Gaining Competitive Advantage through Green Port Technologies – Case of Selected Adriatic and Ionian Ports

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Ports are important transport, industrial and energy hubs that can create the conditions for environmentally friendly operations and therefore influence the greening of the logistics chain. Ports represent a major added value for the European economy as they are points where supply chains intersect and where different stakeholders with different business interests work together. One would think that by now all have a common interest in the environment and the greening of transport; however, this is not always the case as the focus is still often on, performance and profitability maximisation. By correctly and consistently implementing greening activities and new technologies, ports can become role models for other logistics actors. Therefore, appropriate port development strategies must be established. The progressive ports include the greening concepts necessary for the decarbonization of port activities and their sustainable development in general. Ports no longer compete only in terms of their throughput, but also in terms of green development. Ports need to prepare technical, operational and financial measures that promote sustainable development. These include the electrification of port equipment (e.g. electric cranes, trucks or forklifts), the installation of shore power for ships (cold ironing), the use of alternative energy sources (e.g. solar or wind energy), the use of improved energy efficiency technologies (e.g. LED lighting and energy-saving machinery) and environmentally friendly terminal renovations and expansions, etc. Adriatic-Ionian ports could gain a competitive advantage by timely investing in green technologies, as many major shipowners and business partners prefer to work with environmentally responsible ports. The literature review shows that the authors generally use three main groups of parameters to describe ports and their performance: Dimensional parameters (quay length, total and covered storage areas, etc.); Equipment parameters (number of ship-to-shore cranes, different gantry cranes – RTG Rubber Tired Gantry Crane, RMG Rail Mounted Gantry Crane, etc.); Production parameters (number of units handled in TEU – Twenty-foot equivalent unit, tonnage, etc.). In this research, the authors are looking for new parameters that represent the environmental, social and economic sustainability of terminal design and operation on a life cycle basis.

KEYWORDS
~ Ports
~ Container terminals
~ Green development
~ Sustainable development
~ Adriatic Ionian Sea

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1. INTRODUCTION

The geographical area of the Adriatic and Ionian Sea is of great importance for European transport, as it represents the natural link between the main container traffic flows through the Mediterranean and the European continent. The increase in container traffic increases the need for modern and efficient ports. In addition to modern handling equipment, good port organisation and efficient connections to the hinterland, ports are also expected to develop in a sustainable way. Ports are one of the biggest consumers of energy and polluters of the environment, that together with shipping contribute significantly to air pollution in the world. For this reason, green factors are becoming increasingly important in port development, especially in recent years due to the global pressure to reduce the environmental footprint of global logistics and maritime transport.

Today, ports are important transport, industrial and energy hubs that can influence the greening of transport and create the conditions for the environmentally friendly handling of goods. Ports represent a major added value for the European economy as they are points where supply chains intersect and where different actors with different business interests meet. All stakeholders should have a common interest in the greening of transport, but this is often not the case as some still focus on short-term financial gains, productivity maximization and overall cost reduction

Maritime transport and port activities influence their contexts, both directly and indirectly, generating impacts, particularly from an environmental point of view (Cocuzza et al., 2024). The proximity of many ports to urban centres makes the problem of pollution even more acute. However, each measure required to combat climate change quickly and efficiently to ensure sustainable development means additional cost, which is a negative impulse for those involved in the transport chain. While the ports themselves can do a lot within their area, they have little influence on tackling issues outside their area. One way to increase their influence on the decarbonization of the European economy is to collaborate with other actors in the country or region when it comes to developing clean energy solutions.

By correctly and consistently implementing activities in their areas, ports can become role models for other actors in the transportation chain. Therefore, appropriate port development strategies must first be drawn up and the strategies must include the green activities necessary for the decarbonization of activities and sustainable development. The aim of this article is to show how selected ports in the Adriatic-Ionian region are preparing for new challenges by introducing green technologies. Based on the interviews conducted, we have summarised the most important activities of the selected ports.

2. THEORETICAL BACKGROUND

The volume of seaborne trade reached 12,292 million tons in 2023, an increase of 2.4% compared to 2022. According to UNCTAD (2024) the volume of seaborne trade will increase at an annual growth rate of 2% in 2024, with the volume of trade in containers growing by 3%. By 2029, UNCTAD expects total maritime trade to grow by an average of 2.4% annually and containerized trade by 2.7%. This freight is handled at least twice in the ports, often even several times on the way from the port of origin to the port of destination. This is why ports are so important for the global economy (Zanne et al., 2025).

