# Improving Sustainability of Freight Transport in the Port-City Interface Through the Use of Integrated Approaches

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**Abstract.** The ports represent the land-sea interface and the maritime-land transports junction point and are fundamental links of the global logistics chain. Thus, attention must be paid to a complex system, also made up of retro-ports, inter-ports and intermodal logistics platforms, because the port-city interactions, and between the decision-making actors involved in them, are multiple. Maritime transport and port operations generate externalities on the reference contexts in a direct and indirect way, above all from an environmental point of view. Logistics activities also exert further environmental pressure in the port-city interface and retro-port areas where the transported goods are carried at the end of the supply chain. In fact, the traffic of goods entering/leaving ports by road can influence the dynamics of the urban traffic flow. This paper aims to analyses the sustainability of freight transport in the port-city shared areas through the use of integrated approaches. In order to identify the main critical issues and possible solutions, promoting actions and measures that guarantee the efficiency of the transport of goods (and the relative priority of intervention), the research is articulated into different phases. The first concerns the analysis of the main criticalities in the port-city interface and inland port areas. In the second a literature review of state of the art was conducted. Then, common measures and best practices are examined. Finally, different scenarios have been implemented in order to predict the impact that these options will have on freight mobility. This methodology can allow to evaluate different options and to choose the best strategy.

**Keywords:** Port-city logistics · Sustainable maritime transport · Freight transport · Maritime transport policies

## 1 Introduction

The ports represent the land-sea interface and the maritime-land transports junction point and are fundamental links of the global logistics chain. However, maritime transport and port operations generate externalities on the reference contexts in a direct and indirect

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way, above all from an environmental point of view. For years, the policies of the European Union aim at sustainable development, encouraging a competitive, sustainable and safe transport policy. In accordance with the Sustainable Development Goals promoted by the United Nations, in particular with objectives 11 to reduce the per capita pollution produced by cities and 13 for the fight against climate change, the EU targets for sustainable include: to reduce CO2 emissions from the maritime sector at a rate compatible with the Paris Agreement (−40% by 2030 and −70% by 2050 compared to 2008 levels); to protect citizens from harmful exposure to air-borne pollutants; to reduce the pressure on port-city area roads unable to absorb increasing traffic; to promote the sustainable multimodal freight mobility and to mitigate relevant adaptation measures. Also, the intent of the International Maritime Organization (IMO) measures is to reduce emissions (carbon intensity), probably destined to grow if not counteracted quickly, avoiding as much as possible negative effects on trade and economic growth driven by maritime transport.

The port-city shared areas are of crucial importance for the environmental sustainability of mobility, as it is an area where vehicular traffic is particularly intense and can have a significant impact on air quality and greenhouse gas emissions [1]. The transport and logistics activities are not always included in urban and transport plans, but very often they are also carried out by private companies [2].

Thus, sustainable management of the port-city interface and retro-port areas can help reduce the environmental impact of freight transport, thanks to the adoption of more efficient and sustainable mobility solutions. Therefore, from what has been said so far, it follows that sustainable mobility solutions, for these areas, are important for the health and well-being of citizens who may be exposed to high levels of air contamination and noise disturbance.

In order to alleviate the external impacts previously mentioned, it is necessary a comprehensive approach that integrates territorial and mobility planning, port operation management and eco-friendly technologies integration.

In the European context, various measures, which will be described in paragraph 3, have adopted in order to mitigate the environmental impacts of the port-city shared areas.

Sustainability is a very important topic discussed at the level of States, institutions and companies. It is also an important issue for many seaports, port companies and municipal authorities. According to [3] the main sustainable issues for cities are associated with the evolution of more sustainable transport systems but also with architecture and spatial development as well as with energy use and others.

The already mentioned Goals 11 and 13 of Agenda 2030 focuses on the development of sustainable cities and communities and climate change [4]. Starting from this concept it is necessary to highlight how port cities must pay particular attention to sustainability problems due to pollution and noise caused by ships moved in the port and other port activities.

