# Port Sustainability: A Comparative Analysis of Global Initiatives and Their Efficacy Using Crisp-Set Qualitative Comparative Analysis

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# Abstract

Seaports play a crucial role in global trade and transportation networks, significantly contributing to regional economic performance. However, the rapid urbanization and population growth in coastal port cities have raised global concerns about sustainable development. This study addresses these concerns by conducting a comparative analysis of global port sustainability initiatives using Crisp-Set Qualitative Comparative Analysis (csQCA). The research evaluates 310 port sustainability initiatives across six conditions: digitalization, environmental caring, community building, sustainable infrastructure, health safety and security, and climate and energy measures. The study aims to identify which combinations of these conditions most effectively enhance port sustainability. The findings reveal that no single condition is necessary for sustainability; rather, multiple pathways involving different combinations of conditions can lead to sustainable outcomes. The analysis also underscores the importance of regional contexts in shaping the effectiveness of these initiatives. For instance, ports in developed regions such as Europe and North America show higher sustainability performance compared to those in developing regions like Asia, Africa, and South America, due to differing economic conditions, regulatory environments, and technological advancements. This research fills existing gaps by providing an integrated approach that combines economic, social, and environmental aspects to evaluate port sustainability comprehensively. It offers actionable insights and practical recommendations for policymakers, port authorities, and stakeholders involved in maritime logistics and port management, aiming to develop more sustainable and resilient port systems. Ultimately, this study contributes to the broader goal of achieving balanced growth through integrated environmental protection and social equity in port cities.

**Keywords:**

Port sustainability; Crisp-Set Qualitative Comparative Analysis (csQCA); Global port initiatives; Sustainable development; Regional comparison; Environmental impact; Comprehensive assessment

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# Chapter 1: Introduction

## 1.1 Reason and Purpose

Seaports play a crucial role in global trade and worldwide transportation networks, as transit points and accelerators for logistics exchange and information transmission (Kokot et al., 2008). Port cities contributed to more than 20% of the regional Gross Domestic Product (GDP) in many countries like France, China, and the Netherlands (Merk et al., 2011; Shan et al., 2014; Van Den Berghe et al., 2018).

Above the economic impacts, coastal port cities host the majority of the world's population (T. Hossain et al., 2021). As the built area and population of these port cities continue to grow, the issue of sustainable development in port and port cities has gradually become a global concern for scholars in fields such as planning, transportation, and the environment (Akhavan, 2017; Xiao & Lam, 2017). Added to this preoccupation is a growing awareness of the importance port cities play with respect to their potential impact on economic development and, as more recently recognized, in striving for balanced growth through integrated environmental protection measures hand-in-hand with fundamental elements of social equity.

The increasing emphasis on sustainability in maritime logistics and port operations, as highlighted in recent initiatives and reports by organizations such as the International Association of Ports and Harbors (IAPH)[1] and the World Port Sustainability Program (WPSP)[2], is bringing significant attention to this issue (IAPH, 2021; WPSP, 2020). Despite the significance of this larger issue, there is still a notable lack of research on how these initiatives can effectively promote the sustainable development of ports (Styliadis et al., 2022).

[1] https://www.iaphworldports.org/

[2] https://sustainableworldports.org/


Figure 1 Announcement of the Creation of IAPH (Source: IAPH website)

A quantitatively comprehensive literature analysis conducted by Wagner assesses current research trends on the sustainability of port cities (Wagner, 2019). The study highlights that while there are important research clusters focusing on environmental issues, port activities, waterfront development and sustainability, there is still a notable disconnect in coherently integrating these aspects. The analysis identified that sustainability issues, although frequently mentioned, often lack a unified approach that bridges the various subfields within port city integrated research, like environment, society and community research (Wagner, 2019).

Moreover, a systematic review of scientific research on sustainable ports by Balić reinforces the idea that there is considerable room for improvement in how sustainability initiatives are implemented and evaluated in port operations. The review, which followed the PRISMA guidelines, highlighted the fragmented nature of existing research and the need for a more structured and integrated approach to comprehensively assess port sustainable performance. (Balić et al., 2022).

These findings collectively highlight the need for more integrated and practical research efforts to effectively promote sustainable development in ports. Addressing these research gaps will be crucial for developing comprehensive strategies that not only identify sustainable practices but also ensure their effective implementation in diverse port contexts.

## 1.2 Research Question

Given the significant role ports play in global economic performance and their impact on regional social harmony and environmental pollution, it is crucial to explore how to assess port sustainability and identify initiatives that effectively enhance it. Therefore, in these articles, I aim to address the following key research question:

**What initiatives or practices are most effective in enhancing the sustainability of seaports?**

To explore this overarching question, the study will delve into several sub-questions:

1. Key Initiatives: What are the key sustainability initiatives undertaken by ports around the world?
2. Assessment and Evaluation: How can the overall sustainability of ports be assessed and evaluated?
3. Impact Analysis: How do these initiatives impact the economic, social, and environmental pillars of sustainability?
4. Conditions confirmation: How can different sustainability themes (such as climate & energy, community building, digitalization, environmental caring, health security & safety, and infrastructure) be effectively combined to promote overall port sustainability?
5. Regional Comparison: How do ports in different regions compare in terms of their sustainability efforts and outcomes?

By investigating these questions, this research aims to establish a comprehensive evaluation system for port sustainability that integrates economic, social, and environmental aspects. It assesses the sustainability initiatives proposed by ports in recent years and conducts a comparative analysis of port sustainability across different continents. The study provides policy recommendations for ports at various development stages, offering actionable insights and practical recommendations for policymakers, port authorities, and other stakeholders involved in maritime logistics and port management. The ultimate goal is to contribute to the development of more sustainable and resilient port systems that can effectively support social, economic, and environmental objectives.

## 1.3 Framework Flow and reading guide

This research aims to provide actionable insights and practical recommendations for enhancing port sustainability. The findings contribute to the academic literature by filling existing research gaps and offering a comprehensive evaluation of sustainability initiatives. Practically, the study offers guidelines for policymakers and port authorities to develop more effective sustainability strategies.

By addressing these research questions and employing a mixed-methods approach, this study seeks to enhance our understanding of how sustainability initiatives can be effectively implemented in seaports, ultimately contributing to the development of more sustainable and resilient port systems.

Chapter 1 provides the introductionthat highlights the crucial role of seaports in global trade and their significant contribution to regional economic performance. It addresses the growing concerns about sustainable development due to rapid urbanization and population growth in coastal port cities. The study aims to explore which port sustainability initiatives are most effective, focusing on key initiatives, assessment methods, impacts, thematic conditions, and regional comparisons. The ultimate goal is to provide actionable insights and practical recommendations for developing more sustainable and resilient port systems.

