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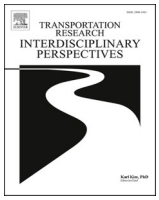

# How do seaports use foresight to face environmental sustainability disruptions?

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ABSTRACT

The Port serves as a pivotal intermodal (rail and road) and international nexus, seamlessly connecting land-sea transportation across a dense network of European markets. Different disruptions, primarily originating from external forces, profoundly influence its stakeholder engagement strategies, data digitization efforts, and the pursuit of sustainable transformation.

This paper delineates how the Port employs foresight methodologies to effectively address these disruptions. Providing a contextual backdrop, the paper outlines the Authority's origins, organizational structure, core objectives, operational mandates, and mechanisms of accountability. The paper elucidates the ramifications of these disruptions on initiatives related to digitalization, environmental sustainability, and stakeholder management, offering a comprehensive analysis of their implications.

## 1. Introduction

In today's landscape, a growing array of disruptions is exerting influence on the operations of organizations and ecosystems (Ansari et al., 2016; Burgelman and Grove, 2007; Christensen, 1997; Danneels, 2004; Markides, 2006). These disruptions, defined as forces impeding a system from proceeding as usual (Kilkki et al., 2018), are particularly impactful on commercial seaports, which serve as vital nodes within intricate global transportation networks and international supply chains (Cetin and Cerit, 2020). Notably, recent events such as the conflict in Ukraine have underscored the susceptibility of the shipping industry to such disruptions, including port closures (Fernandes et al., 2023).

Given that modern global trade heavily relies on seaports – handling over 80 % of global goods – their functionality is indispensable for the functioning of the world economy (Soares et al., 2022; Garrido Salsas et al., 2022; Roa Perera et al., 2013). As crucial economic engines, seaports attract commercial activities and play a pivotal role in national prosperity. Consequently, their resilience and adaptability are vital for sustaining global economic development (Musso, 2014). Navigating these disruptions demands more than conventional predictive models; it necessitates anticipatory strategies that encompass foresight methodologies (Édes, 2021). Foresight transcends traditional forecasting by integrating weak signals, emerging trends, and potential evolutionary paths to construct plausible scenarios (Battistella and De Toni, 2011; Battistella, 2014; Rohrbeck et al., 2015). By embracing complexity and uncertainty, foresight enables organizations to envision future possibilities and devise informed strategies (De Toni et al., 2017).

In this context, the Port serves as a compelling case study, employing foresight practices to govern and anticipate disruptions, particularly those related to environmental sustainability. This paper aims to address the gap in literature by exploring how ports anticipate and manage external disruptions through the following research question: *How do ports anticipate and govern external disruptions?*

The paper is organized as follows. Section 2 elucidates the concept of disruption and its significance for ports, while also tracing its evolution. Section 4 outlines the methodology employed, paving the way for the presentation of results in Section 5. The findings underscore the Port's phased approach to anticipating and governing disruptions, comprising preparatory and execution foresight phases, followed by strategic actions in the future-thinking phase. Finally, Section 6 concludes by highlighting the article's contributions, including the identification of organizational requirements essential for managing external disruptions effectively.

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## 2. Theoretical background

### 2.1. Literature review on disruptions

The academic discourse has long grappled with defining the concept of "disruption". Initially, it was linked to the impacts of technology on business operations, particularly in terms of product innovation or the generation of novel ideas (Lynn et al., 1996; Veryzer, 1998). Walsh et al. (2002) further elaborated that disruptive technology ushers in discontinuous innovations, necessitating behavioral changes from users and adopters.

Scholars such as Geels (2018) characterize disruptions as rapid change processes, while emphasize the magnitude of change involved. Christensen (2013) and Yu and Hang (2008), on the other hand, delve into the components of disruptions, positing them as composed of a "disruptor" and "disruptees". The former denotes an event disrupting the operations of other agents, while the latter refers to an agent compelled to redesign its strategy to adapt to environmental changes.

