

Review of the Climate Change Resilience Measures in Port Context

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Abstract. Ports are one of the least sustainable places in the world. Port operations' negative externalities contribute significantly to global warming, representing a threat especially to human and animal communities living nearby. Simultaneously, ports, alongside coastal areas, are starting to be seriously affected by climate change hazards, with numerous environmental and economic implications. This paper investigates different climate change resilience strategies to be implemented in the port context, arguing for the importance of such action beings ports the direct stakeholders of climate change from both sides of the same coin. Through a comprehensive and organic approach, it analyses five different lines of action aimed at reducing the negative externalities of port's operations, enhancing port's climate resilience and protecting the surrounding environment: adaptation, mitigation, soft measures, nature-based solutions and digitalization. Finally, it explores the case study of the port of Rotterdam, an excellent example of a committed port in terms of climate resilience, ultimately demonstrating the efficiency and validity of a holistic approach to climate change resilience in the port context in terms of emissions reduction and environment resilience.

Keywords: Port Development · Sustainable Ports · Climate Change

1 Introduction

This paper aims to study in a conjunctural manner the variety of measures aimed at climate change resilience to be implemented in the port context, arguing for the importance of the role of ports in climate change resilience development, being the directs stakeholders of climate change both as contributors and as victims [1].

In fact, ports can be described as one of the least sustainable places in the world from two perspectives. On one hand, ports contribute to climate change in terms of global warming through negative port externalities, which refer to shipping activities in port, to activities on the port land, and to the hinterland transport to and from the port. In fact, ports contribute to global warming through the emission of greenhouse gas emissions, as well as through Common Air Contaminants (CACs) [2, 3]. Although maritime transport is considered one of the most efficient and clean modes of transport

© The Author(s), under exclusive license to Springer Nature Switzerland AG 2026
O. Gervasi et al. (Eds.): ICCSA 2025 Workshops, LNCS 15894, pp. 142–155, 2026.
https://doi.org/10.1007/978-3-031-97648-3_10

in terms of emissions per unit of cargo carried, even if this data considers the whole maritime transport emissions, the majority of negative impacts occur at port level, given the location of the majority of ports in urban areas (90% in Europe), particularly affecting human and animal communities living nearby port terminals [4]. In addition, other negative impacts of ports include water and soil pollution, toxic waste deriving from oil spills and leakages, and dredging, resulting in the degradation of natural environment and harm on the local biodiversity [5]. Moreover, ports are the cause also of problems related to noise, light, traffic, odor, dust, as well as social and security issues and land-use conflicts, ultimately being detrimental to human and animal health physically and psychologically [6].

On the other hand, ports, alongside coastal areas, are starting to be seriously affected by climate change hazards, resulting in numerous environmental implications and significant economic losses for the sector [4]. Being located in coastal areas, as well as in low-lying estuaries and deltas, ports are particularly exposed to climate change hazards, leading them to be frequently affected by sea level rise, floods, increased frequency and intensity of storm surges, winds and waves, riverine and pluvial flooding, extreme temperature and precipitation variability, drought, heat waves, land erosion and degradation, and ocean acidification [7]. This results in damages of sea, road and rail infrastructure and equipment, poor visibility, decreased maneuverability of locks and vessels, ship-to-ship accidents and limited traffic, ultimately leading to operational disruptions and delays across global supply chains with extensive economic and trade-related losses [8].

Based on a review of the state of the art, this paper investigates the existing and potential climate resilience measures to be implemented in the port context, through a holistic analysis considering five different levels of analysis: adaptation, mitigation, soft measures, nature-based solutions and digitalization. In particular, the second paragraph explains the data and methods through which the analysis had been conducted; in the third section will be presented the case study of the port of Rotterdam; in the fourth will investigates the main results of the research and, finally, in the fifth paragraph the conclusions will be carried out.