Ports are complex entities that play a critical role in handling various types of cargo to supply their hinterland. Ports contribute significantly to economic and social development of the region and countries. However, they also pose a challenge to the environment, mainly due to port operations, shipping traffic and surrounding transportation activities. In response, efforts have been stepped up in recent years to reduce the impact of maritime transport on the environment. Ports are increasingly committed to decarbonizing the maritime sector - a trend that is expected to continue. As part of these initiatives, ports are pursuing sustainable strategies that balance environmental responsibility with safe and efficient operations (Psaraftis, Zis, 2022). Ports are a driving force for change in the maritime industry. They combine new technologies and sustainable practices to improve operational efficiency, safety and environmental protection. This approach transforms environmental challenges into opportunities for innovation and growth.

Ports compete with each other in terms of throughput (transhipment), but in recent years also in terms of green development. For this reason, one of the first tasks of a port is to prepare technical, operational and financial measures that promote the development of green activities. This starts with the acquisition of handling equipment, without which the port cannot operate. At first glance, switching from the current diesel engines to electric motors may seem like a simple measure, but this is not the case. In addition to the financial investment for the purchase of the new equipment, a new way of operating the equipment, a new infrastructure for charging the batteries and new facilities at the terminals are also required. The second point is a better distribution of modes of transport when it comes to transporting freight from the port to the hinterland. Rail transport must be promoted.

To realise the concept of green port development in the Adriatic Ionian region, it is necessary to integrate environmentally friendly methods of port activities, port operations and port management. In this paper, the authors present potential measures for the establishment of an ecological/green seaport and the opportunities that selected ports are taking or planning to take in becoming greener.

2.1. Environmental indicators

Every year since 1996, ESPO has presented the 10 most important environmental priorities of the European port authorities (ESPO, Environmental Report 2023, Eco Ports in Sights 2023). Monitoring these priorities is crucial for the port sector and other stakeholders. The most important environmental priorities identified by EU port authorities in 2024 are presented in Figure 1.

Figure 1. SPO Top 10 Environmental priorities (Source: ESPO, Environmental Report 2023).

Climate change has become a global challenge. It was first mentioned in their report in 2019 and has now been the most important factor for sustainable port development for 4 consecutive years. European ports are working hard to reduce their GHG emissions and carbon footprint. The impact of climate change is also visible in ports' activities, in planning and building new infrastructure, with the vast majority already considering the potential changes manifesting themselves in the form of strong weather fronts, storms, wind and sea level rise.

Energy efficiency first appeared in 2009 and has always been one of the top three factors since 2013. Energy efficiency assumes reducing energy consumption to achieve the same or even better performance, reducing waste and reducing a port's negative impact on the environment.

Air quality has been one of the most important factors since 2004. The problem arises due to air emissions, mainly from ships in port and port machinery. Ports have been working for many years to reduce this impact, and have implied real-time measurements of air quality, and publicly provide retrieved data.

Noise remains one of the most important factors that the ports continuously monitor and control. The acquisition of modern machinery, which is usually electrically powered, can quickly reduce this negative impact at the terminal. But there is still the negative impact of noise from the ship, which can be reduced by the introduction of cold ironing.

Port development (*land part*) refers to the process of expanding the port, extending or building new terminals, modernising the infrastructure by building road and rail links, building new warehouses or logistics zones to meet the growing needs of maritime traffic.

3. METHODOLOGY

A systematic literature review was chosen as the primary research method to identify and critically evaluate relevant articles and to collect and analyse data from the identified research papers. The aim of the systematic review was to identify empirical evidence relevant to our research area, i.e. the identification of guidelines for the sustainable development and design of container terminals in the Adriatic-Ionian region. All the articles used were published on ScienceDirect, Google Scholar and ResearchGate (Figure 2). A database containing more than 500 articles and 10 dissertations was created. In the next step the articles that stood out the most in terms of content and were most relevant to our research were selected.