Attempting to provide a universally applicable definition, Kilkki et al. (2018) conceptualized disruptions as forces impeding a system from unfolding as usual, a notion endorsed by subsequent literature. In contemporary contexts, disruptions pertinent to various organizations and ecosystems encompass sustainability and digitalization (Kivimaa et al., 2021; Fusko et al., 2020; Valenduc and Vendramin, 2017).

In the domain of ports, sustainability initiatives redefine operational paradigms by integrating environmental objectives, such as the establishment of Green Energetic Hubs, promotion of electric mobility, utilization of diverse ship fuel mixes, and leveraging the blue economy (Salsas et al., 2022; Colarossi et al., 2022; Steen et al., 2024). Concurrently, digitalization initiatives entail the adoption of cutting-edge technologies like big data analytics, automation, Internet of Things, cybersecurity, and cloud and mobile services to enhance port operations (Inkinen et al., 2021). Moreover, the complexity of these disruptions is compounded by the imperative of effective stakeholder management within the port ecosystem (Salsas et al., 2022; Spaniol and Rowland, 2022). Balancing stakeholders' diverse and at times conflicting interests across the port supply chain is essential for ensuring societal acceptance and sustainability of port activities (de Langen, 2006; Notteboomet al., 2015).

### 2.2. Disruptions' impact on ports

#### 2.2.1. Environmental sustainability

Amidst a historical epoch increasingly shaped by concerns over climate change and ecological preservation, the environmental ramifications of port operations have emerged as a pressing issue. The activities and associated functions of ports significantly contribute to their environmental footprint, manifesting in various ways:

- Air Pollution: Berthed vessels emit sulfur oxides, nitrogen oxides, and particulate matter, constituting substantial sources of air pollution. Onshore activities, including cargo handling and equipment operation, further exacerbate air quality degradation through the emission of pollutants, primarily from diesel-powered machinery and vehicles (Carletti et al., 2021).
- Water Pollution: Accidental spills, such as oil, during ship operations pose significant threats to marine ecosystems, necessitating robust response mechanisms (Grifoll et al., 2011).
- Noise Pollution: The constant movement of ships and operation of heavy machinery contribute to noise pollution, disrupting surrounding environments and marine life.
- Land Use and Habitat Impact: The expansion of port facilities often entails the loss of coastal habitats, disrupting local ecosystems (Wooldridge et al., 1999).
- Energy Consumption: Ports are voracious consumers of energy, necessitating a transition to cleaner sources and reduced consumption to mitigate their environmental impact (Salsas et al., 2022).
- Waste Generation: Port activities generate substantial amounts of solid waste, including debris from cargo handling, underscoring the imperative of effective waste management practices (Slišković et al., 2018).

In response to these environmental challenges, global initiatives and regulatory frameworks, such as the UN 2030 Agenda for Sustainable Development, are compelling ports to adapt their practices. These environmental concerns and regulatory shifts serve as external disruptors to traditional port operations. Leveraging tools such as concession policies and forecasting analyses, ports can proactively steer their transformation towards sustainability and effective energy management (Ashrafi et al., 2019; Koukovinos et al., 2019; Pyykkö et al., 2021).

#### 2.2.2. Digitalisation

Ports hold a particular significance within the supply chain landscape, serving as critical infrastructure nodes integrated into a complex network of commerce and logistics (de Langen et al., 2020). As ports undergo a transformative evolution from conventional load and offload points to dynamic intermodal logistical service hubs, the demand for seamless information exchange becomes increasingly critical (European Commission, 2019). In alignment with this progression, European Union actively advocates for the transition to paperless procedures in customs operations, freight documentation, and communication among cargo owners and contract carriers (European Commission, 2017, 2019). This digital shift, endorsed by prominent international bodies like the International Maritime Organization, champions automated electronic data exchange between ships, ports, and relevant stakeholders, thereby enhancing the efficiency, safety, and security of maritime navigation (e.g., Acciaro et al., 2018; Olivier and Slack, 2006).

Previous studies underscore the pivotal role of digitalization in enhancing efficiency, productivity, security, and sustainability within ports, delineating its progression through three distinct generations: adoption of paperless procedures; integration of automated processes and implementation of smart technologies (Brümmerstedt et al., 2017).

