Enhancing Climate Resilience in Maritime Ports: A Decision Support System Approach

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Abstract. Maritime ports, as critical nodes in global trade and transportation, face increasing challenges due to the impacts of climate change. Rising sea levels, extreme weather events, and shifting environmental patterns pose significant threats to port infrastructure and operations. This paper explores the intersection of resilience, maritime ports, and climate change, presenting a comprehensive framework that leverages a Decision Support System (DSS) to fortify port resilience in the face of evolving climate-related challenges. The study begins by examining the specific vulnerabilities of Greek maritime ports to climate change using the collected data from a questionnaire-based survey. Recognizing the complex and interconnected nature of these challenges, the research advocates adaptive strategies centered around the development of a Decision Support System (DSS). The proposed DSS provides decision-makers with actionable insights for long-term infrastructure development as well as actions for minimizing the potential disruptions caused by climate-induced events. The findings contribute to the growing body of knowledge on climate resilience in maritime infrastructure and offer valuable insights for policymakers, port authorities, and researchers seeking to address the complex challenges posed by climate change. By integrating climate considerations into decision support systems, this research provides a forward-looking approach to ensuring the sustainability and adaptability of maritime ports in an era of environmental uncertainty.

Keywords: Resilience · maritime ports · Decision Support System · Climate change

1 Introduction

With climate change, maritime ports—which are essential nodes in the world's transportation and commercial network—face ever-greater difficulties. These crucial nodes' operating efficiency and infrastructure are seriously threatened by the effects of increasing sea levels, more intense weather events, and climatic changes [1–4].

The study using data collected through a questionnaire-based survey addressed to over 150 Greek port authorities, identifies their vulnerabilities related to climate change

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and examines the development of a DSS that can support mid- and long-term decision and not day to day operations [5–9]. This approach provides the decision-makers insights for long-term infrastructure development and a roadmap for mitigating potential disruptions caused by climate-induced events.

By integrating climate considerations into decision support systems, sustainability and adaptability of maritime ports can be achieved in an era of environmental uncertainty. As the global community grapples with the imperatives of climate change, this paper emerges as a valuable asset, guiding stakeholders towards a resilient and climate-ready future for maritime ports worldwide.

2 Literature Review

Maritime ports are complex and dynamic infrastructures, facing a multitude of challenges, including cargo throughput, optimizing operations, and adapting to changing environmental and regulatory landscapes. To effectively address these challenges, maritime ports, as well as transportation systems in general [10, 11], are increasingly adopting Decision Support Systems (DSSs) as a valuable tool for enhancing decision-making and improving their operational efficiency [12] and develop corresponding risk management strategies [13–15].

These systems are information systems that provide decision-makers with the necessary data, models, and analytical tools to support informed decision-making [16]. They are designed to assist users in solving problems, which are characterized by uncertainty, incomplete information, and in some cases multiple conflicting objectives. The DSSs for maritime ports encompass a wide range of functionalities, including a) data integration by collecting and consolidating data from various sources, such as cargo manifests, vessel schedules, weather forecasts, economic indicators, etc.; b) modeling and simulation by developing and using mathematical models to simulate port operations, assessing the impacts of different scenarios and ultimately optimizing resource allocation [17–19]; c) visualization and reporting by generating interactive dashboards, charts, figures and reports to present complex information in a clear and concise manner [20–23]; d) decision guidance and supports by providing decision-makers with recommendations, alerts and insights to assist them make informed choices [24].