2 Data and Methods

In order to conduct the research, different resilience strategies have been considered as data. In particular, they can be categorised as follows: adaptation; mitigation; soft measures; nature-based solutions; and the role of digitalisation. These strategies act on the two aspects of ports' sustainability: on one hand, on the reduction of ports' negative externalities, and on the other, on the enhancement of ports' infrastructure resilience against climate change threats [9, 10]. Moreover, they also contribute to the protection of the natural environment surrounding the port area, ultimately enhancing environmental resilience in a comprehensive way [11]. Finally, it is worth noting that even if the classification utilised for the purpose of the research differentiates between various areas of intervention of port resilience, they may overlap in some aspects [12, 13]. In order to outline the main climate change mitigation and adaptation strategies in the port context, the methodology schematically represented in Fig. 1 was implemented (Fig. 1). The conceptual framework developed above identifies the main five macro-categories of

intervention, which are further articulated, gradually narrowing the focus, particularly with regard to mitigation measures, which are in turn articulated, with reference to the energy transition in five different sub-categories: fuel switch, electrification, wind and solar energy, carbon capture, utilisation and storage and modal shift. All these aspects will be presented in detail in the following sections and then considered and integrated holistically into the case study.

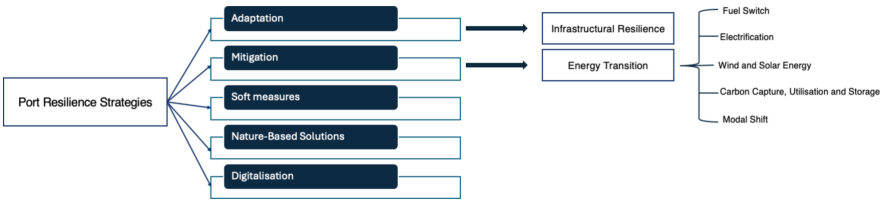


Fig. 1. Schematic representation of the methodology applied. Authors' elaboration.

2.1 Adaptation – Infrastructural Resilience

Climate change resilience in the port context means first and foremost adaptation. The concept of adaptation revolves around the one of vulnerability: it refers to measures aimed at the reduction and minimisation of climate change consequences, through their prevention. It is considered a more passive response: it acts on the effects of climate change adjusting natural and human ecosystems to moderate the negative outcomes [14, 15]. In general, it refers to large-scale infrastructure changes and behavioural shifts, such as water management, coastal defence, sustainable land use planning, green infrastructure, disaster risk management and warning systems, and eventually relocation and resettlement [16].

In the port context adaptation translates mainly into infrastructure resilience: the enhancement of the resilience of existing coastal transport infrastructure and/or the construction of new infrastructure. In the first context, it refers to prevention and mitigation of hydrogeological risk, through the construction of defence infrastructure and water management, as well as building energy saving and streamlining, whereas, the latter refers to the design of new infrastructure and the relocation of existing one in the worst case scenario [17]. The most widespread initiatives refer to the flood proofing of existing infrastructure, given the projected increase in sea level rise along coastlines, including the collection and drainage of water [7, 18]; storm water pumps and culverts; design upgrades as the elevation of structures and port lands above flood levels, for instance docks and roads raising; and hard defence elements such as construction of flood barriers, dykes and breakwater walls [12, 19].

In the worst-case scenario, however, the prevention of hydrogeological instability can also mean retreat from high-risk areas. This entails the relocation of buildings and services, such as terminal, buildings and productive systems delocalisation or eventually the whole port relocation on new port sites [20]. At present, there are no examples yet of relocation of ports for climate change-induced impacts, however, there are some

examples of ports that relocated due to land use problems and conflict of interests with the urban area due to urbanisation expansion and few opportunity costs, which as saw in the previous paragraph, can be also included in negative port impacts. This is the case of the ports of Busan, Shanghai, Rio de Janeiro, Marseille, Kolkata and Bremen [21, 22].