In fact, different factors that affect air quality coexist more than in inland cities, the most important of which are the emissions from ship engines. Port systems are in general the fulcrum of activities related to the sea economy of different contexts such as the Italian one and are scenarios characterized by national and international trade and the transit of goods and the movement of people [5].

Maritime transport also represents an important and growing share of green-house gas emissions produced in our country and ports, often inserted in densely populated contexts, have to face critical issues in terms of acceptance by the citizens who live in the areas where they insist [6, 7].

Fundamental is not only the evolution of strategies to develop and make ports more sustainable and accessible but also the surrounding urban areas [8–11].

The recent pandemic from COVID-19 has also produced, among the many critical issues, the sharp drop in GDP and trade and this has inevitably had a negative effect on Italian ports [12, 13].

This effect was strongly perceived in Italy considering that around 40% of all Italian commercial exchange takes place by ship, a value that rises to 90% for Italian import-export to Asia and America [14].

All Italian ports have experienced significant contractions, even if the ports of the South are more devoted to the energy sector and the agri-food chain and therefore have suffered less from these critical issues [15, 16].

These data are in line with the contraction that has been recorded globally in maritime traffic and containers, the result not only of Covid-19 but also of the growing international trade tensions, especially between China and the United States. The Pacific route had already experienced a significant decline in 2019 after a decade of uninterrupted growth but as of 2022 it has recorded a real collapse with -10%.

Even Suez, taken as a reference port related to the Silk Roads and the traffics that feed the commercial relations between Europe and China, confirms this trend: -15% of passages of large container ships on the route to and from Asia [17, 18].

At the same time, the big carriers, the shipping companies that govern the world market of freight transport by ship, have tried to face the crisis with “blank sailing” operations (cancellation of already scheduled routes) and at the same time with the search for routes and strategies for drastically reduce costs.

For example, the drop in the price of oil, particularly significant in the first few months of the year, saw the return of the Cape of Good Hope route, the circum-navigation of Africa. Certainly, much longer route but which nevertheless be-comes convenient with the low price of fuel compared to the cost of the passage from Suez.

Various signs connected both to the type and frequency of maritime routes underline a phase of acceleration of the process of regionalization of world trade which probably also affects value chains and supply chains. A tangible sign of this is the passages of ships within regional routes (America, Europe-Mediterranean, Asia) and the decrease in passages on global routes [19].

Several studies from 2012 to date have shown that the more ships depart from far away (Asia) and have a port in Northern Europe or the Atlantic coast as their final destinations, the more the center of gravity is shifted towards Gibraltar [20]. Conversely, less distant departure ports or destination ports closer to the Mediterranean area bring the center of gravity more to the centre. A shift of the point of maximum concentration of passages closer to the heart of the Mediterranean and to our country has therefore been observed [21].

The main objective of the paper is to analyze the sustainability of freight transport in the port-city shared areas through the use of integrated approaches.

Identified the main critical issues, the research is articulated into different phases: a literature review of state of the art; an examination of main common actions taken for mitigating environmental impacts and of some best practices to identify the solutions adopted; the implementation of different scenarios in three case studies, in order to predict the impact that these options will have on freight mobility.

## 2 Literature Review

The port-city interface is of crucial importance because the 90% of European ports are located in urban areas and the integrated management of air quality, water, waste, noise and energy consumption must be at the top of the agenda of port authorities and administrations.

The decarbonisation of ports is a fundamental step in strengthening the innovation and competitiveness capacity of the Mediterranean maritime industry. In fact, the port system plays a key role in international trade, in the transport of goods and people and is a vital element for the development of an efficient and sustainable intermodal transport network. The decarbonisation of ports therefore represents a very important environmental and industrial opportunity that the country must be able to seize [22].

Shipping accounts for a large and growing share of greenhouse gas emissions. Emissions associated with port sector are estimated at 940 million tonnes of CO 2 per year, equivalent to approximately 2.5% of global greenhouse gas emissions [23, 24]. These emissions are likely to increase significantly if mitigation measures are not implemented quickly.