The articles reviewed are divided into 3 thematic groups depending on the topic covered, namely: *Port emissions*, including articles dealing with the problem of pollution in ports, from ships and machinery at terminals. Articles describing the possibilities for reducing emissions at terminals and the measures to be taken; *Ship-to-shore power*, including articles analysing the problem of connecting ships to the electricity grid in ports; *Green port & investments*, including articles presenting models for the development of green container terminals.

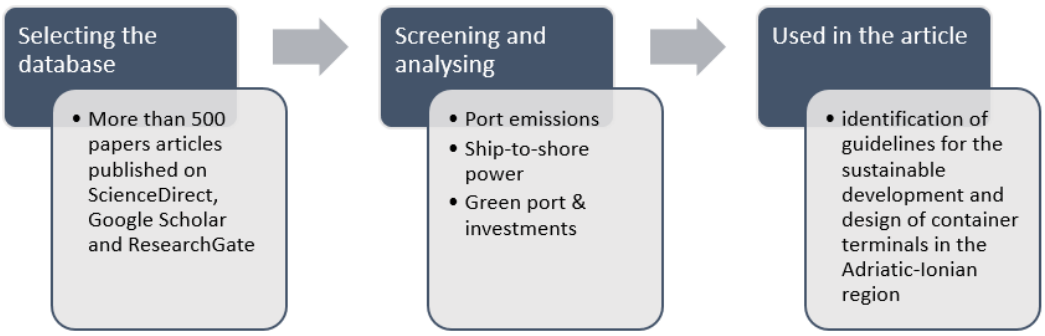

Figure 2. The visualisation of the research methodology applied

3.1. Selected Green port technologies

The articles discuss various technologies for greening ports, such as technologies for measuring port emissions, energy reuse in terminals and other green technologies, and identify green factors that influence the design of container terminals. The selected articles provide an overview of activities in different ports, all aimed at reducing the negative impact on the environment, and provide suggestions for ports to adopt new technologies.

Albo-López et al. (2023) analysed and compared the different methodologies used for the calculation of emissions from ships during their stay in port, through the analysis of a specific cases corresponding to the Ro–Ro ships that call at the Port of Vigo. A simplified estimation of the total emissions from Ro–Ro ships during their stay in port was proposed, using a linear regression curve, as a function of the average value of hours for hotelling of ships in port and the number of ships. Lee H. et al. (2021) collected data from the ships tracking service system with a bottom-up approach to create a comprehensive 2019 local ship emission inventory at Port of Incheon (Korea). They suggested and simulated applicable green policies in practice as realization of local emission control area, ships speed reduction program, application of cold ironing, and establishment of a national integrated emission platform to reduce the volume of emitted emissions in the port. Budiyanto et al. (2019) calculated the total CO_2 emissions from two different energy sources: electricity and diesel fuel. The emissions in a container port were estimated based on modal movements within the terminal area, using data from the terminal's operating records. Mio et al. (2023) on the other hand, dealt with the use of hydrogen in port machinery (including external equipment such as trains) and analysed its use from the economic point of view. This could help ports to make the green transition. Interestingly, their case study is the port of Trieste in the North Adriatic. The main economic factors they have calculated for the use of hydrogen in the Port of Trieste are the energy return on investment (EROEI), the cost of hydrogen (LCOH) and the life cycle analysis (LCA).

A new dynamic simulation model was done in the case study related to the Port of Naples by Buonomano et al. (2023). They specifically developed modern poly-generation systems in ports, which has proven to be a valuable tool. By incorporating different renewable energy sources and implementing a multi-criteria optimization approach, the model can help to design and operate more efficient and sustainable port energy hubs. The model was integrated into a computer program written in MATLAB. Heikkila et al. (2021) analysed the port of Helsinki, which is one of the busiest passenger ports in the world. Passenger ferry and cruise ship terminals are located in the middle of the city, which means that their air emissions are a burden on public health in urban areas. Using port arrivals and departures in combination with EU Monitoring, Reporting and Verifying (MRV), this study estimates that 75–80% of the fuel combusted by ship auxiliary engines fall under the upcoming regulation. However, when using statistical methods to find the associations and effects (to determine the relationship and impact) between ships movements and air quality measurements in the ports, ship departures were found to have noticeable increases in the hourly mean NO_2 concentration measured at the port terminals. This is due to the starting of cold main engines on departure which will not be solved by connecting ships to shore power.

