions. Hence, it is useful to mention some of the current prominent studies on the subject. The tugboat operation involves the simultaneous provision of tug services by several tugboats to a single vessel at the same time. Therefore, scheduling the tugboat operation is an uncommon scheduling challenge. For this purpose, various studies have been conducted in the literature for effective planning and scheduling of tugboats. Liu (2009) proposed a hybrid evolutionary strategy algorithm to optimize tugboat scheduling problem, using a multi-dimension integer encoding and a local search strategy based on crossing-over. The algorithm effectively solves the tugboat operation scheduling problem, combining parallel and dedicated processors in a general set multiprocessor tasks scheduling. Wang et al. (2014) addressed the tugboat assignment problem in container terminals using a hybrid scheduling rule (TAP-HSR) to minimize ship turnaround time. In that study, a mixed-integer programming model and scheduling method were described, and an improved discrete PSO algorithm was proposed, showing better solutions than GA and basic discrete PSO.

Kang et al. (2020) addressed tugboat scheduling problem that involves uncertainty in the arrival and towing processing times of container ships for major ports. The authors formulated a mixed integer linear programming model and developed a special algorithm for large-scale problems. Extensive numerical experiments demonstrate the practical importance of the models and algorithms. Zhu et al. (2021) proposed a mixed integer programming model and a variable neighborhood search algorithm to minimize carbon emissions. Numerical experiments show that the model reduces emissions by 46.93% compared to dispatching rules and 10.46% with barge transshipment. Zhong et al. (2022) introduced a bi-objective, mixed-integer linear programming model for scheduling green tugboats. The first objective of the model minimizes the maximum completion time of the tugboats where the second objective minimizes the total fuel consumption of the tugboats. By doing so, the model aims to enhance port service levels, decrease operating expenses, and reduce emissions. The validity of the model is shown by a case study conducted in Guangzhou Port. The results demonstrate the trade-off between different objectives and serves as a foundation for developing scheduling plans for port tugboats. Tugboats are mostly not taken into consideration in berth allocation and crane assignment problems. An exception to this is a study by Jiang et al. (2024) on dry bulk ports. The researchers considered ship-borne emissions and the availability of tugboats in optimizing port operations. However, the emissions of tugboats were not taken into account.

5. Green Port Incentives

Climate change is a significant concern, and policies such as incentives are crucial for decarbonizing maritime transportation. Incentives schemes and grants are established to support investments in technology adoption in ports, land transport, and ships, which reduce ship emissions, waste, noise, and improve safety. These incentives advance sustainability implementation and internalize socio-environmental externalities. Port authorities provide voluntary incentives, while national, international, or intergovernmental programs often provide grants to support investment in innovative decarbonization measures (Hossain et al., 2021; Alamoush et al., 2022a).

Shipping economic measures (fees and incentives) represent 48% of global measures to reduce shipping emissions and are mainly applied by port authorities. Ports grant incentives to ships according to their type or size, such as discounts on port dues, tonnage tax, and registration fees. Incentives range from 5% to 20% discount/rebate for ships that register in one of the environmental indices or certification programs, with some increasing this percentage to up to 50% (Christodoulou, et al., 2019). International focus on port incentives for ships has led to literature recommends to reduce shipping emissions in ports, cruise ships, and ferries. The ITF and OECD study has reviewed port-based incentives aiming at reducing shipping GHG emissions and demonstrated the impacts and challenges of port-based ships incentives (ITF/OECD, 2018). There are various incentives launched around the world, both by industry and governments. Some of these are briefly explained below.

The ESI (Environmental Ship Index), initiated by World Port Climate Initiative (WPCI) and the International Organisation of Ports and Harbors (IAPH), allows ports to register as incentive providers for certified ships by registering fuel consumption and air emissions. Ports offer incentives as percentage reductions in port dues, with examples including New York, Los Angeles, Rotterdam, Antwerp, Hamburg, Le Havre, Busan, Tokyo, and Dubai (Becqué et al., 2017; ITF/OECD, 2018).