In particular, the Mediterranean coast, with its hundreds of densely populated port cities, is heavily affected by pollution from the maritime sector. And, as air pollutants are transported up to 400km, inland areas are also affected [25, 26].

The evolution of port systems and the city-port combination must consider a range of strategies and actions aimed at decreasing emissions and increasing the ‘accessibility of these areas. As regards the strategies to be applied to port activities, various studies in the literature focus on issues related to infrastructure and means, namely:

- The evolution of cold ironing, related to the evolution and application of technologies by means of which it is possible to supply energy to boats while parked in port, through an electrical connection with the mainland, allowing the elimination of pollution and emissions by vessels in port [27].
- The decarbonisation of maritime transport as an intervention aimed at improving the environment and industry, taking into account not only the geo-morphological aspects but also the systems characterizing the European and Italian port system. This aspect is also correlated with the opportunity to achieve the objectives in the fight against the cli-mate crisis [28].
- The connection of ports with the railway network, to build “green” corridors: an opportunity of great interest for the development of sustainable intermodal logistics [29, 30].
- The electrification of short-distance maritime transport, the subject of numerous experiments to improve the sustainability of connections with the smaller Italian islands, is based on the use of renewable sources [31].

The concept of smart port [32] smart port based on the ability of new technologies to transform port services into interactive and dynamic, more efficient and transparent businesses has been spreading for several years.

This aims to meet the needs of customers and users without forgetting its responsibility towards the city and citizens.

Often the complexity of maritime transport and the lack of a unified system of indicators to evaluate smart ports slows down the implementation of more sustainable and participatory planning.

A limited number of research studies to date define a set of useful indicators to facilitate these actions.

In particular, the study conducted by [33] introduced 25 evaluation indicators and evaluated the key indicators of the quality of the smart port service and their causal relationships, revealing that the main success factors of smart ports are: the accurate and safe delivery of the load together with the accurate transfer of electronic documents. The factors associated with a rapid supply of port berths are also fundamental in order to shorten the rotation times of the ships; convenient and complete logistics and customs practices; transparent integration of in-formation on a single platform; and finally, the use of big data to organize container transport.

A study conducted by [34] points out that a spread of digitization combined with careful planning and management of port operations allows to find intelligent solutions to optimize logistics and environmental impacts, promote efficiency and improve the security of both seaports and the coastal regions involved.

Some studies have developed methodological approaches and have promoted some design applications, in terms of urban regeneration.

With reference to the Italian context, the study conducted by [35] started from the definition of urban regeneration to arrive at the identification of a circular approach and key issues applicable to the case study of Genova Pra'-Palmaro.

Still in the Genoese context, a study conducted by [36] proposed an optimal management strategy for a Smart Port equipped with renewable generation and composed of an electrified quay, operating Cold-Ironing, and a hydrogen quay, supplying ships with zero emissions.

Another study conducted by [37] defined the steps for the activation and co-ordination of a locally integrated partnership towards the development of a multi-term Smart Port Management Strategy to support innovation processes in the sustainable and safe management of the port of Ravenna.

The main methodologies for the mitigation of environmental impacts and best practices were analysed to identify the actions, processes or strategies that have led to positive results in other contexts.

## 3 Main Methodologies for the Mitigation of Environmental Impacts

The port-city shared areas are critical for the environmental sustainability of mobility, because the vehicular traffics are particularly intense and can have a significant impact on air quality and greenhouse gas emissions. Therefore, sustainable management of

these areas can help reduce the environmental impact of vehicular traffic by promoting the adoption of more efficient and sustainable mobility solutions. In addition, these externalities can be, due to the high levels of air and noise pollution, a risk for the health and welfare of citizens and, above all, of residents.