This evolution encompasses critical technological domains such as big data analytics, automation and robotics, cybersecurity, Internet of Things, sensor networks, cloud computing, mobile applications, and social media (Herrero Càrcel, 2016; Sun, 2021). While essential for digitalization, these domains may present challenges and conflicts in adoption and implementation without a strategic, long-term development plan or a technology foresight process (Brümmerstedt et al., 2017; Cepolina and Ghiara, 2013; Fahim et al., 2021; Inkinen et al., 2021; Sun, 2021; Tsakalidis et al., 2021).

Understanding and navigating this complex landscape are paramount for ports, as this transformative shift poses a significant disruption to their long-term competitiveness, necessitating substantial changes and investments in port operational management. Key port activities profoundly influenced by digitalization include:

- Cargo Tracking and Management: Digital technologies enable real-time cargo tracking, offering stakeholders immediate visibility into shipment locations and statuses (e.g., Kasaei and Albadvi, 2023).
- Operational Processes: Automation and robotics optimize terminal operations, leading to increased efficiency in container handling, stacking, and retrieval. Additionally, digital sensors and analytics facilitate predictive maintenance of port equipment, minimizing downtime and prolonging asset lifespan (e.g., Paulauskas et al., 2021).
- Supply Chain Visibility: Digital platforms integrate information across the supply chain, providing stakeholders with comprehensive insights into cargo movements from origin to destination (e.g., Senarak, 2020).

- Security and Safety: Digitalization enhances security through advanced surveillance systems, including CCTV, drones, and sensors, ensuring personnel and asset safety. Concurrently, robust cybersecurity measures are imperative to counter cyber threats and attacks (e.g., Henesey et al., 2020).
- Environmental Management: Digital tools such as sensor networks monitor environmental parameters within and around the port, facilitating compliance with regulations and promoting sustainability (e.g., Puig et al., 2022).
- Decision Making: Big data analytics and predictive modeling support data-driven decision-making in route optimization, resource allocation, and overall logistics planning (e.g., Loukili and Elhaq, 2018).
- Communication and Collaboration: Collaboration tools and cloud services streamline communication among port stakeholders, including shipping lines, freight forwarders, and customs authorities.

#### 2.2.3. Stakeholders' management

Reflecting the diverse nature of the port sector, stakeholders exhibit varied characteristics and needs, encompassing public and private entities, profit and non-profit objectives, geographical considerations, and entities of varying scales (Langenus and Dooms, 2018; Attanasio et al., 2023; Battistella et al., 2017; Battistella and Pillon, 2016) including shippers, shipping companies, terminal operators, and more (Acciaro et al., 2014). Moreover, the sector encompasses a spectrum of activities spanning transportation, logistics, large-scale manufacturing, and beyond (Acciaro et al., 2014).

Recognizing the pivotal role of environmental and social performance in fostering positive relationships with local communities, port authorities acknowledge that sustainability initiatives can confer a competitive advantage and resonate positively with customers increasingly prioritizing sustainable supply chains (Pyykkö et al., 2021; Jokinen et al., 2022). Thus, proactive analysis and management of potential environmental and social megatrends are imperative for port authorities (de Langen et al., 2020; Koukovinos et al., 2019.

The relentless pace of technological advancement characterizing the current era necessitates all stakeholders to adapt swiftly to change. However, responses to this transformation vary among stakeholders, generating divergences within the intricate web of the port ecosystem, such as Trieste. Managing this dynamic challenge demands astute leadership from the port authority. Moreover, beyond the challenge posed by technological evolution, the complexity inherent in human interactions adds another layer of disruption. This complexity is particularly pronounced in the context of our evolving times. Guiding this interconnectedness, the port authority must adeptly align with technological progress while navigating the intricate dynamics of diverse stakeholders. This multifaceted challenge underscores the pivotal role of the port authority in embracing technological advancements and fostering harmonious collaboration amidst the complexity inherent in human interactions within this evolving landscape.

## 3. Methodology

The methodology employed for this paper relied on participant observation, primarily employing passive observation techniques. Participant observation, as elucidated by Madge and Harrisson (1938), enables researchers to document and comprehend the contextual nuances surrounding activities and events, allowing for the observation of behaviors and events as they naturally unfold within their environment.