Chapter 2 lays the theoretical foundations for analyzing port sustainability, incorporating the Triple Bottom Line (TBL) framework, Sustainable Development Goals (SDGs), systems theory, stakeholder theory, and the resource-based view (RBV). These theories provide a comprehensive approach to evaluating the economic, ecological, and social outcomes of port sustainability activities. The integration of these perspectives helps in understanding the complex and interrelated impacts of different port initiatives, providing a robust framework for the study.

Chapter 3, the methodology chapter details the research approach, emphasizing the use of Qualitative Comparative Analysis (QCA) to study port sustainability initiatives. QCA is chosen for its ability to handle complex cause-effect relationships and identify combinations of conditions that lead to desired outcomes. Data is collected from various sources, including the WPSP database and port sustainability reports, and is processed through coding and truth table analysis to identify necessary and sufficient conditions for achieving port sustainability.

Chapter 4 provides a comprehensive overview of the data collected from sources such as the WPSP database, ISL Port Database, ESI, Arcadis Sustainable Cities Index, and Mercer City Ranking. The data includes information on sustainability initiatives, economic indicators, environmental performance, and social impacts of ports worldwide. In addition, this chapter also explain in detailed data processing and findings based on the cs QCA results. The data processing involves coding conditions and constructing a truth table to identify patterns and causal relationships, offering insights into effective strategies for sustainable port development.The findings reveal that no single condition is necessary for achieving port sustainability; instead, multiple pathways involving different combinations of conditions can lead to sustainable outcomes. The study identifies key configurations, such as the integration of health, safety, security measures with infrastructure, and the role of community building and digitalization. Regional variations highlight the importance of context, with developed regions showing higher sustainability performance.

Chapter 5 provides a conclusion that summarizes the study's key findings, emphasizing the multifaceted nature of port sustainability and the importance of regional contexts. Multiple pathways can lead to sustainable outcomes, underscoring the need for integrated strategies that address economic, social, and environmental dimensions. The study provides actionable insights for policymakers and port authorities, contributing to the broader goal of achieving balanced growth through integrated environmental protection and social equity in port cities.

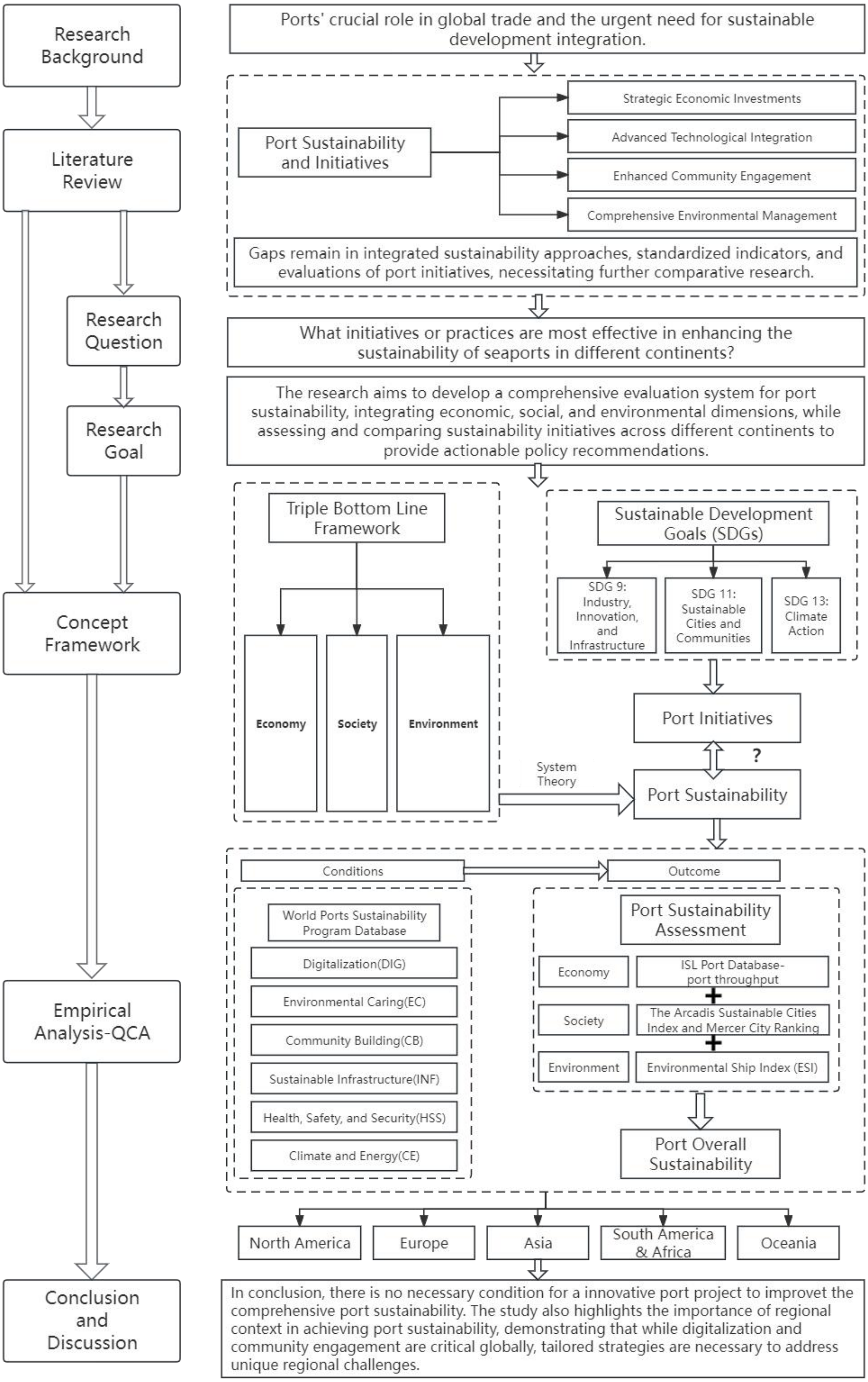


Figure 2 Framework Flow of the Thesis (Source: author)

# Chapter 2: Theoretical Review

## 2.1 Introduction

This chapter explores the theoretical foundations of port sustainability. This is important because it provides a theoretical basis for analyzing the complex and interrelated impacts of different port initiatives on sustainability outcomes. The purpose of this section is to lay the conceptual foundation for studying and evaluating different sustainability initiatives implemented in seaports. The conceptual framework helps readers understand the research logic more clearly and helps understand the principles of data analysis and interpretation of results. It ensures that readers can easily grasp the logic behind the study and understand how to apply the theoretical foundation to analyze the data and draw conclusions.

First, a broad explanation of the theoretical foundation, the triple bottom line (TBL) framework, the Sustainable Development Goals (SDGs), qualitative comparative analysis (QCA), stakeholder theory, and the resource-based view (RBV) is provided. Each of these theories provides a valuable perspective to frame the structure of the study. The TBL framework indicates the economic, ecological, and social outcomes that can be used to evaluate the performance of port sustainability activities (Kashwani, 2019). The SDGs set specific goals, targets, and indicators to underpin global sustainable development, focusing on specifically identified challenges such as industry (SDG 9) and sustainable cities and communities (SDG 11)  (Lam & Yap, 2019).Above that, quantitative comparative analysis has been developed as a methodological tool to study causal relationships under complex conditions and could be used to evaluate sustainable practices in ports (Gerrits & Verweij, 2018b).