The CSI (Clean Shipping Index), founded by public authorities and run by shipping stakeholders in Gothenburg, Sweden, is an online tool used by shippers and ports to compare fuel efficiency in cargo carriers, reducing the environmental footprint of supply chains. Ports like Stockholm, Gothenburg, Vancouver, Prince Rupert, Turku, Petroport and Mariehamn use the CSI for environmentally differentiated port dues (CSI, 2024).

The GA (Green Award) is a private initiative in Rotterdam aimed at promoting shipping safety and environmental protection in the Netherlands and beyond. It involves oil, chemical, and bulk carriers, requiring shipowners to inventory emissions and implement measures to reduce them. Ports such as Rotterdam, Amsterdam, Hamburg, Barcelona and Buenos Aires provide GA-based incentives (e.g. discounts on port fees, etc.). The GA also has a waste module which is designed for ships that take responsible initiatives on ship waste to be recognized in the GA ship certification program. It serves as a verification body for port reductions on ship waste fees, aligning with the EU Directive (EU) 2019/883. Waste handling has been integrated into the Green Award program for over 20 years, making it a logical step for Green Award to cooperate (GA, 2024).

RightShip's GHG Rating rates commercial vessel emissions, ranging from A to E. It's the gold standard for emissions comparison in the shipping industry and incorporates EEXI values. Ports can assess emission profiles to develop decarbonization strategies, such as port incentive programs, to attract more efficient vessels (RightShip, 2024).

GM (Green Marine) is an environmental certification program for the North American (USA and Canada) marine industry, certifying ships, ports, terminals, and shipyards for better environmental performance in air emissions reduction, water pollution, noise, and garbage indicators. The program is now available to European shipowners through a partnership with Surfrider Foundation Europe (GM, 2024).

National governments and port authorities also initiate various incentive programs for ships to reduce Sox (Sulphur Oxides) or NOx (Nitrogen Oxides) emissions. These programs, such as the Green Ship program in Long Beach, Finland's Investment Aid, Hong Kong's Fair Wind Charter, Norway's Business Sector NOX Fund, and Sweden's Differentiated Port and Fairway Dues program, support the adoption of emissions reduction technologies and alternative fuels. These programs depend on revenues from emissions tax and tariff changes (Alamouch, et al., 2022a).

Current shipping incentive schemes may not significantly change shipowners' decisions to invest in green technologies on operating ships. Port costs account for only 10% of ships' voyage costs, and port dues account for almost 10%. However, port dues represent almost half of European ports' revenues. Port authorities typically provide financial incentives and rebates for ships that comply with incentive programs, but it is important to assess whether the incentive received can cover the extra cost of being greener. A high value incentive can be profitable and make a good business case for shipowners (ESPO 2019; Alamouch et al., 2022a).

Port authorities should offer discounts on port dues, pilotage, towage, anchorage, and other port fees. Other incentives, such as booking and docking priority, can contribute to reducing ship turnaround time and port demurrage. Some ports provide electricity tax exemption for ships using OPS, while others provide rebates related to ship emissions performance on the waste collection fee (COGEA, 2017; Mjelde et al., 2019).

6. Conclusion and Future Research

Ports are one of the most important links in the supply chain. Rising levels of activities in ports undoubtedly cause environmental problems, including high energy consumption and high GHG emissions, with high health impacts among populations living in coastal cities close to ports. The idea of green ports emerged after various initiatives to reduce the number of emissions from port activities. Green port refers to the incorporation of environmentally sustainable practices into a port's operations and management. One of the first issues that come to mind regarding the environmental impacts of ports is carbon emissions. Carbon emissions in ports mainly arise from three main factors: handling equipment, tugboats and ships. The number of studies on carbon emissions caused by port handling equipment has been increasing in the literature, especially in the last decade. The vast majority of research on port handling equipment is focused on efficient planning of equipment. For this purpose, optimization models have been developed in studies. Such models can also be used in the field of decarbonization, as efficient planning and use of port handling equipment will also allow for the reduction of carbon emissions. Emissions of GHGs from ships in ports are of significant importance due to their significant impact on global climate change and local air quality. Studies in the literature have also shown that the application of new

technologies, improving fuel efficiency, and adopting alternative fuels are essential strategies to reduce these emissions and their related effects. In the literature, there are very few studies on the emissions caused by tugboats in ports. Studies on tugboats have mostly been about operational planning. However, in recent years, the number of studies on emissions caused by tugboats has been increasing.