Data collection involved a mixed-method approach utilizing participant observation to gather requisite information aligning with the study's objectives. Information was primarily amassed through the analysis of organizational documentation, formal and informal interviews, and life histories.

The information-gathering process adhered to the four main stages outlined by Howell (1973) commonly utilized in studies employing participant observation:

1. Establishing a relationship: Initial contact was established with a key member of the organization handling special projects, providing a comprehensive overview of the entire port.
2. In the field activity: A questionnaire was formulated and presented to our contact during the initial face-to-face meeting. Alongside questionnaire responses, valuable insights regarding port operations were shared. Additional meetings were conducted to delve into areas of particular interest, followed by on-site meetings with our contact and three major terminal operators at the port, during which unstructured interviews were conducted.
3. Recording observations and data: Field notes and interview transcripts were meticulously recorded, supplemented by insights gleaned from prior studies in the port sector to enrich the research.
4. Thematic data analysis: Data was structured around recurring themes identified in interviews and qualitative data, facilitating the coherent construction of the study's focal points.

Critical to the information-gathering phase were online and in-person meetings with the project manager at the Port Authority, serving as our primary contact within the port. These interactions offered invaluable insights into port operations and ecosystem dynamics. Moreover, the project manager played a pivotal role in validating information obtained from internal and external sources, ensuring a comprehensive understanding of port dynamics. Their contribution primarily focused on examining foresight methodologies employed within the port ecosystem, offering insights for future development. Furthermore, the project manager facilitated communication with terminal operators within the port, coordinating meetings and interventions. During our visit, meetings were conducted with representatives from three terminal operating companies, including discussions with CEOs, terminal managers, and operational personnel. Notably, two of these companies boast longstanding presences within the port, while the third commenced operations more recently.

## 4. Results

### 4.1. The port system authority – ports of Trieste and Monfalcone

The Port System Authority, encompassing the Ports of Trieste and Monfalcone, operates as a non-economic public entity endowed with administrative, budgetary, and financial autonomy, overseen by the Minister of Infrastructure and Transport.

Central to its mandate is the management and administration of port infrastructure and land in the Trieste and Monfalcone region on behalf of the Italian State. Key responsibilities of the Port include the maintenance of crucial port elements such as docks, warehouses, and terminals, ensuring adherence to safety and security regulations to safeguard all port operations. Additionally, the Port oversees budgetary management and financial transactions while actively engaging with diverse stakeholders, ranging from shipping companies to government bodies and local communities. This holistic approach underscores the Port's dedication to optimizing the functionality and sustainability of the Trieste port.

Port operations, however, are entrusted to private entities selected through a competitive tendering process. Upon winning concessions, these entities assume responsibility for all facets of port operations, including equipment procurement and economic performance. Leveraging its strategic location at the crossroads of Central and Eastern Europe, the Port serves as a crucial trade gateway, facilitating commerce between these regions and the global market. Its advantageous positioning grants access to major transportation routes, complemented by robust rail connections enabling efficient rail-based multimodal transport and well-developed road networks facilitating seamless cargo transportation to and from the hinterland. Consequently, the port's strategic allure attracts numerous transport companies, fostering ongoing development. Notably, in 2022, the Port handled 57,591,733

tons, registering a 4 % increase compared to 2021, solidifying its status as Italy's largest port in terms of freight tonnage (AdriaPorts, 2023). Moreover, the Authority actively seeks collaborations with other Italian or European ports, exemplified by its ongoing partnership with the Koper port in Slovenia. This collaborative endeavor aims to establish a joint venture to install offshore solar farms, furthering renewable energy production initiatives.

### 4.2. AUTHORITY faces environmental disruptions

In anticipation of potential disruptions, the Port has embarked on a strategic trajectory, strategically prioritizing environmental sustainability. Recognizing its pivotal significance for both the port's future competitiveness and the well-being of all stakeholders, the Port aims to proactively address these challenges. This strategic choice reflects a departure from viewing environmental sustainability solely through the lens of regulatory compliance, instead recognizing it as a strategic imperative essential for ensuring long-term viability. By embracing sustainable practices, the Authority aligns itself with the global trend towards greener and more resilient port operations. Additionally, the city of Trieste stands to benefit significantly from these sustainable initiatives, as they enhance residents' quality of life and underscore the port's role as a responsible community contributor.