In addition, stakeholder theory helps to understand the role and influence of different stakeholders in the operation and management of sustainable projects. This concept is used to identify and manage the interests of different stakeholder groups and tries to find conflicts between different parts, which is crucial to achieve sustainable outcomes in port initiatives (Dooms, 2018; Freeman & McVea, 2001). The theory has important implications for the social development and community-building aspects of port sustainability (Felício et al., 2023). The last relevant theory in the framework is the resource-based view (RBV). RBV aims to study how internal port resources can be strategically used to gain a competitive advantage and ensure long-term sustainability (Barney, 1991; Grant, 1999). RBV theory helps to understand the environmental, energy, and infrastructure sustainability performance of port development.

In the next section, an in-depth conceptual review of selected studies on port sustainability, their methods and results are presented. This review outlines the current understanding, identify limitations, and the contribution that this study hopes to make. This is mainly based on the literature on the integration of maritime logistics cooperation and environmental management in academic journals, industry reports, and books (Merk et al., 2011; Notteboom, 2009; Rodrigue, 2022). The literature source includes journals such as Maritime Policy and Management, Ocean and Coastal Management, and Sustainable Development, as well as various works by prominent authors such as D. Merk, T. Notteboom, Athanasios Pallis, P. de Langen, J-P. Rodrigue, and Adolf K.Y. Ng to provide a solid background understanding

Next, I define and explain the core concepts and their interrelationships, clearly presenting the key components of port sustainability. I discuss in detail the concepts of port sustainability initiatives, economic, social, and environmental outcomes, and synergies between different initiatives. Finally, I discuss the application of these theoretical frameworks, explaining how they apply to the research framework of this study and how they help explain the results. The QCA analysis model, a comprehensive assessment model for port sustainable development, is incorporated to represent the relationship between port sustainable development initiatives and their economic, social and environmental outcomes in an intuitive way. This chapter lays the foundation for a rigorous and systematic exploration of sustainable practices in the context of seaports.

## 2.2 Theoretical Background

The three dimensions of the TBL framework (economic, environmental and social) are consistent with the broad sustainable development goals of the SDGs and provide a comprehensive approach to the evaluation of sustainable development performance (Alhaddi, 2015). The holistic perspective of system theory is compatible with the QCA set theory, which is suitable for exploring the interactive and combined effects of conditions, providing more causal mechanism perspectives than traditional quantitative analysis, and ensuring that sustainable development initiatives take into account all interrelated components (Ragin, 1999). The RBV framework supports the TBL framework by emphasizing the strategic use of resources to achieve balanced sustainable development outcomes in economic, environmental and social dimensions (Madhani, 2010; Zubac et al., 2010).

These interrelated theories provide a solid foundation for the analysis and implementation of sustainable practices in port operations, ensuring that all dimensions of sustainable development are considered and addressed.

### 2.2.1 Triple Bottom Line (TBL) Framework

The Triple Bottom Line (TBL) Framework was introduced by John Elkington in 1994. It is an accounting framework that incorporates three dimensions of performance: social, environmental, and financial (Wikipedia, 2023; Sustainability Success, 2023). The primary goal of TBL is to measure a company's commitment to corporate social responsibility and sustainable development by evaluating their performance across these three areas. This framework has led to significant research outcomes, such as Roe's (2013) examination of maritime governance and policy-making, Lam and Notteboom's (2014) analysis of port sustainability practices, and Bansal's (2005) longitudinal study on corporate sustainable development. Additionally, Dempsey et al. (2011) used the TBL framework to explore urban social sustainability, underscoring the interdependence of social, environmental, and economic factors. These studies have demonstrated the utility of TBL in providing a comprehensive assessment of sustainability initiatives and have contributed to the development of more integrated and strategic approaches to sustainability in both corporate and urban contexts.

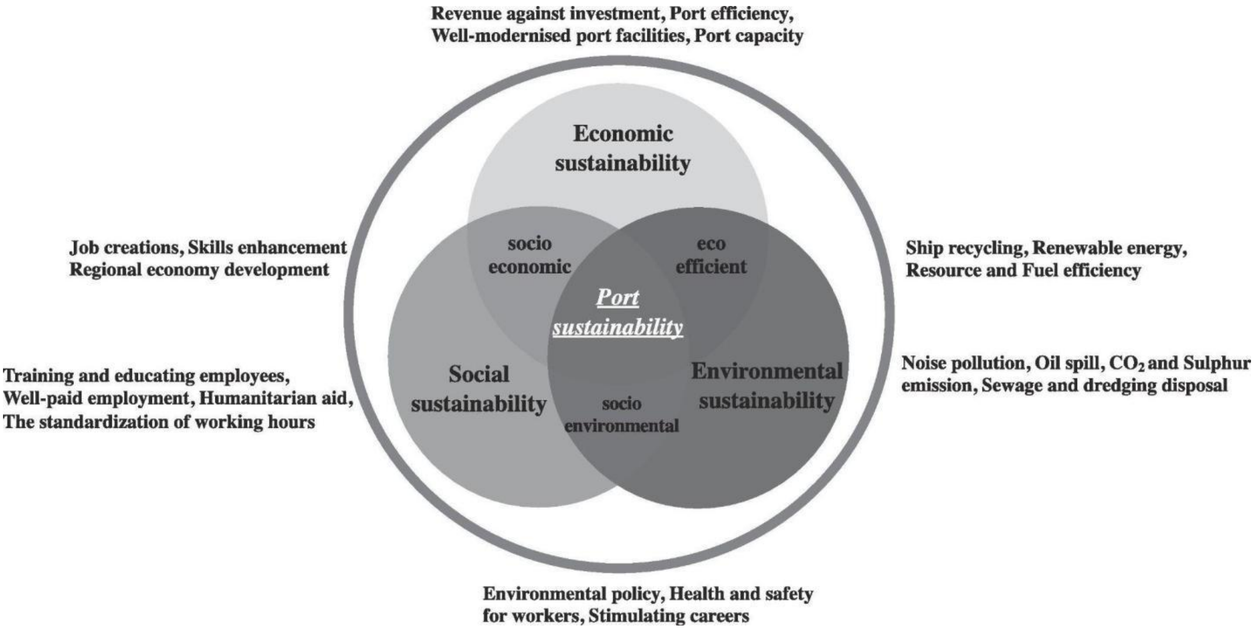


Figure 3 The Three Pillars of Port Sustainability (Source: Lim et al., 2019).