Based on what DSSs offer as functionalities, maritime ports' possible benefits are the following: a) improved efficiency and productivity, b) enhanced-decision making, c) risk mitigation and d) compliance and regulatory adherence. The DSSs for maritime ports are in most cases developed to address specific-decision needs. There are three (3) major types of DSSs: a) operational, focusing on real-time optimization of port operations, such as berth allocation, crane scheduling, and yard management; b) tactical, addressing medium-term planning and resource allocation decision, such as staff levels, equipment utilization, and pricing strategies; c) strategic, assisting port managers and authorities to make long-term strategic decisions related to infrastructure planning, capacity expansion, and market positioning [25, 26]. Despite the numerous benefits of DSSs, there are challenges that need to be addressed when implementing and using them effectively: a) ensuring the accuracy, completeness, and timeliness of data is crucial for the reliability of DSS outputs, b) DSS users need to be trained on how to effectively

utilizes the system and interpret its outputs, c) DSSs should integrate seamlessly with existing port management systems to avoid data silos and duplication of effort, and d) DSSs should be designed to accommodate the growth and complexity of maritime operation over time. It must be noted that the future of DSSs for maritime ports is promising, with advancements in Artificial Intelligence (AI), Machine Learning (ML), and big data analytics enhancing further their capabilities.

In addition to the above, DSSs that are specifically designed to assist maritime ports strengthen their resilience against the impacts of climate change are gaining increasing prominence. These systems utilize advanced data analytics, modeling, and simulation tools to assess the vulnerability of port infrastructure and operations to various climate-related hazards, such as sea level rise, extreme weather events, and changes in precipitation patterns. By integrating real-time data from weather stations, tide gauges, and other sources, DSSs can provide port operators with predictive insights into potential disruptions and risks. This information can then be used to implement proactive measures to mitigate the impacts of climate changes such as: a) enhancing the resilience of port facilities, such as raising quay walls, building seawalls, and installing flood barriers, b) optimizing port operations to minimize the impact of weather disruptions, such as shifting berthing schedules and rerouting vessels, c) developing contingency plans and risks mitigation strategies to address potential disruptions, such as developing alternative supply chains and securing backup power sources, and d) integrating climate-resilient design principles into new port developments and implementing energy-efficient operations.

The implementation of DSSs focusing on climate resilience is essential for maritime ports to adapt to the charging climate and ensure the continued safe and efficient movement of goods and people. These systems can help ports make informed decisions, optimize operations, and minimize the impact of climate change-related disruptions. For example:

- DSSs can help port operators assess the potential inundation of port areas due to sea level rise, this information can be used to plan for the relocation of critical infrastructure, such as terminals and warehouses.
- DSSs can simulate the impact of hurricanes, typhoons, and other extreme weather events on port operations. This information can be used to develop contingency plans for evacuations, cargo protection, and equipment repair.
- DSSs can analyze historical precipitation data and climate models to predict potential changes in water availability for ports operation. This information can be used to develop strategies for water conservation and drought mitigation.

3 Methodology

As above mentioned, the objective if the research is to develop a DSS to enhance the resilience of maritime ports against the impacts of climate change. The first step in achieving this goal is to determine and evaluate how vulnerable maritime ports are to risks associated with climate change. Therefore, a Resilience Index (RI) is under development taking into consideration the international experience, such as the Climate Vulnerability Index (CVI) developed by the United Nations Development Programme (UNDP) to assess the resilience of ports in the Caribbean [27], and the Ports Resilience

Index (PRI) which is a self-assessment tool developed by the United States Resilience Toolkit [28].

Second, gathering pertinent data on port operations, infrastructure, and climate change is crucial as well as involving all stakeholders [29]. Lastly, the Analytical Hierarchy Process (AHP) is the foundation upon which our method to building the DSS rests when determining the weights of indicators (see Fig. 1) pertaining to the following areas:

- Infrastructure resilience (4 indicators);
- Operational and supply chain resilience (8 indicators);
- Digital resilience (6 indicators);
- Socioeconomic and Environmental resilience (9 indicators);
- Governance and Compliance resilience (6 indicators).

The selection of the aforementioned criteria was predicated on the creation of an efficient DSS that addresses the long-term strategic requirements of the maritime ports rather than their daily operations. In addition, the DSS needs to accurately evaluate the five areas of interest pertaining to the indicators that are vulnerable to climate change, take into account all pertinent factors that may have an impact on their resilience, offer guidance on strategic decision-making, be simple for port operators and administrators to use and comprehend, and be reasonably priced to implement and update.