The strategic emphasis on environmental sustainability, with its attendant social and competitive implications, underscores a forward-thinking approach. Foresight practices assume critical importance in envisioning and orchestrating the cohesive development of the entire port ecosystem towards this sustainability objective. By providing strategic insights into emerging trends, foresight practices facilitate the formulation of a comprehensive and forward-looking roadmap.

The anticipation process employed by the Port unfolds through a structured approach comprising three distinct phases: a preparatory phase, a foresight execution phase, and a future thinking phase. The Port conducts the preparatory phase internally, identifying pertinent issues to focus anticipation efforts. In the foresight execution phase, encompassing short- to medium-term anticipation, the Authority collaborates with external partners such as the University. For long-term planning, including foresight execution through methods like Delphi, and the futures thinking phase, the Authority leverages these external collaborations.

### 4.3. Process of anticipating and governing disruptions in the AUTHORITY

#### 4.3.1. Preparatory phase

This phase signifies a crucial juncture in the Port's anticipation process, aiming to identify and prioritize the most pertinent issues within the port's operations. Employing a strategic tool known as the materiality matrix, the Authority navigates this multifaceted landscape.

The materiality matrix stems from an analytical process facilitating the identification of 'material' environmental sustainability aspects most relevant to the company and its stakeholders. It serves as a graphical representation, enabling a visual depiction of these critical aspects. Emphasizing the concreteness and measurability of sustainability elements, the term "materiality" underscores the company's commitment to sustainability, as mandated by the Global Reporting Initiative standard. This analysis enables effective communication of sustainability commitments both internally and externally, fostering stakeholder engagement. The materiality matrix reflects issues pertinent to the Authority and stakeholder expectations. For an issue to be deemed relevant or "material," it must significantly impact economic, social, and environmental performance, thereby influencing stakeholder assessments and decisions. The process of defining material issues involves three stages:

1. Identification: An analysis identifies sector-specific issues, best practices, and stakeholder expectations.
2. Issue Evaluation: Identified issues and trends undergo internal and external comparison to assess relevance for the Authority and stakeholders.
3. Prioritization: Issues with higher priority levels, determined through internal and external comparison, are highlighted and reported in the Sustainability Report.

Beyond its analytical function, the materiality matrix embodies the Port's commitment to transparency and stakeholder engagement. It serves as a communication platform, updating stakeholders on sustainability issues and facilitating participatory decision-making through structured feedback mechanisms. This collaborative approach enriches the sustainability strategy with diverse perspectives. Linking the matrix to the sustainability report ensures adherence to reporting standards while strategically positioning the Port to address energy management challenges. Performance Monitoring and Evaluation Systems complement this phase, providing transparent performance reports to stakeholders and influencing materiality matrix priorities.

Subsequent to materiality matrix utilization, data analysis forms the foundation for the foresight execution phase, enabling the generation of alternative future scenarios. This comprehensive understanding of potential developments sets the stage for informed decision-making. Table 1 provides a summary of the Preparatory phase.

#### 4.3.2. Foresight execution phase

This phase is geared towards selecting and implementing a foresight method to discern trends in the identified issue. It delineates the strategic approach of the Port in foreseeing the future of port operations, emphasizing the adoption of both periodic and non-periodic methods.

The Port employs a multifaceted approach encompassing various methods to systematically anticipate the future. While some methods are recurrently applied at regular intervals (periodic methods), others are employed sporadically without adhering to a specific schedule (non-periodic methods). A key mechanism frequently employed by the Port is the Three-Year Operational Plan, aimed at planning within a medium-term timeline.

Aligned with the results of the materiality matrix, the Three-Year Operational Plan considers the most relevant environmental sustainability aspects and potential challenges and opportunities within the port ecosystem. This ensures a flexible strategy capable of adapting to external disruptions, facilitating proactive adjustments by the Port and stakeholders.