The economic dimension involves assessing the financial performance and economic contributions of ports. Metrics such as cargo throughput are used to measure economic impact, where ports handling more than 10 million tons of cargo are considered economically sustainable (Harvard Business School, 2020). In this study, economic sustainability is gauged using port throughput data from the ISL Port Database, with a threshold set at 10 million tons (ISL, 2023). The economic dimension of TBL has evolved to include more sophisticated financial metrics and the integration of long-term economic impacts in sustainability assessments (Norman & MacDonald, 2004).

The environmental dimension focuses on the ecological impacts of port activities, including emissions, resource consumption, and biodiversity. Participation in environmental initiatives like the Environmental Ship Index (ESI) is a key indicator of environmental sustainability (WPSP, 2020). The involvement in the IAPH Environmental Ship Index (ESI) scheme is used to assess environmental performance. Ports participating in ESI are considered environmentally sustainable (IAPH, 2023). Over time, the environmental dimension has expanded to incorporate broader ecological impacts and lifecycle assessments of environmental footprints (Bansal, 2005).

Social sustainability encompasses community benefits, labor practices, and health and safety. The inclusion of ports in indices such as The Arcadis Sustainable Cities Index and Mercer City Ranking indicates social sustainability (Arcadis, 2022; Mercer, 2023). Initially, the social dimension was less understood compared to the economic and environmental dimensions, but recent developments have emphasized social justice, equity, and community engagement as critical components (Dempsey et al., 2011).

The TBL framework ensures a holistic assessment of port sustainability, integrating economic viability, environmental stewardship, and social responsibility. Its evolution reflects a growing understanding of the interconnectedness of these dimensions and the need for comprehensive sustainability strategies (Elkington, 2018).

### 2.2.2 Sustainable Development Goals (SDGs)

The Sustainable Development Goals (SDGs) were established by the United Nations in 2015 as a universal set of goals to address global challenges and achieve a better and more sustainable future. For ports, specific goals like SDG 9, SDG 11, and SDG 13 are particularly relevant. Numerous scholars have used these goals in high-impact studies, emphasizing their importance in guiding sustainable development.

**SDG 9: Industry, Innovation, and Infrastructure**: This goal emphasizes the development of sustainable and resilient infrastructure, promoting inclusive and sustainable industrialization, and fostering innovation (UN, 2015). Projects related to infrastructure development and digitalization in ports align with SDG 9, contributing to their evaluation as sustainable initiatives. Research by Alamoush et al. (2021) demonstrated that port authorities implementing sustainable infrastructure projects significantly improve operational efficiency and environmental performance. Jansen (2023) highlighted the contributions of ports in advancing industrial innovation and infrastructure sustainability through strategic initiatives and partnerships. High-impact studies such as those by Herrero et al. (2017) in the *Journal of Cleaner Production* further demonstrate the critical role of SDG 9 in enhancing industrial sustainability.

**SDG 11: Sustainable Cities and Communities**: This goal focuses on making cities and human settlements inclusive, safe, resilient, and sustainable (UN, 2015). Port activities play a crucial role in urban development and community well-being. Community building initiatives and projects enhancing connectivity between ports and urban areas are evaluated under this goal. Research has shown that well-integrated port-city planning can bolster urban resilience and quality of life. Studies by Bjerkan and Seter (2019) and Hall and Jacobs (2012) emphasize the importance of ports in supporting sustainable urban ecosystems and fostering community engagement. High-impact research by Acuto (2013) in *Global Environmental Change* has shown the significant influence of urban infrastructure projects in achieving SDG 11.

**SDG 13: Climate Action**: Urgent action to combat climate change and its impacts is at the core of SDG 13 (UN, 2015). Ports can contribute significantly by reducing emissions and adopting climate-resilient infrastructure. Environmental caring and climate and energy initiatives in ports are analyzed as part of this goal. Jansen (2023) found that ports implementing comprehensive climate action plans effectively reduce their carbon footprint and enhance overall sustainability. Additionally, studies by Poulsen et al. (2018) and Alamoush et al. (2021) have shown that ports aligning their strategies with SDG 13 can lead to significant environmental benefits and resilience against climate-related risks. High-impact studies, such as those by Rockström et al. (2017) in *Nature*, highlight the global significance of climate action initiatives in achieving SDG 13.

The SDGs provide a comprehensive framework for evaluating and guiding port sustainability efforts. By aligning port initiatives with these goals, ports can ensure that their operations contribute to broader sustainable development objectives, thereby enhancing their social, environmental, and economic impacts.

### 2.2.3 Systems Theory

Systems Theory views ports as complex systems with interconnected components. This theory highlights the importance of understanding the interactions between different elements of port operations, environmental impacts, and social factors to achieve holistic sustainability (Meadows, 2008).

Numerous studies have applied Systems Theory to port sustainability, demonstrating its utility in providing a comprehensive view of port operations and their impacts. For example, a study by Chhetri et al. (2014) developed a systems framework for the sustainable development of port cities, particularly in the case study of Singapore. The research emphasized the dynamic interactions between port operations, urban development, and environmental sustainability, showing that changes in one area (e.g., infrastructure improvements) can significantly influence other areas (e.g., environmental performance and social benefits) (Chhetri et al., 2014). Another significant study by Zheng et al. (2020) in Sustainability journal used a systems approach to assess the sustainability of port cities, integrating economic, social, and environmental dimensions to propose holistic development strategies.

This study employs systems theory to analyze the interplay between various sustainability initiatives and their collective impact on port operations. By viewing the port as an integrated system, the research assesses how changes in one area (e.g., infrastructure improvements) can influence other areas (e.g., environmental performance and social benefits).

### 2.2.4 Stakeholder Theory

Stakeholder Theory, introduced by R. Edward Freeman in 1984, emphasizes the importance of identifying and managing the interests of various stakeholders in achieving organizational success (Freeman, 1984). This theory is crucial for understanding the role and impact of different stakeholders in port sustainability.

Scholars have widely applied Stakeholder Theory to analyze port sustainability. Dooms et al. (2013) discussed how stakeholder management can enhance port sustainability, focusing on the role of stakeholders in port governance and the adoption of sustainable practices. Another significant study by Schipper et al. (2017) in the *Journal of Cleaner Production* examined how stakeholder engagement is critical to the successful implementation of sustainable port practices.

The success of community building initiatives and social sustainability projects depends heavily on effective stakeholder management. This study evaluates projects based on their engagement with stakeholders and the extent to which they address stakeholder concerns (Dooms, 2019).

### 2.2.5 Resource-Based View (RBV)

The Resource-Based View (RBV) framework, developed by Jay Barney in 1991, focuses on the strategic utilization of a firm's internal resources to achieve a competitive advantage and ensure long-term sustainability (Barney, 1991; Grant, 1991). RBV theory relates closely to environmental, energy, and infrastructure sustainability.