Giuffrida et al. (2021) analyse the port-related problems arising from the implementation of a new container terminal and the associated new port operations. The focus was on air pollution (climate change due to emissions), noise pollution and dredging. In this way, the authors presented a comprehensive decision support framework for the potential planning of terminal optimization aimed at efficient handling of goods transported by container ships while ensuring a minimization of

the environmental footprint associated with these port activities by calculating their impact. The AHP (Analytic Hierarchy Process) methodology was applied as a specific tool for ranking the main Italian ports related to container traffic from the point of view of the governance of the national port system. The port ranking could also support the prioritisation and coordination of public infrastructure investments. Carrese et al. (2022) presented the use of AHP methodology that is divided into three main phases. The first dealt with the construction of the database containing data on port characteristics (e.g. port draft, container terminal area, the ratio between annual throughput and terminal capacity, the catchment area, the overlap index, the PLSCI (Port Liner Shipping Connectivity Index) index used as a measure of maritime connectivity in the global container transportation market, and the presence of rail tracks in the port), the second phase was the scenario building to identify the possible evolution of the port system in terms of container traffic in the Italian context, and the third phase was the application of the AHP methodology for each scenario developed. The AHP method was combined with the scenario planning technique to measure and explicitly consider uncertainty by developing two different scenarios to predict the future development of the port system.

4. SUSTAINABLE DEVELOPMENT OF CONTAINER TERMINALS IN THE ADRIATIC-IONIAN REGION

Adriatic-Ionian ports can gain a competitive advantage by investing in green technologies, as many large shipowners and business partners prefer to work with environmentally conscious ports. This includes the electrification of port equipment (e.g. electric cranes, trucks or forklifts), the installation of shore power for ships (cold ironing), the use of alternative energy sources (e.g. solar or wind energy), the use of improved energy efficiency technologies (e.g. LED lighting and energy-saving machinery) and environmentally friendly terminal renovations and expansions, etc.

The research focuses on three ports, namely Catania, Koper and Bar (Figure 3), where dedicated interviews with port authorities or board members have been conducted.

Figure 3. Analysed ports in Adriatic Ionian area

The questions posed during the interviews were:

1. What do you think are the most important changes port terminals will have to face in the next 10 to 15 years?
2. Operational efficiency: How do you think port terminals can improve their operational efficiency? Are there key technologies or infrastructures that should be integrated?
3. Environmental sustainability: What environmental objectives should be prioritized when planning terminals? What are the most urgent measures to reduce the environmental impact of port activities?
4. Connectivity and infrastructure: How important is for you to connect the port to other infrastructure (rail, road, etc.)? Which investments do you consider a priority?
5. Digital technologies and automation: What digital or automated technologies do you think could revolutionize terminal management? How can they improve safety and productivity?
6. Resilience to future challenges: What challenges do you think port terminals will face (e.g. climate change, increasing traffic, cyber security) and how should they prepare for them?
7. Economic enhancement: What economic objectives (e.g. attracting new traffic, local economic development) should be considered in the design of the terminals?
8. Involvement of local communities: What role should local communities and surrounding areas play in the design and management of the terminals? How can they be involved and benefit?
9. What do you think are the top three priorities that should be considered in the design of port terminals?
10. Is there anything else you would like to add or an aspect we have not covered that you think is important?

The most important foundations are listed in Table 1.