Logistics activities also exert further environmental pressure in these areas where the transported goods are carried at the end of the supply chain. In fact, the traffic of goods entering/leaving ports by road can influence the dynamics of the urban traffic flow. These emissions are likely to increase significantly if mitigation measures are not implemented as soon as possible and effectively. Thus, also thanks to a reconnaissance in the international sphere, some main common actions taken for mitigating environmental impacts were identified and reported in the following Table 1:

**Table 1.** The common practices for mitigating environmental impacts

| IMPACTS | METHODOLOGY | ACTIONS |
|---|---|---|
| Noise generated by ships and port and logistics activities affecting quality of life of people living near the port | Use of noise emission control systems | Use of noise mitigation techniques (construction of noise barriers) |
| | | Relocation of heavy port activities |
| Emission of exhaust gases and other pollutants to air and water generated by ships and port and logistics activities | Implementation of environmental emission control, management and monitoring systems | Integration of filtration systems for ship |
| | | Management of port-generated waste |
| | | Implementation of strategies for managing wastewater and preventing pollution |
| | | Use of sustainable energy sources for port operations |
| | Development of low-emission zones | Introduction of speed limits, access restrictions and the adoption of low-emission technologies |
| | Promotion of alternative modes of transportation | Promotion of walking and cycling, the use of public transport and electric vehicles |
| | Digitization of port processes | Adoption of automation processes, process cargo at a higher speed with less error and increase their effectiveness |

(*continued*)

**Table 1.** (*continued*)

| IMPACTS | METHODOLOGY | ACTIONS |
|---|---|---|
| | Improving efficiency and safety | Use of innovative technologies such as Internet of Things, robotics and artificial intelligence |
| | Optimizing logistics processes | Use of port activity planning and management techniques to reduce waiting times |
| | Use of energy sources with low environmental impact | Use of environmentally friendly vehicles and fuels |
| Overlapping. Flows between network with local functions and goods distribution networks | Adoption of solutions to improve the efficiency of port and logistics traffic | Analysis of traffic flows through the use of mathematical models to identify critical points in the port system and interface area |
| | Involvement of the local community in decisions regarding port activities and environmental impact assessment | Inclusion of public consultation and participation in the planning of port activities |

From what has been said above, it would be useful to identify some phases necessary to develop sustainable development strategies.

- Conduct a thorough examination of the port-city shared area in order to identify main critical issues and development opportunities.
- Engagement of different internal and external stakeholders, to foster shared and inclusive planning. In fact, given the consolidated importance of freight transport in urban areas, it is necessary to foster the cooperation among all stakeholders implicated at different levels. This further highlights the need to adopt an integrated approach as it demands the harmonized coordination and implementation of long-term policies and initiatives among the involved parties.
- Establish a coherent vision and objectives for the port-city connection area based on the assessment of the current situation.
- Plan appropriate infrastructure and related services to ensure the safe and efficient flow of traffic, support for commercial activities, and accessibility for residents.
- Adequately ensure cooperation and coordination among the various authorities involved in the planning and management of the port-to-city interface area. This may include establishing coordination mechanisms between local authorities, the port, businesses, and other stakeholders.
- Regularly monitor and evaluate the effectiveness of planning and implemented actions to ensure that objectives are being met and to identify any areas for improvement.

This means that port cities should work with stakeholders to ensure the necessary infrastructure for the development of the port and the city [38] city. They must have a clear and creative vision of the goals they want to achieve.

In the European context, several ports have adopted an integrated approach to mitigate the environmental impacts of the port-city interface. Therefore, some best practices have been reported briefly:

- In Rotterdam was developed a strategic plan for sustainability that aims to reduce CO2 emissions, increase energy efficiency, and promote inter-modality. The port has created a "Low Emission Zone" in the port-city interface areas to reduce air pollution caused by vehicle emissions. It partnered with municipal and provincial administrations to outline the criteria for authorized vehicles and entry zones, thus curbing private vehicle circulation. Consequently, the Rotterdam Harbor has witnessed a notable decrease in particle and nitrogen dioxide discharges within the harbor-urban interface.
- In Hamburg was adopted a strategy diminishing private vehicle circulation and advocating for interconnectivity. Has been formulated a traffic supervision system to enhance transportation effectiveness.
- In Valencia have been implemented various initiatives to enhance the ecological balance of the harbor-city shared areas, including harnessing renewable energy sources, fostering intermodal transportation, and instituting a traffic regulation mechanism.
- In Copenhagen has been implemented a sustainability blueprint geared towards diminishing CO2 discharges, advancing interconnectivity, and refining energy productivity. Thus, it has incentivized the utilization of eco-friendly technologies and instituted a shoreside power network for vessels to curtail the utilization of diesel generators while docked. Furthermore, the port has collaborated with municipal administrations to refine the harbor's accessibility and reduce individual vehicle circulation.