Several studies have utilized RBV to analyze port sustainability. A notable study by Song and Panayides (2008) in the *International Journal of Logistics Management* explored how ports can leverage their unique resources, such as advanced technology and infrastructure, to achieve sustainability. Another significant study by Woo et al. (2013) examined the application of RBV in enhancing the environmental and operational performance of ports through strategic resource management.

Ports that effectively utilize resources such as advanced technology, efficient infrastructure, and renewable energy sources are more likely to be sustainable. This study examines how ports leverage their unique resources to implement sustainable practices and achieve competitive advantages.

# 2.3 Literature Review

This literature review provides a comprehensive overview of existing studies on port sustainability and related initiatives, highlighting key findings, methodologies, and research gaps. The aim is to underscore the importance of sustainable development in port operations by balancing economic, environmental, and social objectives.

## 2.3.1 Port Sustainability and Initiatives

Port sustainability has been a growing area of research, focusing on the need for ports to achieve economic viability, environmental stewardship, and social responsibility. The economic dimension of port sustainability involves assessing financial performance and contributions to local economies. Key indicators include cargo throughput, financial investments in infrastructure, and the broader economic impact on surrounding communities. Studies such as those by Lim et al. (2019) and Song and Panayides (2008) emphasize the role of economic management in achieving sustainable port operations, highlighting how strategic investments can enhance both efficiency and sustainability.

Environmental sustainability in ports focuses on reducing pollution, managing waste, and adopting green technologies. Chhetri et al. (2014) explored the implementation of environmental management systems in ports, stressing their importance for sustainable operations. Similarly, Poulsen et al. (2018) examined how ports contribute to environmental upgrading within global value chains, showcasing the potential for ports to drive significant environmental improvements through targeted initiatives.

Social sustainability encompasses community benefits, labor practices, and overall stakeholder engagement. Schipper et al. (2017) emphasized the critical role of stakeholder engagement in promoting social sustainability in ports. Integrating ports into urban planning and assessing their impact on local communities are essential for ensuring that port activities support broader social goals. The integration of social sustainability practices helps in fostering community support and improving the quality of life for residents in port cities.

Numerous port initiatives have been launched to address sustainability challenges. Digitalization initiatives aim to improve efficiency, reduce emissions, and enhance overall sustainability through advanced technologies. Research by Lam and Notteboom (2014) highlights the transformative impact of digitalization on port operations, suggesting that technological advancements can lead to significant sustainability gains.

Environmental caring initiatives focus on reducing the environmental impact of port activities. Studies by Chhetri et al. (2014) and Poulsen et al. (2018) underscore the importance of adopting green technologies and practices to mitigate negative environmental effects. These initiatives are crucial for achieving long-term environmental sustainability in ports.

Community building efforts engage local communities to improve social outcomes and ensure that port operations contribute positively to the surrounding areas. Research by Schipper et al. (2017) highlights the importance of stakeholder engagement in these initiatives, demonstrating that successful community integration can lead to enhanced social sustainability.

Sustainable infrastructure projects are essential for improving port operations and reducing environmental impacts. Alamoush et al. (2021) demonstrate the benefits of sustainable infrastructure investments, which include enhanced operational efficiency and reduced carbon footprints. These projects are critical for achieving sustainability goals in port operations.

Health, safety, and security initiatives ensure the well-being of workers and local communities. PSA Singapore, for example, places a strong emphasis on health and wellness, aligning with national health strategies and promoting preventive care. Their initiatives include leveraging technology to minimize accidents and ensure safety excellence through continuous safety surveillance and collaboration with relevant authorities (PSA Singapore, 2024). Similarly, Dublin Port's SafePort initiative aims to enhance safety culture and practices across the port, involving extensive collaboration with terminal operators and local authorities to standardize safety procedures and promote long-term safety awareness (Dublin Port, 2024).

Climate and energy initiatives focus on reducing carbon emissions and adopting renewable energy sources. Research by Jansen (2023) and others highlights the role of ports in climate action, suggesting that ports can significantly contribute to global climate goals by implementing comprehensive climate strategies.

### 2.3.2 Trend of Methods in Literature

The methodologies used in port sustainability research are diverse and include systematic literature reviews, empirical analyses, case studies, and qualitative comparative analyses. Systematic reviews, such as those by Lim et al. (2019), provide a comprehensive evaluation of existing literature, identifying trends and research gaps. Empirical studies, including those by Song and Panayides (2008), offer practical insights into the application of sustainability initiatives in ports. Case studies, like those conducted by Zheng et al. (2020) and Hall and Jacobs (2012), provide detailed analyses of specific port sustainability practices. These methodologies collectively contribute to a deeper understanding of port sustainability.

### 2.3.3 Research Gaps

Despite significant progress, several research gaps remain. Integrated approaches that combine economic, environmental, and social dimensions are needed to provide a holistic view of port sustainability (Liu et al., 2021). The lack of standardized indicators for measuring sustainability performance across different ports poses a challenge for comparative analysis (Wagner, 2019). Further research is required to understand the role of stakeholders in implementing and sustaining port sustainability initiatives(Balić et al., 2022). Additionally, more studies are needed to evaluate the effectiveness of various port initiatives in achieving sustainability goals, particularly through comparative and longitudinal studies.

The literature on port sustainability and initiatives reveals significant progress in understanding the multifaceted nature of sustainable port operations(Bjerkan & Seter, 2019; Zheng et al., 2020). However, research gaps remain, particularly in the integration of sustainability dimensions, standardization of indicators, and innovative projects implementation. This study aims to address these gaps by exploring the effectiveness of various port initiatives and their impact on overall port sustainability.

## 2.4 Core Concepts

To effectively analyze port sustainability, this section will define the core concepts of this study and explain their interrelationships.

### 2.4.1 Sustainability

Sustainability is a broad concept that refers to the ability to meet the needs of the present without compromising the ability of future generations to meet their own needs. It encompasses three primary dimensions: economic, environmental, and social. This concept is foundational for understanding the specific sustainability goals and initiatives within port operations.

Elkington (1997) introduced the Triple Bottom Line framework, which emphasizes the importance of balancing economic growth, environmental protection, and social equity. This framework has been instrumental in shifting the focus from purely economic outcomes to a more holistic approach that includes social and environmental dimensions. The integration of these three dimensions is essential for achieving sustainable development, as it ensures that economic activities do not harm the environment or society. The Triple Bottom Line framework has been widely adopted in various fields, including business, policy-making, and environmental management, highlighting its versatility and importance in promoting sustainability (Elkington, 1997; Norman & MacDonald, 2004).

Research in sustainability has evolved to address the complex interactions between these three dimensions. For example, studies by Gladwin, Kennelly, and Krause (1995) discuss sustainable development as an intertwined relationship of economic, ecological, and social aspects, arguing that these elements must be addressed simultaneously to achieve true sustainability. Additionally, Sachs (2015) outlines the need for integrated approaches that consider economic, social, and environmental sustainability as mutually reinforcing pillars, essential for the long-term well-being of societies and ecosystems.