It should be highlighted that not all of the 33 indicators are based on quantitative data, despite the fact that their total number might be considered as noticeably high. Ninety percent (90%) of the indicators use qualitative data, which reduces the amount of data required and streamlines the AH Process. The choice was made to avoid giving the experts a very large comparison matrix, which would have complicated their decision-making and, consequently, the process of calculating the weights [30].

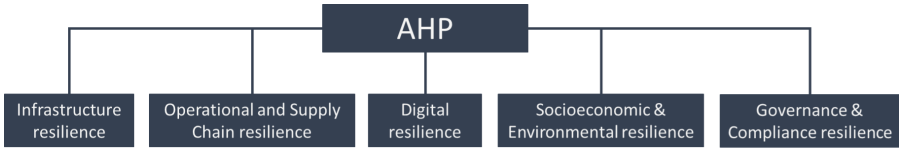

Fig. 1. Proposed areas of interest for examining the vulnerability of maritime ports related to the impacts of climate change

4 Analysis and Results

The under development DSS, is effectively related to a questionnaire-based survey addressed to maritime authorities and operators as well as to Living Labs implemented with the participation of stakeholders involved to ports' operation (see Fig. 2).

Regarding port resilience, the questionnaire-based survey offers insightful information about the viewpoints and experiences of authorities and maritime operators. The survey aids in obtaining a comprehensive picture of the resilience landscape of the port by requesting respondents to rate their opinions of the port's existing resilience levels,

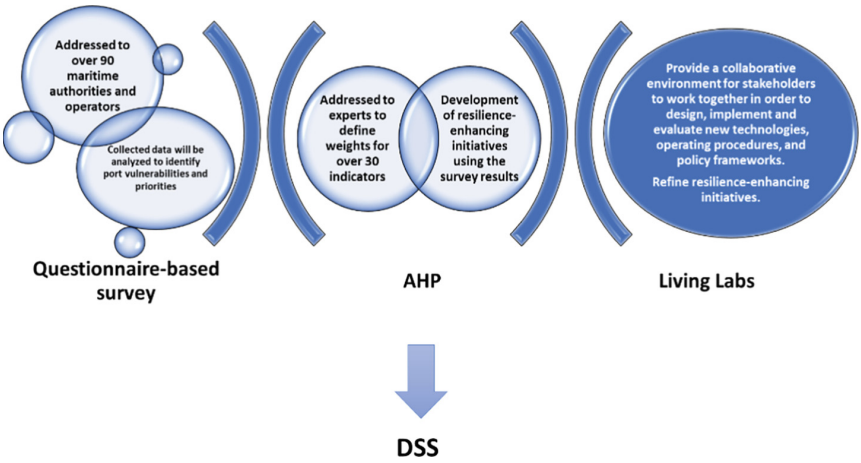

Fig. 2. Integrated approach for developing a Decision Support System to enhance maritime ports' climate resilience

identify potential risks and vulnerabilities, and prioritize areas for development. In order to help design specific resilience-enhancing strategies, the survey collects specific data on port infrastructure, operating procedures, and stakeholder engagement. The questionnaire is addressed to over 90 port operators and authorities, and the response rate at the moment is almost 15%.

As mentioned on the above, an AHP will be used to define the weights (addressing the indicators to multidisciplinary experts covering different scientific and research areas) of multiple indicators which will be then used to calculate the Ports Resilience Index (PRI) identifying the ports' level of vulnerability against the impacts of climate change. The AHP as a multi-criteria decision-making (MCDM) method will be used to prioritize and evaluate potential resilience-enhancing initiatives and also identify the most impactful and feasible interventions for improving ports' resilience.