Question	Eastern Sicily Sea Port System Authority	Terminal Container Catania/Augusta	Port of Koper	Port of Bar
1. Main changes that port terminals should face in the next 10-15 years?	Automation and digitization especially for container terminals (to reduce cargo dwell times); ship conversions (changes in power systems, cold ironing, etc.); ship gigantism especially for cruise terminals	Digitization, terminal automation, green technologies for handling equipment	Electrification of the container and passenger terminal. Improvement of in-port traffic flows	Green and smart/digital concept, electrification, automatization
2. Operational efficiency		Cold ironing, electrification, renewable energy	Automated port processes and procedures	Implementation of technologies
3. Environmental sustainability	Energy efficiency of ships and ground handling equipment, cold ironing, power supply for equipment, emission management	Zero emissions, automation	Zero-emission operations (OPS, ABB develops large batteries for ships) and low-emission operations (LNG, methanol, ammonia)	Environmental aspects, reduction of all emissions in the port
4. Connectivity and infrastructure	Rail/road connections, intermodality, integration with logistics nodes, advanced cybersecurity	Rail/road connections, intermodality, integration with logistics nodes, advanced cybersecurity	Rail/road connections, intermodality	Rail/road connections
5. Digital technologies and automation	Truck automation, blockchain, cybersecurity	Management software, automation of handling equipment	Automation or semi-automation of handling equipment	Internet of things, digital twins, automatization of working processes
6. Resilience to future challenges	Climate change, cybersecurity, increasing traffic	Climate change, cybersecurity, increasing traffic	Climate change, cybersecurity, increasing traffic, political instability in Med	Climate change, cybersecurity
7. Economic enhancement	Infrastructure competitiveness, strategic hub, back-port for added value		Investment in the container and the RORO terminals	Investment in infrastructure
8. Involvement of local communities	Public consultations, urban projects, local tourist routes	Comparison tables	Collaboration with the city, support to the societies	Work on minimization of potential effects
9. three most important priorities	Sustainability, efficiency, connectivity	Digitalization, green infrastructure, zero environmental impact	Electrification, digitalization and green development	Productivity, Safety and Security, Environmental Protection
10. Other	No	No	No	No

Table 1: Responses of the port representatives to the questionnaire

From the responses they are aware of the problem. Therefore, they see the greatest investments to achieve environmental efficiency in:

- *Sustainable infrastructure*: where ports are adopting green technologies, such as renewable energy (e.g. solar and wind), more efficient terminals, using alternative fuels (e.g. LNG) and building smart grids to reduce their carbon footprint.
- *Energy efficiency*: ports are optimising their energy consumption, introducing LED lighting and energy-efficient handling equipment
- *Digitalization and smart systems*: automation and use of intelligent traffic monitoring systems to reduce congestion and emissions.

5. CONCLUSION

The advantage of the Adriatic-Ionian ports is their proximity to Central European countries compared to Western European ports, such as Rotterdam, Antwerp, etc. They are located close to important transport routes that connect the Far East with Europe via the Suez Canal and vice versa. This gives them great strategic importance for European and global

logistics. To fully leverage their geographical advantage, ports and countries must invest in the development of hinterland infrastructure. This primarily involves modernizing railway infrastructure, increasing its capacity, and constructing missing sections along key European TEN-T corridors. EU funding, such as the Green Deal, can support these efforts by co-financing projects through various programs like the Connecting Europe Facility (CEF), which promotes the green transformation of ports.

Increasing global maritime container traffic poses new challenges for these ports. To ensure that the Adriatic-Ionian ports can compete with other Mediterranean ports, the existing terminals must be expanded and the cargo handling equipment has to be improved. At the same time, ports must consider the requirements for environmentally friendly and sustainable development of container terminals, i.e. they must use renewable energy sources, increase terminal efficiency and use alternative fuels for port machinery to reduce their carbon footprint. In addition, opportunities for cold ironing of ships in port must be created. Automation systems and intelligent traffic monitoring solutions should also be introduced to reduce congestion and emissions. However, all ports face challenges related to high initial costs, as green technologies and modern information systems are highly demanding and expensive. Another issue is the time constraint, as obtaining the necessary documentation for building modern infrastructure takes considerable time, and procurement processes for port equipment are often lengthy and slow. Additionally, the limitations of new technologies, such as the long lead times and high costs of acquiring new equipment, like batteries and charging infrastructure, affect the implementation of the green transition. International regulatory alignment and harmonization also influence the speed of the shift toward sustainable port infrastructure.

Furthermore, investments in innovative environmental technologies, such as the electrification of port facilities, shore power systems and carbon capture systems are essential to achieve EU and global sustainability goals. Collaboration between ports, shipping companies and policy makers will play a crucial role in promoting green logistics corridors that increase efficiency while minimizing environmental impact. By taking these green initiatives, Adriatic-Ionian ports can position themselves as pioneers in sustainable maritime transportation and secure a competitive advantage in the evolving global supply chain.

CONFLICT OF INTEREST

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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