The strategic vision involves configuring the port authority as a collaborative group wherein various stakeholders contribute to the development and management of the port system. While individuals from different areas participate in planning and anticipation activities like the Three-Year Operational Plan, no internal unit is exclusively dedicated to foresight activities. Performance Monitoring and Evaluation Systems play a pivotal role in ensuring stakeholders are aligned with the strategic plan. Additionally, they serve as a communication tool, transparently conveying progress and influencing strategic priorities. Furthermore, the Port occasionally employs sophisticated techniques, outsourced for specific, in-depth studies on pertinent topics. This advanced approach aims to garner nuanced insights into future trends and challenges, exemplified by collaborative initiatives with external

**Table 1**
Preparatory phase.

| **Preparatory phase** | |
|---|---|
| Aim of the phase | • Identify issues to be prioritised |
| Tools used | • Materiality matrix<br>• PMES |
| Output | • Identification of issues relevant to the authority and stakeholders<br>• Transparent performance information to all actors |

partners such as the University.

A notable example is a foresight study on energy management in port systems conducted in collaboration with the University of Udine. This venture underscores the Port's proactive stance in addressing critical issues by leveraging external expertise. The Delphi method was chosen for this study due to its effectiveness and pragmatic applicability, enabling the identification of trends in energy management within port operations.

In summary, the Port's foresight efforts encompass a strategic blend of internal and outsourced methods, ensuring a comprehensive understanding of future trends and challenges. Table 2 provides a summary of the Foresight execution phase.

#### *4.3.3. Futures thinking phase*

This phase is pivotal in determining strategic directions for the future through the analysis, management, and monitoring of the Port's anticipation efforts.

The primary objective is to envision possible futures by generating multiple scenarios based on the outcomes of long-term foresight techniques, such as the Delphi method previously discussed. This scenario creation process typically commences with identifying the key trends characterizing the subject under examination.

A common approach involves identifying trends with the most significant impact on the port value chain, which then shape the remainder of the study. For instance, with the Delphi method, the subsequent step involves analyzing the Delphi results to categorize trends into a "criticality map." This map assesses the likelihood of occurrence, impact on the port, and desirability of each trend. Positioning trends on the criticality map reveals potential scenarios—most critical, most desirable, and most uncertain. Developing multiple scenarios enables strategic planning for actions to be implemented in response to each scenario. For example, identifying the most critical scenario empowers the Port to prepare for the future actively, enhancing competitiveness compared to ports that do not utilize foresight methods. This proactive approach aligns with the principle of foresight, advocating that organizations should not passively react to events but proactively anticipate future changes.

Furthermore, the Port aims to identify strengths, weaknesses, opportunities, risks, and threats to sustain its success. To achieve this, it has developed the Plan for the Prevention of Corruption and Transparency, addressing risks associated with the geographical location near the border with Slovenia and the wide sea outlet hosting various economic activities related to port operations. The Authority continually updates and expands its risk prevention instruments while utilizing specific Key Performance Indicators to assess organizational performance and identify future actions.

The Performance Monitoring and Evaluation System and Performance Plan play integral roles in this regard. The PMES outlines the administration's performance cycle rules, while the Performance Plan delineates objectives for the General Secretary, Managers, and employees, cascading from the annual objectives assigned by the supervising Ministry to the President.

In summary, the Futures thinking phase entails envisioning possible futures, identifying risks and opportunities, and developing strategic responses to maintain and enhance the Port's effectiveness and competitiveness. Table 3 provides a summary of the Futures thinking phase.

## 5. Conclusions and contributions

This study aimed to investigate how ports anticipate and manage external disruptions, focusing on the case of the Port of Trieste and Monfalcone.

The Port has demonstrated a commitment to efficiency and effectiveness in its operations by employing diverse methods to anticipate the future through a multi-phase anticipation process. These methods, both periodic and non-periodic, have yielded valuable results, positioning the Port of Trieste as the most competitive port in Italy and one of the most important in Europe. They enable the Port to navigate future challenges with preparedness and clarity.