Among the various initiatives aimed at reducing greenhouse gas emissions, it is worth mentioning those promoted by the Port of Valencia through the application of renewable energy sources, the installation of shore-based electricity for ships and the promotion of intermodal transport and implementation of a traffic control system.

Furthermore, it is also necessary to remember the actions to promote alternative transport systems such as electric vehicles and bicycles. Finally, the port has introduced recycling and waste reduction programs and is promoting the use of recyclable materials in the port area.

## 4 Case Studies

All of the above strategies have produced a significant reduction in greenhouse gas emissions and an improvement in air quality in the port-city interface areas.

From this it is possible to draw inspiration to consolidate in other contexts a series of synergistic actions that can be achieved by local authorities and port authorities through the development of the following factors:

1. Integrated infrastructure planning:
   - Develop a comprehensive and integrated infrastructure plan focusing on the port-city area and including the different types of infrastructure and transport services that connect both areas and beyond.
   - Ensure the development of port structures in line with the overall urban development plan of the city. In this sense, it is necessary to apply an integrated approach to increase the sustainability of freight transport in the port-city areas.
2. Economic diversification:
   - Promotion of the development of industries and businesses near the port. These could, for example, be logistics companies, manufacturing plants and distribution centers.
   - Create special economic zones or industrial parks near the port attracting more businesses that can benefit from the port's services.
3. Urban redevelopment:
   - Use port development as a catalyst for urban regeneration through the enhancement and revitalization of port areas and public spaces and parks to improve the overall quality of life of citizens
   - Combine residential, commercial and recreational areas to create an integrated and sustainable environment.
4. Environmental sustainability:
   - Define and apply actions to combat environmental pollution through, for example, the reduction of emissions, the introduction of green infrastructures and the promotion of sustainable transport options.
   - Increase the number of green spaces and improve the seafront to improve the aesthetic appearance of the city while contributing to environmental sustainability.
5. Cooperative management:
   - Encourage collaboration between port authorities, local government and community stakeholders to make resolutions of critical issues, mitigation of impacts and participation of all stakeholders more effective
   - Establish joint committees or working groups to oversee the coordinated development of the port and the city.
6. Promote tourism and culture:
   - Starting from the historical and cultural significance, promote a series of actions to increase the tourist influx. In particular, to promote the development of cultural sites and promotion of heritage near the port and create attractions that attract visitors and contribute to the city's economy.
   - Promote events and festivals that celebrate the port's maritime heritage and attract both residents and tourists.
7. Education and innovation:
   - Foster the creation of educational and research bodies and institutes focused on maritime studies, logistics and related sectors. This action can encourage the increase in the qualified workforce and can promote technological evolution in the port and logistics sector

- Encourage collaboration between universities, research institutes and businesses, promoting innovation and technological progress applied to port operations.

In this way the port-city combination can be characterized by a dynamic and sustainable environment in which both entities thrive, to develop and support each other [39].

After having analyzed critical issues and some common practices adopted in the international sphere, different scenarios have been implemented in order to predict the impact that these options will have on freight mobility in three case studies analyzed: Catania (Italy), Trieste (Italy) and Koper (Slovenia). These are three medium-sized cities, which enjoy a strategic location and whose ports are important drivers of their regional economies. When comparing the city-port connections various factors such as transportation infrastructure, logistics, urban planning and overall integration are taken into account. In the Table 2 is a comparison for selected cities.