In parallel with the so far described process, Living Labs (LLs) are organized and implemented, as they can be an invaluable resource for creating and executing creative resilience-boosting solutions. The objective of these LLs is to verify the efficacy and acceptability of new technologies, operating processes, and regulatory frameworks by working with stakeholders, such as marine operators, port authorities, and local populations. The under development DSS will be updated with the insights gained from the LLs as well as the collected data by the questionnaire-based survey, resulting in ongoing enhancements to ports' resilience. In particular, the core actions of the and to be implemented LLs can be summarized as following:

- Engaging Collaborative Stakeholders.
- Evaluation of the risks of climate change.
- Co-creation of innovative solutions.
- Proposing potential pilot projects.
- Constant monitoring and adaptation.
- Information exchange and capacity building.

It must be mentioned that LLs are used worldwide to address the mitigation of climate change impacts, focused however mainly on urban areas, such as the Climax [31], the Urban Living Lab for Climate Resilience [32], the Climate-KIC Living Lab [33] and the Nordic Urban Living Lab [34].

Through the combination of the best features of AHP-based DSS, questionnaire-based surveys, and LLs implementations, ports will be assisted and guided to develop a holistic resilience management strategy. The LLs will test and improve resilience-enhancing activities in real-world settings, the AHP will prioritize and assess resilience-enhancing projects, and the questionnaire survey will supply the first baseline data. By using an integrated strategy, ports will be able to make well-informed decisions regarding resilience investments and achieve long-term enhancements to their infrastructure and operations.

According to Lind et al. [35] four factors were identified as essential for ports to be successful:

- Efficient handling of cargo: This includes having the necessary equipment and facilities to load and unload cargo quickly and efficiently.
- Effective connectivity: Ports must be well-connected to other modes of transport, such as roads, railways, and waterways. This ensures that cargo can be easily transported to its final destination.
- A competitive cost base: Ports must be able to provide services at competitive prices in order to attract customers.
- A safe and secure environment: Ports must be safe and secure for workers, cargo, and the environment.

Based on the data from the questionnaires collected so far by 12 maritime operators and administrators, it was made clear that although the majority of Port Authorities (PAs) collect and analyze data on climate parameters, their measurements mainly concern wind speed/direction, waves (height, length, period, direction) and water quality, for specific areas. When PAs were asked about what additional information would be useful for the development of a Climate Adaptation Plan (CAP), the answers were divided between the assessment of vulnerability of port infrastructure, economic impact assessments and stakeholder engagement data (see Fig. 3).

Specifically, the following additional information was requested:

- Vulnerability assessment of port infrastructure to climate change impacts. This includes assessing the potential impacts of climate change on port infrastructure, such as sea level rise, storms, and extreme weather events.
- Economic impact assessments of climate change on ports. This includes assessing the potential economic impacts of climate change on ports, such as the cost of damage to infrastructure, the loss of trade, and the disruption of supply chains.
- Stakeholder engagement data. This includes data on the views and concerns of stakeholders, such as port users, residents, and environmental organizations.