Various incentives from both industry and governments are being implemented around the world to reduce emissions. Ports provide incentives to ships based on their type or size, such as discounts on port dues, tonnage tax, and registration fees. Moreover, various indices have been developed by different institutions to measure emissions caused by ships. Taking these indices into account, ports offer significant incentives to shipping companies, especially discounts on port fees. It can be said that such incentives will increase even more in the future. Given the decarbonization strategies of both the World Maritime Organization and the European Union, such initiatives will increase and become even more important in the future. Future studies to individually investigate the ports that best implement decarbonization and incentive practices and to standardize this would be very useful.

Acknowledgements

This study is part of the project called Greenport Alliances, funded with support from the European Union's Erasmus+ programme. Project Number: 101139879.

References

- AAPA. (2007). Sustainable Port Development: a Practitioner's Perspective. Retrieved from. http://aapa.files.cmsplus.com/SeminarPresentations/08FINANCE_Degens_Sebastian.pdf
- Alamouh, A. S., Ballini, F., & Ölçer, A. I. (2020). Ports' technical and operational measures to reduce greenhouse gas emission and improve energy efficiency: A review. *Marine Pollution Bulletin*, 160, 111508. <https://doi.org/10.1016/j.marpolbul.2020.111508>
- Alamouh, A. S., Ölçer, A. I., & Ballini, F. (2022a). Ports' role in shipping decarbonization: A common port incentive scheme for shipping greenhouse gas emissions reduction. *Cleaner Logistics and Supply Chain*, 3, 100021. <https://doi.org/10.1016/j.clscn.2021.100021>
- Alamouh, A. S., Ölçer, A. I., & Ballini, F. (2022b). Port greenhouse gas emission reduction: Port and public authorities' implementation schemes. *Research in Transportation Business & Management*, 43, 100708. <https://doi.org/10.1016/j.rtbm.2021.100708>
- Alzahrani, A., Petri, I., Rezgui, Y., & Ghoroghi, A. (2021). Decarbonization of seaports: A review and directions for future research. *Energy Strategy Reviews*, 38, 100727. <https://doi.org/10.1016/j.esr.2021.100727>
- Becqué, R., Fung, F., Zhu, Z. (2017). Incentive Schemes for Promoting Green Shipping. *Natural Resources Defense Council (NRDC)*.
- Christodoulou, A., Gonzalez-Aregall, M., Linde, T., Vierth, I., & Cullinane, K. (2019). Targeting the reduction of shipping emissions to air. *Maritime Business Review*, 4(1), 16–30. <https://doi.org/10.1108/mabr-08-2018-0030>
- COGEA. (2017). Study on Differentiated Port Infrastructure Charges to Promote Environmentally Friendly Maritime Transport Activities and Sustainable Transportation. Study for the European Commission. <https://doi.org/10.13140/RG.2.2.14895.59041>
- CSI. (2024). Clean Shipping Index. <https://www.cleanshippingindex.com/> (accessed 12.06.2024).
- Dinwoodie, J., Tuck, S., Knowles, H., Benhin, J., Sansom, M. (2012). Sustainable development of maritime operations in ports. *Bus. Strat. Environ.* 21 (2), 111–126.
- Ekmekçioğlu A, Kuzu SL, Ünlügençoğlu K, Çelebi, U. B. (2020) Assessment of shipping emission factors through monitoring and modelling studies. *Sci Total Environ.*, 15;743:140742. doi: 10.1016/j.scitotenv.2020.140742. Epub 2020 Jul 5. PMID: 32653717.
- Ergüven, O, Bayırhan, İ., Deniz, C., Gazioğlu C. (2023). Role of Port Tugs in Ship-Borne Emissions: an Analysis in Turkey's Izmit Bay, *International Journal of Environment and Geoinformatics (IJEGEO)*, 10(2):180-186.
- ESPO. (2019). *Environment Report: EcoPorts in Sights 2019*. Belgium, European Sea Port Organization, Brussels.
- EU Climate Action. (2024). What is the EU ETS?, https://climate.ec.europa.eu/eu-action/eu-emissions-trading-system-eu-ets/what-eu-ets_en