**Table 2.** The city-port connections

| | Catania | Trieste | Koper |
|---|---|---|---|
| Geographical proximity | Port is close to the city, making it easily accessible for businesses and residents | Located close to the city center and is easily accessible for residents and businesses | Well-integrated port near the city center that is easily accessible to both residents and businesses |
| Transportation infrastructure | Port is connected to the city via the road and rail network, which facilitates the transportation of goods<br>Catania's location in Sicily makes the city a strategic gateway for trade between Europe and North Africa | Port is well connected to the road and rail network and serves as an important transportation hub for goods moving through Central and Eastern Europe. Trieste has excellent connections to the most important European markets | A well-developed road and rail network connects the port with the city and the surrounding area, enabling efficient transportation of goods<br>Koper is part of the Trans-European Transport Network (TEN-T), which ensures connectivity at European level |
| Logistics and trade | Port of Catania handles a variety of goods, including containers, bulk and general cargo, the logistics services contribute to the efficiency of trade operations in the region | Trieste is an important hub for container traffic, ro-ro services (roll-on/roll-off) and logistics activities<br>The free port of Trieste enables efficient customs procedures and thus contributes to its role as a strategic trade gateway | Koper is an important logistics center offering services such as warehousing, distribution and customs clearance<br>Various types of goods are handled in the port, including containers, cars and bulk goods |

(*continued*)

**Table 2.** (*continued*)

| | Catania | Trieste | Koper |
|---|---|---|---|
| Urban planning | Urban planning in Catania is likely to focus on harmonizing port activities with the overall development of the city, taking into account factors such as land use and traffic | The city and the port are integrated into the urban fabric, and urban planning takes into account the coexistence of port activities with other urban functions | Urban planning in Koper emphasizes the integration of port activities with the development of the city to ensure a symbiotic relationship |

This overview provides a starting point for a detailed comparison. It's important to delve deeper into specific aspects based on your focus areas or criteria for evaluation. Additionally, considering the most recent developments or changes in each location will provide a more accurate picture.

## 5 Discussion and Conclusions

This paper aims to highlight some solutions to accelerate the decarbonization of maritime transport and the reduction of pollution in port systems not only be-cause a reduction in the use of fossil fuels is imperative in the fight against cli-mate change, but also because the containment of the environmental impact of port activity as a whole is crucial for the sustainability and public perception of these areas.

It also pays special attention to the challenges by the port-city interface, as outlined in the preceding sections, because it is evident that sustainable freight transport requires a multifaceted approach that integrates environmental, economic, and social considerations. The policy frameworks set forth by the European Union and other global entities provide important guidance for addressing these challenges, with an emphasis on reducing emissions, promoting inter-modality, and protecting public health. However, effective implementation of these policies necessitates collaboration among various stakeholders, including port authorities, local governments, businesses, and community representatives.

Therefore, the methodological comparison, previously described, allows us to define some impact mitigation actions, i.e. they offer a basis for the selection of practical solutions which may concern, for example, emission control systems and/or the digitalisation of port services.

These strategies not only make it possible to mitigate environmental impacts but bring benefits in terms of increasing operational efficiency and safety.

The case studies presented, namely the ports of Rotterdam, Hamburg, Valencia and Copenhagen, highlight the need for proactive measures such as the creation of low-emission zones and the integration of renewable energy in order to improve and make the port-city commubio more sustainable.

Among the actions to be promoted are:

1) increase in synergies between ports and port cities (for example through integrated infrastructure planning and economic diversification) which offer valuable ideas for holistic development strategies.
2) promotion of innovation in order to create dynamic and sustainable urban and port environments.
3) highlight specific actions and challenges as understood from the case study of Catania, Trieste and Koper.

In conclusion, improving the sustainability of freight transport at the port-city interface requires integrated approaches, aimed at mitigating environmental impacts and therefore at greater sustainability and improving competitiveness.

This could also bring medium and long terms benefits to residents living in the immediate vicinity of the port areas.

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