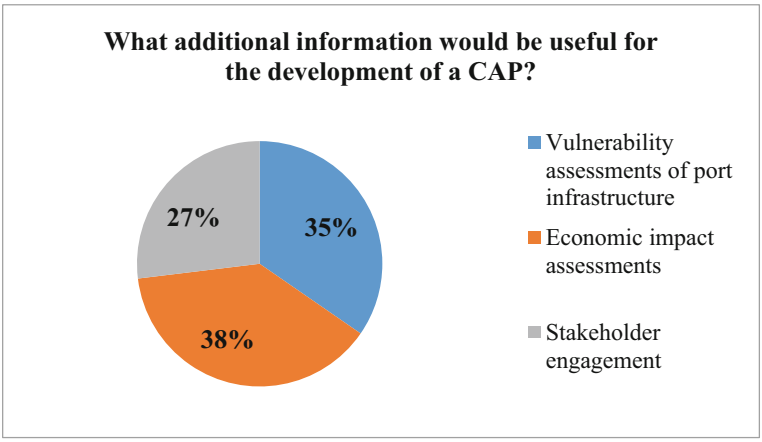

Fig. 3. Assessment of additional information for the development of a DSS

In a subsequent question, the opinions of the PAs were explored on whether and to what extent data sharing, collaborative planning, scenario analysis, and stakeholder engagement can contribute to a DSS to assist them to coordinate with other stakeholders (shipping companies, port clusters, local communities) as well as to address the impacts of climate change. Focusing on the answers that consider that these measures can offer 'a lot' and 'very much', it is concluded that 50% of the PAs believe that collaborative planning can contribute in this direction, while 60% believe that this can be achieved through scenario analysis and stakeholder engagement. 60% also believe that data sharing can contribute from 'moderately' to 'not at all'.

According to Cortes Arbues et al. [36] who "*estimated the relative changes in value added (factor measuring the contribution of each individual sector to GDP) for nine sectors*", Greece's GDP will be affected mostly in a negative way by the seal level rise. The worst scenario regarding Greece's inland regions concerns the Region of Thessaly, which is estimated to be heavily affected losing up to 10% of its GDP. For Greek islands, the above-mentioned research estimated that they all be negatively affected, losing from 0.5% (Crete) to over 10.0% of their GDP (North Aegean). Through the survey, Pas were asked about their opinion on how feasible is to reinforce existing or/ and building new infrastructure as well as implement adaptation measures to address possible future extreme events related to climate change. Figure 4 presents the distribution of the (so far) 12 PAs returning the questionnaires, among the possible choices (Not at all, Somewhat, Neutral, Very, Absolutely) given to them as answers for the respective question.

Although 33% of PAs are neutral on this issue, 50% of them think that it is quite necessary and feasible for them to interfere with their ports' infrastructure (with either reinforcing the existing and/ or building new) in order to address possible future extreme events related to climate change. A recent report analyzed data from several countries and case studies and came to the following (among other) conclusions [37]:

- Without further emissions reduction measures, the shipping industry could face an additional cost of $25 billion per year by 2100.

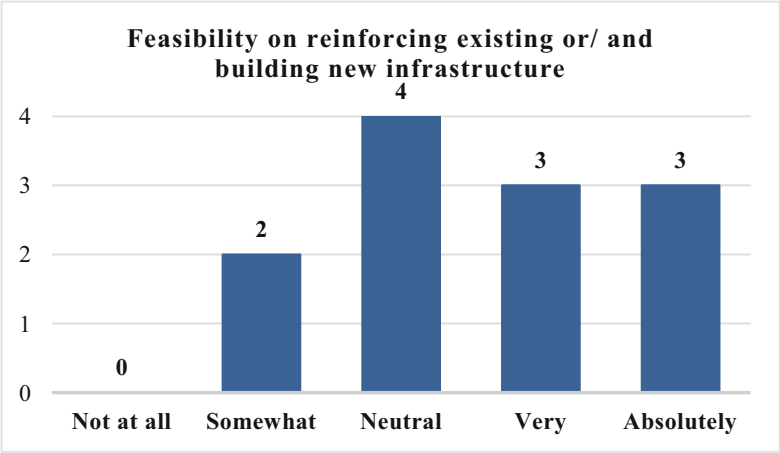

Fig. 4. PAs opinion on how feasible is to reinforce existing or/ and building new infrastructure as well as implement adaptation measures to address possible future extreme events related to climate change {own elaboration)

- An analysis of extreme weather events related to storms in 74 ports in 12 countries found that an additional 1 m in wave height or 10 m per second in wind speed are associated with an increase of 2 days in the average duration of port closures.
- Most studies on the costs of port adaptation have focused on raising the elevation of port facilities, with costs ranging from $30 million to over $200 million per km^2 of port area.
- Global annual storm damage to ports is estimated to be around $3 billion.
- By 2100, the additional annual damage and port closure costs are projected to reach $25.3 billion.
- The cost of raising the elevation of port facilities to protect them from sea level rise and storm surges is likely to be significant.