### 2.4.2 Port Sustainability

Port sustainability extends the concept of sustainability to the specific context of port operations. It involves ensuring that port activities contribute positively to economic growth, environmental health, and social well-being. Key indicators of port sustainability include economic performance (e.g., cargo throughput), environmental impacts (e.g., pollution levels), and social contributions (e.g., community engagement).

Port sustainability necessitates a comprehensive approach that balances the economic benefits of port operations with the need to mitigate environmental impacts and enhance social equity. This involves implementing policies and practices that promote efficient and environmentally friendly operations, as well as engaging with local communities to ensure that the benefits of port activities are widely shared. Ports are complex entities that operate at the intersection of global supply chains and local economies, making their sustainability critical for both economic development and environmental stewardship (Lam & Notteboom, 2014).

Lam and Notteboom (2014) highlight the greening of ports and compare management tools used by leading ports in Asia and Europe to enhance sustainability. Their research underscores the importance of adopting best practices and innovative technologies to reduce the environmental footprint of port operations while maintaining high levels of efficiency and competitiveness.

Lim et al. (2019) provide a systematic review of port sustainability and performance, identifying key trends and gaps in current research. Their findings emphasize the need for standardized metrics and frameworks to evaluate port sustainability comprehensively. The review also points out the disparities in sustainability practices across different regions, suggesting that context-specific strategies are crucial for effective implementation.

Further research by Hall and Jacobs (2012) explores the urban dimension of port sustainability, examining how ports can be integrated into urban planning to promote more sustainable cities. Their work highlights the potential for ports to act as catalysts for broader urban sustainability initiatives, fostering economic growth while minimizing environmental impacts and enhancing social well-being.

In summary, port sustainability is a multifaceted concept that requires coordinated efforts across various domains to ensure that port operations contribute to sustainable development goals. By adopting comprehensive strategies that address economic, environmental, and social dimensions, ports can achieve sustainable growth that benefits both local and global communities.

### 2.4.3 Port Initiatives

Port initiatives refer to specific projects or actions taken by port authorities and stakeholders to promote sustainability. These initiatives are designed to address the various dimensions of sustainability through targeted efforts. Examples include adopting green technologies, enhancing digital infrastructure, and engaging with local communities. These initiatives are essential for reducing environmental impacts, improving economic efficiency, and fostering social equity within port operations.

Schipper et al. (2017) discuss stakeholder perspectives on port sustainability, emphasizing the role of various initiatives in achieving sustainable outcomes. They highlight the importance of stakeholder engagement and collaboration in the successful implementation of sustainability initiatives. Stakeholders, including government agencies, private companies, and local communities, play a crucial role in shaping and supporting these initiatives, ensuring that they align with broader sustainability goals.

Gonzalez-Aregall et al. (2021) review port initiatives aimed at promoting freight modal shifts, providing evidence from port governance systems. Their research illustrates how strategic initiatives can encourage the use of more sustainable transport modes, such as rail and inland waterways, over road transport. This shift not only reduces congestion and emissions but also enhances the overall efficiency and sustainability of the freight transport system. The study underscores the significance of governance frameworks in facilitating and managing these initiatives, highlighting the need for coordinated policies and investments to achieve desired sustainability outcomes.

These studies collectively demonstrate that port initiatives are multifaceted and require coordinated efforts across various sectors to be effective. By focusing on green technologies, digital infrastructure, and community engagement, ports can address the economic, environmental, and social dimensions of sustainability, ultimately contributing to more sustainable and resilient port operations.

### 2.4.4 Six Thematic Conditions

The six thematic conditions are specific areas of focus for port initiatives, each contributing to different aspects of sustainability. They all come from SDGs. These conditions include:

1. Digitalization involves the implementation of advanced digital technologies to enhance operational efficiency and reduce environmental impacts in port operations. By adopting technologies such as IoT, big data analytics, and automation, ports can streamline processes, improve cargo handling efficiency, and reduce emissions. Research by Heilig et al. (2017) demonstrates how digitalization can lead to significant improvements in port logistics and environmental performance. Additionally, digital twin technologies allow for real-time monitoring and optimization of port operations, contributing to greater efficiency and sustainability (Tao et al., 2018).

2. Environmental Caring focuses on adopting green technologies and practices to minimize pollution and manage waste effectively. This includes measures such as using cleaner fuels, implementing waste recycling programs, and investing in renewable energy sources. Studies by Acciaro et al. (2014) highlight the impact of environmental initiatives on reducing emissions and improving air quality in port areas. Furthermore, environmental certification programs, such

as the EcoPorts initiative, provide frameworks for ports to systematically improve their environmental performance (Puig et al., 2015).

3. Community Building involves engaging with local communities to enhance social outcomes and support economic development. Effective community engagement can help ports gain public support, mitigate social conflicts, and contribute to local development. Research by van der Lugt et al. (2016) emphasizes the importance of transparent communication and active collaboration with community stakeholders in achieving social sustainability. Initiatives such as community advisory panels and local development projects can foster positive relationships between ports and their surrounding communities.

4. Sustainable Infrastructure entails the development of infrastructure projects that prioritize sustainability and reduce environmental impacts. This includes building energy-efficient terminals, using sustainable construction materials, and incorporating green design principles. Studies by Notteboom and Rodrigue (2005) underscore the benefits of sustainable infrastructure investments for enhancing operational efficiency and reducing carbon footprints. The implementation of green port infrastructure, such as shore power systems and eco-friendly building designs, can significantly lower environmental impacts and support long-term sustainability goals (Ng et al., 2014).

5. Health, Safety, and Security ensures workers and local communities is a healthy and safe work circumstance. This involves implementing robust safety protocols, health initiatives, and security measures to create a safe working environment. Research by Hollenbeck et al. (2011) highlights the importance of safety culture in reducing workplace accidents and promoting worker well-being. Ports like PSA Singapore and Dublin Port have developed comprehensive safety programs that include regular training, safety audits, and collaboration with local authorities to enhance overall safety and security (PSA Singapore, 2024; Dublin Port, 2024).

6. Climate and Energy initiatives focus on reducing carbon emissions and transitioning to renewable energy sources. Ports play a significant role in global climate action by implementing strategies to reduce their carbon footprint and enhance energy efficiency. Studies by Cullinane and Bergqvist (2014) examine the effectiveness of various climate mitigation strategies in ports, including the adoption of alternative fuels and energy-saving technologies. Initiatives such as the Carbon Footprint Project provide ports with tools to measure and manage their greenhouse gas emissions, contributing to global efforts to combat climate change (Schøyen and Bråthen, 2015).