Periodic methods like the materiality matrix and data analysis used in the preparatory phase help identify relevant issues that may develop into disruptions. In the foresight execution phase, both periodic and non-periodic methods are applied. For instance, the three-year operational plan, renewed every three years, defines objectives, strategies, and operational activities based on internal expectations. In contrast, the Delphi method, a non-periodic approach, creates scenarios based on external trends and disruptions.

In the future thinking phase, strategic directions are identified based on the results of the previous phases. Anticipating the future requires critical capabilities and processes such as system perspective, interpretation of trends, and organisational ambidexterity. While the Port has partly outsourced these capabilities through collaboration with the University, the goal should be to integrate them internally through a dedicated foresight unit. This unit would facilitate integrated foresight activities, requiring changes in organisational culture, commitment from top management, and effective communication within the organisation. However, integrating the foresight unit requires significant effort and gradual implementation, starting with raising awareness within the organisation and progressing towards organisational, managerial, and strategic development of foresight capabilities.

From a practical standpoint, this study sheds light on the process of anticipating and managing environmental sustainability disruptions, offering insights and tools for port decision-makers. Future research could expand the scope by including case studies beyond Trieste, thereby broadening our understanding within the context of the Mediterranean.

## CRediT authorship contribution statement

**Giovanna Attanasio:** Writing – original draft, Investigation, Formal analysis, Data curation. **Cinzia Battistella:** Supervision, Funding acquisition, Conceptualization. **Elia Chizzolini:** Writing – original draft, Investigation, Formal analysis, Data curation.

## Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Cinzia Battistella reports financial support was provided by Italian

**Table 2**
Foresight execution phase.

| Foresight execution phase | |
|---|---|
| Aim of the phase | • Identify trends in the selected issue |
| Tools used | • Periodic: Three-Year Operational Plan; PMES<br>• Non-Periodic: Delphi method |
| Output | • Design of a medium-term strategic plan<br>• Checking goals to obtain.<br>• Data gathering on long-term future trends |

**Table 3**
Futures thinking phase.

| Futures thinking phase | |
|---|---|
| Aim of the phase | • Find the strategic directions for the future |
| Tools used | • Criticality map<br>• Performance Monitoring and Evaluation System<br>• Plan for the Prevention of Corruption and Transparency Scenario development |
| Output | • Construction of multiple future scenarios |

Ministry of Research. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

## Data availability

Data will be made available on request.

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## Appendix

Delphi method explanation

The Delphi method, widely utilized in scientific business research for qualitative foresight, is an iterative inquiry process involving independent experts. It operates through two or three steps, structuring asynchronous group communication for handling complex topics effectively (Linstone and Turoff, 1975; Acone and Urbani, 2018). This method is an established decision-making process and is particularly adept at harnessing shared knowledge to resolve ambiguous situations, necessitating a well-constituted expert panel for meaningful solutions (Acone and Urbani, 2018). This leads to the question: "How can structured communication foster collective intelligence?" Addressing this question, four pivotal rules guide the process of "organized communication" in the Delphi method (Linstone and Turoff, 1975; Belton et al., 2019; Acone and Urbani, 2018): 1. Provide regulated feedback on individual contributions; 2. Statistically aggregate responses for evaluating judgments; 3. Allow iterative idea revisions; 4. Ensure anonymity for individual responses.

The Delphi technique's simplest form involves individuals providing anonymous responses to questions using quantitative estimates (such as event probabilities or timing). A facilitator compiles these responses, creating a statistical summary along with the reasons given. This process unfolds through distinct stages, contributing to a comprehensive and structured exploration of the chosen topic. The application of the Delphi method in this collaborative study exemplifies the Port System Authority's commitment to employing robust and systematic approaches to gain nuanced insights into the complex landscape of energy management within port systems. The Delphi method, employed in the survey conducted within the Port System Authority, underwent a meticulous process consisting of distinct steps to ensure the robustness and efficacy of the foresight study.