Combining the above mentioned, it is quite evident that PAs, inevitably, will have to invest to innovative technologies, infrastructures and measures in order to address the impacts of climate change. A DSS developed to support based on real data, PAs' decision for med- and long-term periods is essential. Figure 5 presents the framework for the under development DSS based on the above mentioned.

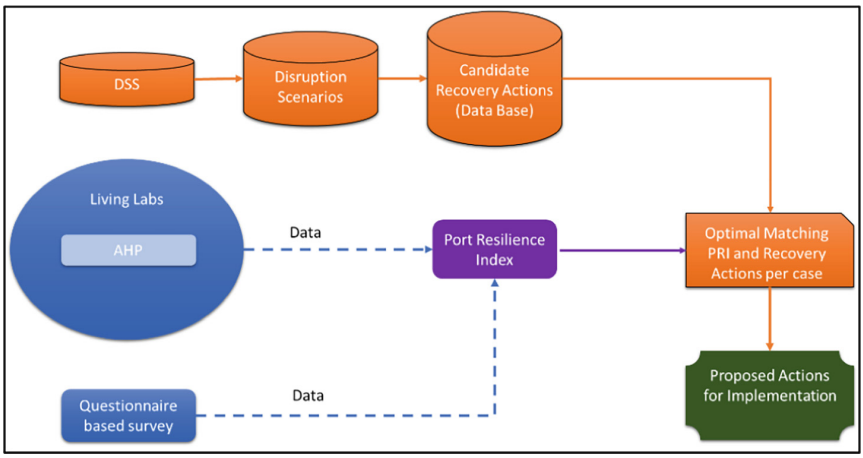

Fig. 5. Basic architecture of the under development DSS

5 Conclusions

Our research has demonstrated the pressing need for maritime ports to enhance their resilience against the impacts of climate change. A Decision Support System (DSS) is proposed as a promising tool to address this challenge. The DSS will be developed by integrating data from a questionnaire-based survey, an Analytical Hierarchy Process (AHP) analysis, and Living Labs (LLs). The questionnaire-based survey was used to gather information from port authorities and operators about their vulnerabilities to climate change, while the AHP analysis will prioritize resilience-enhancing initiatives. The LLs provide a platform for stakeholders to collaborate on developing new resilience-enhancing strategies using real-world settings.

The research findings have also highlighted the importance of data sharing, collaborative planning, scenario analysis, and stakeholder engagement in developing a successful DSS for maritime ports. By incorporating these elements, the DSS can provide port authorities with the information and tools they need to make informed decisions about resilience investments.

The research has several limitations. The questionnaire-based survey has only been completed by a small number of port authorities; however, it is expected the response rate to be increased on the following time period through direct communication between PAs and the authoring team. Additionally, the DSS is still under development, so its effectiveness has not yet been fully evaluated. Furthermore, the proposed methodology has to be tested during the scheduled Living Labs, mostly to verify whether the AHP (Analytic Hierarchy Process) as estimated by the authors or the ANP (Analytic Network Process) will be the more suitable, as the DSS is directly related to the Port Resilience Index that will be calculated for all ports.

Despite these limitations, the research has provided valuable insights into the challenges and opportunities associated with developing a DSS for maritime ports. The findings will be used to refine the DSS and make it a more effective tool for supporting ports' resilience.