2.2 Mitigation – Energy Transition

Mitigation is considered the most classical and widespread approach to combat climate change: while adaptation is a temporary solution, mitigation represents the only long-term solution to save the planet [23, 24]. If adaptation focuses on the effects of climate change, mitigation acts on the causes: it aims at the reduction of the greenhouse effect through the implementation of human-made measures finalised at the reduction of the sources of these gases or by the enhancement of their storage [25]. These measures imply long-term strategies aimed at net zero emissions to limit human-caused global warming and they include the transitioning from fossil fuels to very low- or zero-carbon energy sources, widespread electrification, approaches of carbon capture removal, energy generation diversification and green energy supply sector, and modal shifts [23, 26].

Fuel Switch

The most ambitious energy transition element is the switch from fossil fuels to clean fuels in the maritime transport. Among the low-emission ones we identify especially Liquified Natural Gas (LNG), hydrogen, ammonia, and biofuels [27, 28].

Firstly, LNG is a consolidated and available technology particularly useful for the reduction of sulphur content in fuels, however its GHG reduction is still questionable, and it faces storage challenges and security issues. Secondly, hydrogen represents one of the most promising clean solutions, however only when "green", that is, produced solely with the use of renewable energy [29]. Thirdly, renewable ammonia represents another most auspicious solution, given its stockage and transport ease, however, its main challenge is represented by its toxicity leading it to be currently banned by the International Code of Safety for Ships using Gases or other Low-flashpoint Fuels [28]. Finally, biofuels represent an innovative solution for transforming waste to energy, however they still face technology and industry immaturity [30, 31]. Nevertheless, although the majority of these technologies are still limited, unexplored, or too expensive, unsafe or with a marginal impact, their widespread experimentation is expected to grow, prompting future innovation and technologies, ultimately leading to a significant oil demand decrease by 2050 [32, 33].

Electrification

Electrification in the port context represents another important cost-effective strategy able to reduce emissions of port and cargo-handling operations.

On the one hand electrification refers to the adjustment or replacement of existing diesel port equipment with electric machines, that applies to vehicles, to land-side terminal or cargo handling equipment such as terminal tractors and mobile harbour cranes, and to some extent to vessels, resulting in fully electric solutions or hybrid diesel solutions [34, 35]. The use of batteries for electric naval engines is still experimental and faces problems of resilience, velocity and distance, however they are projected to reach

a fast development, also in the light of already existing cases of electric vessels around the world [36].

On the other hand, electrification implies the use of the technology of the "cold ironing", otherwise called On Shore Power Supply (OPS), referring to the possibility to provide electricity connection to docked ships while berthed and during overnight stay, as an alternative to the use of power to keep ship services and functioning available. Its benefits include the reduction of pollution and emissions from ships in the port, mainly small vessels, cruises and container, improvement of air quality and noise mitigation [37]. Despite requiring huge economic investments, it represents an available and technologically mature solution, which is already a reality in numerous ports, especially in Europe, with Helsingborg, Gothenburg, and Venice as leaders [38].

Wind and solar energy

Among renewable energy, wind and solar energy (and to a less extent wave and tidal energy) are the most widespread renewable energy sources produced within port areas in the context of the decarbonisation effort [39, 40].

On one hand, as an on-site power, it is used to power port office buildings, sheds, workshops, surrounding buildings, port equipment and vehicles, and in some cases OPS.

On the other hand, offshore wind and solar energy is projected to become one of the fastest-growing renewable energy markets, through the transmission of electricity to public grids with an onshore substation. Its challenges include availability of land, landscape integration and ecology, limited funding, and overcapacity [41, 42].

Carbon Capture, Utilisation and Storage (CCUS)

Carbon capture, utilisation and storage technologies can be used to capture CO2 for objectives of use or storage underground, in order to reduce or permanently remove CO2 emissions from industrial activity and energy generation (such as blue hydrogen). As regards the capture of the CO2, it is compressed, chilled, and transported mainly through pipelines to an offshore storage site. Whereas, in the case of the utilisation, it is reused in other production cycles which reduce its concentration in the atmosphere, such as in industrial, synthetic fuels, chemical and building materials productions [43]. Despite representing a temporary solution, it is one of the few technologies able to tackle emissions from heavy or energy-intensive industries, including those in the surrounding port areas, and is expected to play an important role in the energy transition especially as concerns hydrogen production [44].