- Fadiga, A., Ferreira, L. M. D., & Bigotte, J. F. (2024). Decarbonising Maritime Ports: A Systematic Review of the Literature and Insights for New Research Opportunities. *Journal of Cleaner Production*, 452, 142209. <https://doi.org/10.1016/j.jclepro.2024.142209>
- GA. (2024). Green Award. <https://www.greenaward.org/> (accessed 12.06.2024).
- GM. (2024). Green Marine. <https://green-marine.org/> (accessed 10.06.2024).
- Hoang, A.T., Foley, A.M., Nizetić, S., Huang, Z., Ong, H.C., Ölçer, A.I., Nguyen, X.P., et al. (2022). Energy-related approach for reduction of CO₂ emissions: A strategic review on the port-to-ship pathway. *J. Clean. Prod.* 131772.
- Hossain, T., Adams, M., & Walker, T. R. (2021). Role of sustainability in global seaports. *Ocean & Coastal Management*, 202, 105435. <https://doi.org/10.1016/j.ocecoaman.2020.105435>
- IMO. (2015). Study of Emission Control and Energy Efficiency Measures for Ships in the Port Area. International Maritime Organization, London: UK. <https://doi.org/10.1017/CBO9781107415324.004>
- IMO. (2018). IMO Action to Reduce Greenhouse Gas Emissions From International Shipping. <https://wwwcdn.imo.org/localresources/en/MediaCentre/HotTopics/Documents/IMO%20ACTION%20TO%20REDUCE%20GHG%20EMISSIONS%20FROM%20INTERNATIONAL%20SHIPPING.pdf>
- ITF, OECD. (2018). Reducing Shipping Greenhouse Gas Emissions: Lessons from Port-Based Incentives. International Transport Forum and Organisation for Economic Cooperation and Development, Paris.
- Jameson, P. J. (2022). Shipping decarbonization: why is no one speaking about tugs?, <https://www.linkedin.com/pulse/shipping-decarbonization-why-one-speaking-tugs-peter-jonathan-jameson#:~:text=Today%2C%20over%2021%27000%20tug,7%20million%20cars%20per%20year>
- Jiang, X., Zhong, M., Shi, J., & Li, W. (2024). Optimization of integrated scheduling of restricted channels, berths, and yards in bulk cargo ports considering carbon emissions. *Expert Systems With Applications*, 124604. <https://doi.org/10.1016/j.eswa.2024.124604>
- Kang, L., Meng, Q., & Tan, K. C. (2020). Tugboat scheduling under ship arrival and tugging process time uncertainty. *Transportation Research. Part E, Logistics and Transportation Review*, 144, 102125. <https://doi.org/10.1016/j.tre.2020.102125>
- Kara, G., Emecen Kara, E.G., Okşaş, O., 2022. Estimation of land-based emissions during container terminal operations in the Ambarlı Port, Turkey. *Proc. Inst. Mech. Eng., Part M: J. Eng. Marit. Environ.* 236 (3), 779–788.
- Kasm, O. A., Diabat, A., & Bierlaire, M. (2021). Vessel scheduling with pilotage and tugging considerations. *Transportation Research. Part E, Logistics and Transportation Review*, 148, 102231. <https://doi.org/10.1016/j.tre.2021.102231>
- Liu, Z. (2009). Hybrid Evolutionary Strategy Optimization for Port Tugboat Operation Scheduling. <https://doi.org/10.1109/iita.2009.490>
- Loh, A., Kim, D., Hwang, K., An, J. G., Choi, N., Hyun, S., & Yim, U. H. (2023). Emissions from ships' activities in the anchorage zone: A potential source of sub-micron aerosols in port areas. *Journal of Hazardous Materials*, 457, 131775. <https://doi.org/10.1016/j.jhazmat.2023.131775>
- Martínez-Moya, J., Vazquez-Paja, B., Maldonado, J.A.G. (2019). Energy efficiency and CO₂ emissions of port container terminal equipment: Evidence from the Port of Valencia. *Energy Policy* 131, 312–319.
- Mjelde, A., Endresen, Y., Bjørshol, E., Gierløff, C. W., Husby, E., Solheim, J., Mjøs, N., & Eide, M. S. (2019). Differentiating on port fees to accelerate the green maritime transition. *Marine Pollution Bulletin*, 149, 110561. <https://doi.org/10.1016/j.marpolbul.2019.110561>
- Okşaş, O. (2023). Carbon emission strategies for container handling equipment using the activity-based method: A case study of Ambarlı container port in Türkiye. *Mar. Policy* 149, 105480.
- Ortega-Piris, A., Diaz-Ruiz-Navamuel, E., Martinez, A. H., Gutierrez, M. A., & Lopez-Diaz, A. I. (2022). Analysis of the Concentration of Emissions from the Spanish Fleet of Tugboats. *Atmosphere*, 13(12), 2109. <https://doi.org/10.3390/atmos13122109>
- Paulauskas, V., Filina-Dawidowicz, L., & Paulauskas, D. (2020). The Method to Decrease Emissions from Ships in Port Areas. *Sustainability*, 12(11), 4374. <https://doi.org/10.3390/su12114374>
- RightShip. (2024). GHG Rating. <https://rightship.com/solutions/ports-terminals/ghg-rating> (accessed 11.06.2024).
- Qi, Y., Yang, J., & Qin, K. S. (2024). Spatial-temporal analysis of carbon emissions from ships in ports based on AIS data. *Ocean Engineering*, 308, 118394. <https://doi.org/10.1016/j.oceaneng.2024.118394>
- Sim, J., 2018. A carbon emission evaluation model for a container terminal. *J. Clean. Prod.* 186, 526–533.