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References

1. IPCC: Special Report on the Ocean and Cryosphere in a Changing Climate. Intergovernmental Panel on Climate Change. Geneva, Switzerland (2019)
2. Nicholls, R.J., et al.: Integrated assessment of social and environmental sustainability dynamics in the coastal zone. Estuar. Coast. Shelf Sci. **212**, 294–303 (2018)
3. Hallegatte, S., et al.: Future flood losses in major coastal cities. Nat. Clim. Chang. **3**, 802–806 (2013)
4. Colle, S., et al.: New York City panel on climate change 2015 report chapter 2: sea level rise and coastal storms. Ann. N Y Acad. Sci. **1336**, 36–44 (2017)
5. Mar-Ortiz, J., Gracia, M.D., Castillo-Garcia, N.: Challenges in the design of decision support systems for port and maritime supply chains. In: Valencia-García, R., Paredes-Valverde, M., Salas-Zárate, M., Alor-Hernández, G. (eds.) Exploring Intelligent Decision Support Systems. Studies in Computational Intelligence, vol. 764, pp. 49–71. Springer, Cham (2018). https://doi.org/10.1007/978-3-319-74002-7_3
6. Georgoulas, D., Koliousis, I., Papadimitriou S.: An AHP enabled port selection multi-source decision support system and validation: insights from the ENIRISST project. J. Ship. Trade **8**(16) (2023). https://doi.org/10.1186/s41072-023-00144-x
7. Hinkel, J., et al.: Coastal flood damage and adaptation costs under 21st-century sea-level rise. Proc. Natl. Acad. Sci. **111**(9), 3292–3297 (2018)
8. Juan, N.P., Valdecantos, V.N., del Campo, J.M.: Review of the Impacts of Climate Change on Ports and Harbours and Their Adaptation in Spain. Sustainability **14**(12), 7507 (2022). https://doi.org/10.3390/su14127507
9. Christodoulou, A., Demirel, H.: Impacts of climate change on transport - a focus on airports, seaports and inland waterways. EUR 28896 EN, Publications Office of the European Union, Luxembourg (2018). ISBN 978-92-79-97039-9, https://doi.org/10.2760/378464, JRC108865
10. Musolino, G.: Methods for risk reduction: modelling users' updating utilities in urban transport networks. Sustainability **16**, 2468 (2024). https://doi.org/10.3390/su16062468
11. Russo, F., Rindone, C.: Methods for risk reduction: training and exercises to pursue the planned evacuation. Sustainability **16**, 1474 (2024). https://doi.org/10.3390/su16041474
12. Hickford, A., et al.: Decision support systems for resilient strategic transport networks in low-income countries. Final Report, Project HVT043, Funded by UKAID through UK Foreign, Commonwealth & Development Office under the High Volume Transport Applied Research Programme, DT Global (2023). https://transport-links.com/wp-content/uploads/2023/10/final-report-decision-support-systems-for-resilient-strategic-transport-networks-in-low-income-countries.pdf
13. Wan, Z., Lang, Q., Zhang, Y., et al.: Research on Evaluation of Resilience and Improvement Strategy of Changchun Transportation System Based on Natural Hazard Risk Assessment, 27 September 2023. PREPRINT (Version 1) available at Research Square https://doi.org/10.21203/rs.3.rs-3374405/v1