Modal Shift

Finally, modal shifts constitute another method that port authorities and transport agencies can employ aiming at reducing emission related to the maritime transport. In particular, emissions generated by rail transport account for a third of those generated by road, therefore ports are encouraging shifts from road transport to rail one in the hinterland area [45]. Moreover, it is also effective in reducing port-related traffic congestion, especially the truck-related one, as well as creating green corridors between ports and major rail nodes [46, 47].

Another efficient shift, apart from rail transport, is towards water, such as by inland waterways, pipelines and short sea shipping. An effective way to reach the modal shift is

through tax, subsidies, and incentives schemes, however, not all ports are well connected to railway lines and systems of inland waterways, with the Northern Range ports being the most developed in this sense [48].

2.3 Soft Measures

In addition to infrastructure resilience and the energy transition, other complementary measures can contribute to the reduction of port emissions and the containment of its external negative impacts, the so-called soft measures. While hard measures include capital-intensive, large, complex, inflexible technology and infrastructure, soft measures require natural capital, community control, simplicity and appropriateness.

In the port context they refer especially to port incentives for some ships behaviours. These include encouraging the reduction of steaming speeds through the use of velocity indexes; rewards or lower ports dues, taxes and fees based on the environmental performance of ships; the delivery of training programs to raise awareness on sustainability; old truck retirement programmes and reduction of turnaround time; the promotion of services such as antifouling treatments, hull cleaning and propeller polishing to prevent organic or inorganic deposits to cause friction, and of ballast water management to reduce hull stress.

Moreover, as regards the reducing of external negative effects of harbour activities, soft measures include wastewater management through the creation of wastewater reception facilities; strategies to cope with sewage, sludges and oil spills; solid waste management; marine debris reduction; and circular economy measures. While as regards the reduction of social impacts caused by port activities they act on the reduction of port and shipping noise through noise impact assessments, engine silencers, port layout and design change, insulation of buildings, buffer zones; as well as land use mitigation through alignment of port and city land use plans, and the reduction of traffic congestion.

2.4 Nature-Based Solutions

Nature-based solutions are multifunctional measures that can be categorised in between adaptation and mitigation. They refer to solutions provided by nature itself, devoted to the conservation, the protection, the restoration and the management of the Earth's ecosystems in order to reduce its climate vulnerability, ultimately protecting and creating benefits for human and animal communities living in them [2, 50].

They include forest conservation, wetland restoration, biochar burial, peatland conservation, soil conservation, green roofs and walls, urban open spaces, forests, community gardens and wind breaks, improved plantation, cropland management, grassland restoration, agroforestry, and river management. In the port context flood risk reduction and coastal management are relevant, translating into natural dunes creation, beach nourishment, oyster beds, salt marshes, restoration of floodplains and tidal wetland, and rainwater capture [51, 52].

2.5 Digitalisation of the Processes

Finally, the digitalisation of port activities and services can be also included in the aspects of sustainability in ports. Smart ports or ports 4.0 are ports that prioritise digital

innovation in the context of automation, sustainable development and collaboration, utilising interface technologies, such as IoT and visualisation [53]; network technologies, such as cloud, blockchain and cybersecurity; and data processing technologies to support decision-making, such as big data, machine learning and simulation [54, 55].

It the port context the following measures are significant in terms of climate change resilience: the provision of forecasting and warning systems against climate hazards, especially flood-related; land and sea traffic optimisation and monitoring; logistic chain optimisation and predictability; facilitation of shipping virtual arrival; container terminal automation and operation systems; port community systems to share information; drones to identify leakages and pollution; digital twins and virtual prototypes; and prevision of ship behaviour, efficiency and performance. This results in improved terminal operations efficiency, more fluent hinterland and seaside traffic, reduction of ships path and time, errors and risk reduction, ultimately leading to a reduction of energy use and therefore of air emissions [56].