- Styhre, L., Winnes, H., Black, J., Lee, J., & Le-Griffin, H. (2017). Greenhouse gas emissions from ships in ports – Case studies in four continents. *Transportation Research. Part D, Transport and Environment*, 54, 212–224. <https://doi.org/10.1016/j.trd.2017.04.033>
- Şakar, G., Çetin, C. (2012). Port sustainability and stakeholder management in supply chains: a framework on resource dependence theory. *Asian Journal of Shipping and Logistics* 28 (3), 301–320.
- Wang, S., Zhu, M., Kaku, I., Chen, G., & Wang, M. (2014). An Improved Discrete PSO for Tugboat Assignment Problem under a Hybrid Scheduling Rule in Container Terminal. *Mathematical Problems in Engineering*, 2014, 1–10. <https://doi.org/10.1155/2014/714832>
- Winnes, H., Styhre, L., & Fridell, E. (2015). Reducing GHG emissions from ships in port areas. *Research in Transportation Business & Management*, 17, 73–82. <https://doi.org/10.1016/j.rtbm.2015.10.008>
- Yang, Y.-C., Chang, W.-M. (2013). Impacts of electric rubber-tired gantries on green port performance. *Res. Transp. Bus. Manag.* 8, 67–76.
- Yu, H., Ge, Y.-E., Chen, J., Luo, L., Tan, C., Liu, D., 2017. CO2 emission evaluation of yard tractors during loading at container terminals. *Transp. Res. Part D: Transp. Environ.* 53, 17–36.
- Yun, P., Xiangda, L., Wenyuan, W., Ke, L., Chuan, L., 2018. A simulation-based research on carbon emission mitigation strategies for green container terminals. *Ocean Eng.* 163, 288–298.
- Zhong, H., Zhang, Y., & Gu, Y. (2022). A Bi-objective green tugboat scheduling problem with the tidal port time windows. *Transportation Research. Part D, Transport and Environment*, 110, 103409. <https://doi.org/10.1016/j.trd.2022.103409>
- Zhu, S., Gao, J., He, X., Zhang, S., Jin, Y., & Tan, Z. (2021). Green logistics oriented tug scheduling for inland waterway logistics. *Advanced Engineering Informatics*, 49, 101323. <https://doi.org/10.1016/j.aei.2021.101323>