14. Pallis, P.L.: Port risk management in container terminals. Transp. Res. Procedia **25**, 4411–4421 (2017). ISSN 2352-1465, https://doi.org/10.1016/j.trpro.2017.05.337
15. Nagi, A., Schroeder, M., Kersten, W.: Risk management in seaports: a community analysis at the Port of Hamburg. Sustainability **13**, 8035 (2021). https://doi.org/10.3390/su13148035
16. Tubis, A., Werbinska-Wojciechowska, S.: Conception of decision support systems for resilience management of seaports supply chains. J. Pol. Saf. Reliab. Assoc. **7**(1), 177–186 (2016)
17. Stylios, C.D., et al.: A web based decision support system for intermodal port and dry port facilities. J. Transp. Technol. **7**(1) (2017). https://doi.org/10.4236/jtts.2017.71003
18. Liu, S., Duffy, A.H.B., Whitfield, R.I., Boyle, I.M.: Integration of decision support systems to improve decision support performance. Knowl. Inf. Syst. **22**, 261–286 (2010). https://doi.org/10.1007/s10115-009-0192-4
19. Button, M., Davey, O., Leitch, A.: Resilience4Ports: Gateways to a Resilient Future, Reslience Shift, UK (2021)
20. Demirkan, H., Delen, D.: Leveraging the capabilities of service-oriented decision support systems: putting analytics and big data in cloud. Decis. Support. Syst. **55**, 412–421 (2013). https://doi.org/10.1016/j.dss.2012.05.048
21. Chaudhuri, S., Dayal, U., Ganti, V.: Database technology for decision support systems. IEEE Xplore **34**(12), 48–55 (2001). https://doi.org/10.1109/2.970575
22. Echeverry, A.X.H., Islam, S.M.N., Nino, H., Obregon, N.: The intelligent decision support system prototype for port informational integration. In: European Modeling and Simulation Symposium, at Barcelona, Spain (2017)
23. Kehoe, I.E., Pepino, J.A., Lee, J., Hahn, J.O., Reisner, A.T.: End-user evaluation of an interface for clinical decision support using predictive algorithms. In: 44th Annual International Conference of the IEEE Engineering in Medicine & Biology Society (EMBC), Glasgow, Scotland, United Kingdom, pp. 1149–1151 (2022). https://doi.org/10.1109/EMBC48229.2022.9871939
24. Bouzekri, H., Bara, N., Alpan, G., Giard, V.: An integrated decision support system for planning production, storage and buld port operations in a fertilizer supply chain. Int. J. Prod. Econ. **252**, 108561 (2022). https://doi.org/10.1016/j.ijpe.2022.108561
25. Mansouri, M., Nilchiani, R., Mostashari, A.: A policy making framework for resilient port infrastructure systems. Marine Policy, Elsevier **34**(6), 1125–1134 (2010)
26. Mansouri, M., Mostashari, A., Nilchiani, R.: A Decision analysis framework for resilience strategies in maritime systems. In: INCOSE International Symposium, Singapore, vol. 19, no. 1, pp. 1406–2427 (2009). https://doi.org/10.1002/j.2334-5837.2009.tb01023.x
27. United Nations Development Programme, Mapping Climate Change Vulnerability (2015). https://www.undp.org/publications/mapping-climate-change-vulnerability
28. United Stated Climate Resilience Toolkit, Ports Resilience Index (2017). https://toolkit.climate.gov/tool/ports-resilience-index
29. Kalaidjian, E., Auston, B., Sandra, P.: Operationalizing resilience planning, theory, and practice: insights from U.S. seaports. Front. Sustain. **3** (2022). https://doi.org/10.3389/frsus.2022.963555
30. John, A., Yang, Z., Riahi, R., et al.: A risk assessment approach to improve the resilience of a seaport system using Bayesian networks. Ocean Eng. **111**, 136–147 (2016)
31. Climanthon. https://climathon.climate-kic.org/who-we-are/
32. Rotterdam. Make It Happen. https://rotterdammakeithappen.nl/en/showcases/rotterdam-is-our-living-lab/
33. EIT Climate-KIC. https://www.climate-kic.org/who-we-are/what-is-climate-kic/
34. Nordic Urban Living Labs. https://www.nordicinnovation.org/programs/nordic-urban-living-labs

35. Lind, M., et al.: Ports as multidimensional hubs. In: Lind, M., Michaelides, M., Ward, R., Watson, R.T. (eds.) Maritime Informatics. PI, pp. 39–59. Springer, Cham (2021). https://doi.org/10.1007/978-3-030-72785-7_3
36. Cortés Arbués, I., Chatzivasileiadis, T., Ivanova, O., et al.: Distribution of economic damages due to climate-driven sea-level rise across European regions and sectors. Sci. Rep. **14**, 126 (2024). https://doi.org/10.1038/s41598-023-48136-y
37. Van Houtven, G., Gallaher, M., Woollacott, J., Decker, E.: Act now or pay later: the costs of climate inaction for ports and shipping. Environmental Defense Fund, RTI International (2022). https://is.gd/bZOF3f