Finally, despite challenges in terms of lack of standardisation, cultural barriers, and inadequate infrastructure, this process demonstrated that ports are becoming places where information circulates and is generated, ultimately characterising ports apart from as logistic hubs and energy hubs, also as information and data hubs [57, 58].

3 Application of the Climate Change Resilience Measure: The Case of Rotterdam

This research demonstrates the effectiveness and validity of the implementation of a holist approach to enhance port's sustainability aspects. In particular, it shows how the implementation of five different climate change resilience strategies – adaptation, mitigation, soft measures, nature-based solutions, and the role of digitalisation – succeed in reducing port's negative externalities, in enhancing port's climate change resilience and in protecting the environment. Firstly, adaptation measures provide for strategies aimed at protecting the existing infrastructure and at maximising their resilience power especially towards flooding events. Secondly, mitigation measures are able to reduce considerably greenhouse gas emissions produced by port operations inshore and offshore, and allow for the exploitation of renewable energy. Thirdly, it highlights also the role of complementary measures in the path towards ports' climate resilience. In fact, soft measures improve the relationship between the port and the community by reducing externalities such as noise and light pollution, ultimately complementing mitigation measures in the light of the decarbonisation process. Additionally, nature-based solutions protect and improve the surrounding environment also creating recreational opportunities. Finally, the implementation of digitalisation in ports allows for an enhanced logistic efficiency and optimisation. The results of this comprehensive approach are particularly visible as regards the case study of the port of Rotterdam. This port is an outstanding example of a committed port in terms of climate resilience, characterising as the "greenest" port in the world for its effort in reducing greenhouse gas emissions and improving flood resilience [59–61]. In particular, as regards adaptation it excels in terms of adaptation to sea level rise through flood risk management systems, among which the Maeslant barrier constitutes a world primacy. Moreover, as regards mitigation, it is notable for the

production and utilisation of alternative fuels, with special reference to the hydrogen industry and to the technology of the cold ironing, as well as to carbon capture systems, ultimately making the port a world leader in their supply chain [62, 63]. Finally, the use of a circular economy approach, the reduction of noise pollution, the promotion of sustainable shipping awards, as well as the protection of natural areas and biodiversity and the use of digital platforms for transport efficiency contribute to the ports' path towards transport and operations sustainability. As a result, it is highly probable that the port of Rotterdam will reach its climate neutrality objective by 2050, constituting a world example on climate resilience commitment and success [64, 65].

4 Results and Discussion

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As the analysis showed, ports and sustainability represent an oxymoron, yet, it is precisely for their involvement as direct stakeholders of climate change, that it is crucial to act on port climate resilience. The case study demonstrates how the implementation of a wide range of climate resilience strategies in the port context are able to counter climate change consequences both from as contributors and as victims. As a result, it is deemed necessary the implementation of climate resilience polities in the port context aimed at reducing their negative externalities and enhancing their climate resilience [3, 41].

Despite the premature and pioneering concept of port sustainability and the difficulty of translating these objectives into laws, given the "creeping" nature of the climate crisis - for which the prediction of its consequences is difficult and requires long-term plans - numerous initiatives can be found at international, European and national levels. In this context the following initiatives are relevant: the effort of the United Nations Convention on the Law of the Sea on the reduction of pollution from ships and of the International Maritime Organization on emission reduction and energy efficiency targets; the European Union "Fit for 55" Package on energy efficiency, diversification and independence, carbon dioxide management mechanisms, waste management, power supply, nature restoration and intermodality; and the Italian National Recovery and Resilience Plan on energy transition, digitalisation, and sustainability and the National Climate Change Adaptation Plan on adaptation [14].

Worldwide, the ports that choose to prioritise environmental conservation and sustainability are increasing. In particular, the endorsement of sustainability in the port and maritime transport context is prompting the experimentation and development of new technologies, including engineering, technological and chemical ones, contributing significantly to the reduction of negative externalities, especially as regards greenhouse gases, ultimately enhancing the local and the world quality of life. Not only major world ports, such as Shanghai, Rotterdam and Los Angeles, but also medium and minor ports are moving towards this direction, such as ports like Genoa, Venice and Barcelona. The most common measures implemented in these contexts are related to energy efficiency, electrification, the development of renewable energy, digitalisation and automation, and to a smaller extent the protection of the natural environment [54].