## 2.5 Theoretical Framework

This theoretical framework flow chart illustrates integrates Sustainable Development Goals (SDGs) with port sustainability initiatives, leveraging various theoretical perspectives. It aligns SDG 9 (Industry, Innovation, and Infrastructure), SDG 11 (Sustainable Cities and Communities), and SDG 13 (Climate Action) with port initiatives. Innovation Theory is linked to SDG 9, focusing on infrastructure (INF) and digitalization (DIG). Stakeholder Theory, associated with SDG 11, emphasizes community building (CB) and health, safety, and security (HSS). The Resource-Based View (RBV), pertaining to SDG 13, addresses environmental care (EC) and clean energy (CE). These elements collectively influence port sustainability, measured by the Triple Bottom Line (TBL), encompassing economy, society, and environment. The framework illustrates the interconnections between these dimensions and theories, highlighting the importance of innovation, stakeholder engagement, and resource management in achieving sustainable port development. By aligning port initiatives with SDGs, the framework ensures that economic, social, and environmental aspects are integrated into sustainable practices, promoting comprehensive port sustainability.

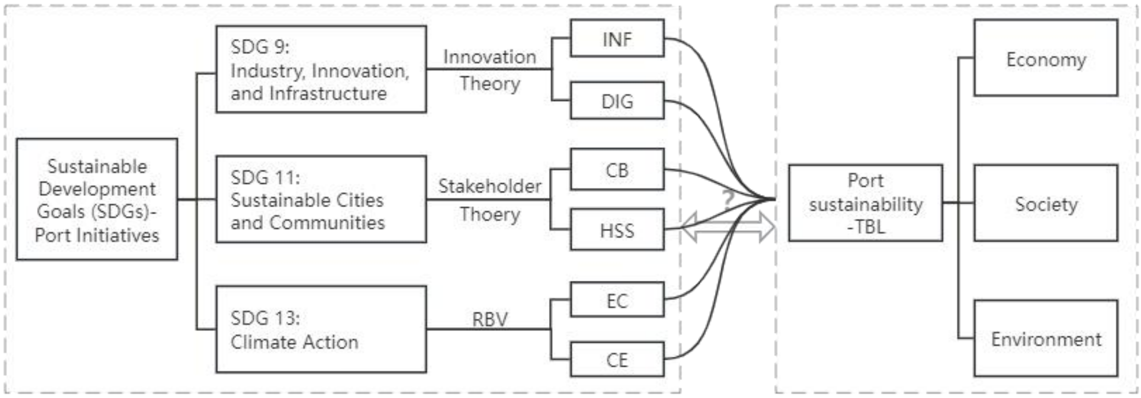


Figure 4: Theoretical Concept Framework (Source: author)

# Chapter 3: Methodology

## 3.1 Ontology and Epistemology

Ontology refers to the nature of reality and what can be known about it. The ontological perspective of this study is consistent with pragmatism, which emphasizes practical solutions to real-world problems(Al-Saadi, 2014). This approach acknowledges that reality is complex and multifaceted. This is particularly true in the context of port sustainability, which involves a dynamic interaction between economic, environmental and social factors. The epistemological stance is constructivist, focusing on understanding the subjective meanings and interpretations of stakeholders involved in port sustainability initiatives. Knowledge was obtained through qualitative analysis, reflecting the different perspectives and experiences of different actors in the port sector (Bhaskar, 1978; Crotty, 2020).

Given the complexity of port sustainability and the context-specific nature, achieving “true” statements requires recognizing the limitations of generalizability. This study used QCA to identify patterns and causal relationships between different cases, acknowledging that the results are condition- and context-specific. True statements are those that remain relevant in the specific context studied and provide actionable insights to improve port sustainability. Triangulation, including multiple data sources and methods, increases the credibility and trustworthiness of the results (Gerrits & Verweij, 2018a; Verweij, 2015; Verweij et al., 2013).

## 3.2 Methods and Justification

The main method used in this study is Qualitative Comparative Analysis (QCA). This method was chosen because it excels at dealing with complex cause-effect relationships and identifying combinations of conditions that produce desired outcomes (Rihoux & Ragin, 2009). QCA is particularly suitable for this study because it helps compare multiple cases and identify necessary and sufficient conditions for achieving port sustainability. The method provides a systematic framework for analyzing different initiatives and their impact on sustainable development outcomes (Verweij, 2013; Verweij, 2015).

### 3.2.1 Introduction to QCA

QCA is a research method that combines qualitative and quantitative techniques to analyze causal relationships in case-based research. Developed by Charles Ragin in the 1980s, QCA is used to identify patterns across cases and determine which combinations of conditions are associated with specific outcomes. It is especially useful for studying complex phenomena where multiple interacting factors contribute to the outcome (Ragin, 1987). QCA allows researchers to systematically compare cases to uncover which specific configurations of factors lead to a particular outcome, offering insights that traditional variable-based methods might miss. This method is particularly valuable in social sciences for its ability to handle complex causality, where different combinations of conditions can lead to the same outcome, known as equifinality (Ragin, 2008; Schneider & Wagemann, 2012).

QCA involves creating a truth table that displays all possible combinations of conditions and their associated outcomes. Researchers then use Boolean algebra to simplify these combinations into a set of logical statements that describe the necessary and sufficient conditions for the outcome. This approach is highly suitable for examining the interplay of multiple factors in real-world settings, making it a powerful tool for policy analysis, organizational studies, and comparative research (Schneider & Wagemann, 2012; Verweij, 2015).

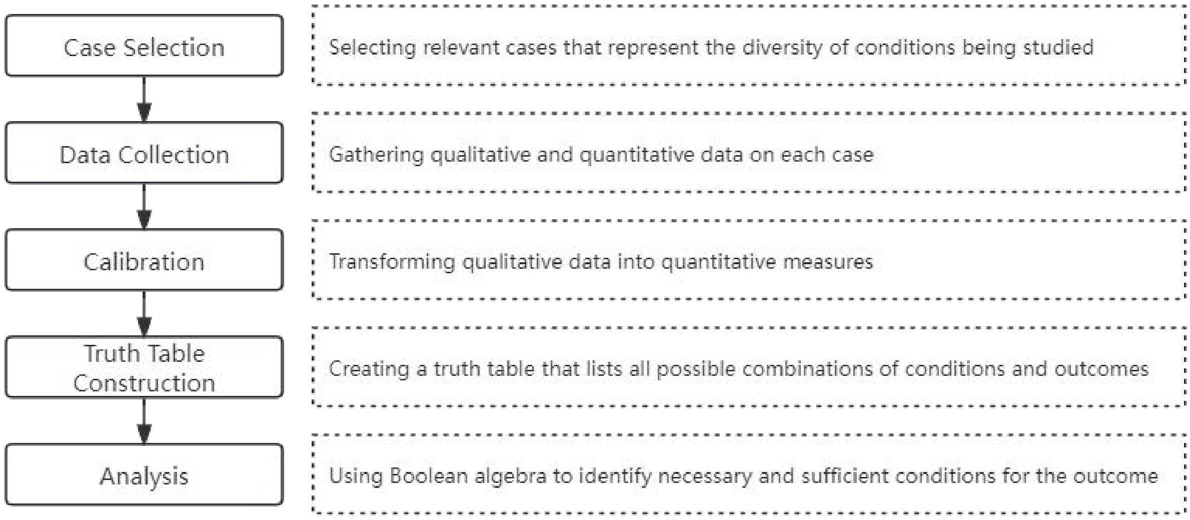


Figure 5: QCA Step Flow (Source: author)

### 3.2.2 Types of QCA

There are three main types of QCA, each suited to different types of data and research needs:

1. **Crisp-set QCA (csQCA)**:
   csQCA uses binary data to indicate the presence or absence of conditions, typically coded as 0 or 1. This method is straightforward and suitable for cases where conditions can be clearly defined as either present or absent. The simplicity of csQCA allows for clear and interpretable results, making it a popular choice for studies where binary conditions are easily identifiable. However, its binary nature can sometimes oversimplify complex realities, as it does not capture variations in the degree to which a condition is present (Ragin, 1987; Schneider & Wagemann, 2012).