- *Preliminary Step:* This step played a pivotal role in shaping the study's foundation. It involved the development of the study concept, a pretest of the investigation, assembling an expert panel, and creating the Delphi platform. Recognized as critical, this step laid the groundwork, ultimately determining the overall quality of the project.
- *Administration Step:* After the preliminary step, the administration step encompassed all aspects from submission to the conclusion of iterations. This stage facilitated the systematic execution of the Delphi method, ensuring a smooth and organized study progression.
- *Data Analysis Step:* The data analysis step, a fundamental part of any Delphi study, was divided into data description and determining study quality. These steps aimed to comprehensively analyze the collected data, contributing to the study's depth and precision.

The initial step defines the research question: "What are the trends in port energy management today, and how are these likely to influence commercial ports in the future?"—. The research question is focused on a 20-year horizon and wants to identify relevant new technologies and management practices as key trends in energy management. In the pursuit of comprehensive information, the first step aimed to systematically collect and analyze data, laying the groundwork for an effective questionnaire aligned with the survey's objectives. An ad hoc framework was created to process the information, ensuring alignment with research goals and a balanced emphasis on topics.

The framework's steps are: Create a logical table with trends in the rows and value chain activities in the columns; Identification of relationships between trends and value chain activities in the cells of the logical table; Translation of the relationships into sentences; Adjusting the sentences to fit the questionnaire. This framework, built on the interplay between energy management trends and port value chain activities, led to 29 projections for the Delphi questionnaire. The careful elaboration of information through the conceptual framework marked the conclusion of the ad hoc process for constructing the Delphi questions.

Before finalizing the questionnaire, a careful process was undertaken to ensure the coherence and participant friendliness of the Delphi study. The order and division of projections were carefully organized to create a questionnaire that was both logical and accessible to participants. Furthermore, an expert inside the Port System Authority and in-port operations conducted a review to guarantee its relevance and linguistic accuracy. The refined questionnaire was then disseminated to the selected panel of experts through an online survey platform. Respondents evaluated different parameters related to commercial ports' identified energy management trends.

This research embraced a two-round Delphi survey, a design influenced by the balance between response stability and time constraints.

Three distinct numerical evaluation modes were chosen for each projection, adding depth to the analysis:

1. Probability: Participants were asked to provide a probability of occurrence for each projection, enhancing the quantitative aspect of the study
2. Desirability: To – subjective opinions, participants used a 5-point Likert scale to express judgments on the desirability of each projection's occurrence. The scale ranged from 1 (not desirable) to 5 (very desirable).
3. Impact: Understanding the implications of projections on port sustainability and operations was crucial. Participants utilized a 5-point Likert scale mirroring the previous considerations to assess the impact of each projection

These carefully chosen evaluation modes aimed to comprehensively assess the identified trends while ensuring ease of response for the participating experts. The combination of quantitative and qualitative data facilitated a nuanced understanding of the potential future trajectories of energy management in commercial ports.

The expert panel for this foresight research was formed by a commitment to capturing a wide array of perspectives. The panel deliberately sought diversity, comprising individuals with academic expertise and practical experience in energy management and port operations. Given the study's intrinsic exploration of the impact of energy management on port operations, this dual focus was considered essential. Selection criteria were intricately tailored, differentiating between candidates based on their academic background and those with hands-on experience in port operations. This thoughtful approach aimed to cultivate a well-rounded and diverse panel, effectively mirroring the intersection of academia and industry, thereby enriching the international scope of the study.

Responses were diligently collected from a comprehensive pool of 36 experts, ensuring a broad spectrum of insights and experiences. The collected data underwent a rigorous analysis, leveraging the collective expertise of the panel to derive meaningful conclusions and identify emerging trends that would shape future scenarios. The research team employed a criticality map as an analytical tool to enhance the depth and clarity of the study's findings. This map served a dual purpose,

allowing for the visualization of the overall probability and impact assessments on a single plane and representing the desirability assessments using symbols. The criticality map provided a comprehensive and intuitive visual representation, effectively portraying the complex interplay of factors that influence the potential future trends of energy management in commercial ports.

The integration of diverse perspectives, methodical analysis, and innovative visualization techniques stands as a testament to the comprehensive nature of the Port System Authority's foresight study. This approach contributed to an understanding of the identified trends. It emphasized the importance of considering numerous perspectives in shaping strategies for the future of port energy management on an international scale. These strategies are shaped during the futures thinking phase.

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