However, the majority of national and local polices are still usually confined to the provision of general guidelines and mostly limited to mitigation strategies. In fact, a strong disproportion can be identified as regards the implementation of adaptation measures compared to mitigation measures. If the latter are widespread, the former are a reality only in few cases, such as Rotterdam, that is where climate change hazards, especially sea level rise, have already started to be a threat to the economic performance of the port, along with the surrounding community survival [13, 53]. This confirms the tendence of national and local governance of waiting until climate change consequences become evident and problematic in order to act, as opposed to international guidelines on adaptation measures implementation [18].

Moreover, even if the majority of port authorities are moving towards this complex direction, it can be noted that they are moving at remarkably different paths. In particular, it can be highlighted Italian ports' embryonic sustainable development, despite sectorial excellences such as Genoa's cold ironing and Venice's flooding prevention mechanisms,

as opposed to European and international ports, for which sustainable evolution is already established [34].

Finally, although ports are experimenting innovation patters, few of them are implementing a comprehensive approach to climate change resilience, concentrating instead on one or few strategies based on their sustainability priorities [2, 48].

5 Conclusions

This research aimed to discuss the present and future role of ports in the development of climate change resilience from a global and local perspective.

The analysis acknowledges the fact that an increasing number of ports is committing to climate resilience, experimenting various innovation patterns, especially regarding mitigation ones, given their immediate benefits as concerns global warming and the enhancement of air quality. In particular, the most explored mitigation technologies at present are related to energy efficiency and the pursuit of the energy transition, with the main actors being the evolution of cold ironing, the general infrastructure and services electrification, and the experimentation of onshore and offshore renewable energies and low-emission fuels as alternatives to fossil fuels, with the most promising being LNG and hydrogen technologies. It must not be neglected also ports' endeavour in achieving the digitalisation transition, with a special focus on vehicles automation, and the widespread effort in enhancing port intermodality, especially rail one. Whereas as regards adaptation strategies, notwithstanding minor cases, the most common ones regard the elevation and the floodproofing of infrastructure. Finally, a notable number of ports demonstrates special attention to environmental protection and natural preservation, through various nature-based solutions related to marine and coastal ecosystems, as well as particular care as concerns the reduction of negative port externalities, especially noise and air pollution.

Despite the existing obstacles and complications, the research concludes that the enormous technological effort undertaken by ports in terms of climate resilience and vulnerability suggests an optimistic future view. In fact, innovation in ports can act as a developer of technological advances for minor ports, as well as driver of the evolution of fields such as engineering, computer science, chemistry as well as biology and social sciences. Moreover, the embracement of sustainability practices in ports determines an increase in their economic and geopolitical competitivity, with the possibility of revival of smaller and less competitive port areas. In this context, for example, the development of sustainable technologies by Italian ports could contribute to the retaliation of their position with respect to European ones, ultimately reducing the systemic gap between Mediterranean and Northern European ports. In particular, renewable energy development as well as GNL endorsement could place Italian ports in a favourable condition as regards their production and supply, expanding their range of action from the Mediterranean to all Europe, ultimately suggesting an optimistic view for the future in terms of climate change resilience development in ports.

Author Contributions. Conceptualization, methodology, formal analysis, materials and resources, software and data curation: all authors. Validation: all authors. In particular: Pisano wrote Sects. 2, 3, 4 Gallo wrote Sects. 1 and 5.

Acknowledgments. This study was funded by the European Union - NextGenerationEU, in the framework of the GRINS - Growing Resilient, INclusive and Sustainable project (GRINS PE00000018 - CUP H73C22000930001), National Recovery and Resilience Plan (NRRP) - PE9 - Mission 4, C2, Intervention 1.3. The views and opinions expressed are solely those of the authors and do not necessarily reflect those of the European Union, nor can the European Union be held responsible for them.

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