2. **Fuzzy-set QCA (fsQCA)**:
   fsQCA allows for partial membership in sets, using values between 0 and 1 to represent varying degrees of membership. This method is more flexible than csQCA and can capture the nuances of real-world phenomena. For example, a port's environmental performance might not be simply "good" or "bad" but could be represented on a scale from 0 (poor performance) to 1 (excellent

performance). fsQCA is particularly useful for social science research where conditions are not strictly binary and can vary in intensity. This method requires careful calibration of data to ensure accurate representation of set memberships (Ragin, 2000; Rihoux & Ragin, 2009).

3. **Multi-value QCA (mvQCA)**:
   mvQCA extends csQCA by allowing for more than two categories per condition. This approach is useful when conditions can take on multiple discrete states, such as "low," "medium," and "high." mvQCA provides a middle ground between csQCA and fsQCA, offering more flexibility than binary coding while maintaining discrete categories. This method can handle more complex datasets with multiple categorical variables, but it also requires careful consideration of how to categorize conditions to ensure meaningful analysis (Cronqvist & Berg-Schlosser, 2009; Ragin & Davey, 2014).

### 3.2.3 Justification for Using csQCA

The choice of csQCA over other types of QCA is based on several factors:

This study uses csQCA. It provides a clear and direct way to analyze the presence or absence of specific conditions in each case, making it easier to identify the combination of conditions that lead to sustainable port results. In this study, there are six conditions, so a total of 64 combinations may occur, and a total of 310 cases were collected in the database. csQCA is most suitable for this study because binary variable coding can effectively reduce the complexity of calculations, reduce noise and outliers generated in the data analysis process, and make it easier to obtain sufficient solutions and necessary conditions (Ragin, 1999; Rihoux & Ragin, 2009)

csQCA can help evaluate various sustainable development initiatives implemented by ports around the world, namely sustainable development initialtives conditions. According to the SDGs and WPSP, these initiatives include digitalization, environmental protection, community building, sustainable infrastructure, health, safety and security, and climate and energy measures (WPSP, 2020). Each of these initiatives can be coded as a binary variable (1 or 0), which simplifies the analysis and helps identify patterns in different cases. After systematically comparing these binary coded conditions across ports, it is possible to determine which combinations of conditions are associated with port sustainable development results. This analytical method is able to handle the complexity of multiple interacting factors and identify necessary and sufficient conditions for achieving sustainability in port operations. Furthermore, csQCA's ability to manage the binary nature of the data ensures that the analysis remains robust and interpretable, providing a clear understanding of the factors driving port sustainability.

### 3.2.4 Comparative Research in Port Sustainability

In the comparative study of port sustainability, I aim to compare the results of port case studies in different regions. I compare the similarities and differences in the sustainability capabilities of ports in different regions, and what conditions and combinations can point to sustainable ports, and explore the reasons and effects behind them in the context of the region (Assche et al., 2020). By comparing the same topic in different contexts, we can better understand diversity. Comparing ports in different regions can better understand how contextual factors such as economic conditions, regulatory environment, and cultural background affect sustainable development outcomes. This approach recognizes the importance of regional differences in shaping the effectiveness of sustainable development initiatives and provides a nuanced perspective on port sustainability (Gan et al., 2021; Ragin, 1999). Comparing the implementation effects of different condition combinations and the reliability of policy implementation can provide reference for policy making. The study can obtain models that can be generalized in different contexts, thereby enhancing the robustness of the research results. This comparative approach ensures that the insights obtained are not limited to specific cases, but can be applied more widely, thereby strengthening the contribution of the research to the field of port sustainability (Hiranandani, 2014b).

Building on the comparative study framework, this research work based on three hypotheses as follow.

Hypotheses 1, Regional Impact Hypothesis: Initiatives to improve sustainability will have a more significant impact in ports in Europe and North America than in ports in developing regions such as Asia, Africa and South America.

First of all, it is significantly reflected in the percentage of sustainable ports among all ports. That is to say, the solution coverage of cases in Europe and North America will be higher, while the solution coverage of Asia, Africa and South America will be significantly lower. Second, sustainability initiatives in European and North American ports are likely to lead to more diverse and comprehensive solutions and better overall sustainability outcomes. This assumption is based on the generally higher levels of economic development, stricter environmental regulations and more advanced technological infrastructure in Europe and North America (Roe, 2013; Lam & Notteboom, 2014).

Hypotheses 2, Comprehensive Initiative Hypothesis: In various sustainability domains, such as digitalization, environmental protection, community building, climate, and energy, I hypothesize that initiatives integrating multiple themes of sustainable development can better enhance the overall sustainability capacity of ports. Based on systems theory, I believe that the integration of multiple conditions will generate synergistic effects, which can better improve the comprehensive sustainability capacity of ports compared to single-theme projects (Poulsen et al., 2018; Schipper et al., 2017).

By integrating comparative research with QCA, this study provides valuable insights into how different combinations of conditions lead to sustainable outcomes in various regional contexts. This approach enhances the overall robustness and generalizability of the findings. The comparative analysis enables the identification of region-specific strategies and best practices that can be adapted and implemented across different ports to achieve sustainability.

## 3.3 Case Selection

The data collection process involved collecting qualitative and quantitative data from various publicly available database sources, including the World Port Sustainability Program (WPSP) database, port authorities' annual reports, and sustainability reports. These data were then coded and analyzed according to the criteria. The QCA process iterated between qualitative data interpretation and quantitative coding, ensuring that the relationship between different initiatives and sustainable development outcomes could be drawn from complex data (Verweij, 2013).

Port initiatives were selected based on their representativeness of different geographical regions and sustainable development initiatives. The study included ports from Europe, Asia, North America, Oceania, Africa, and South America, providing a broad perspective on port sustainable development practices. Due to the similar urban development context of African and South American ports and the limited number of samples in these regions, they were combined into one category in the subsequent comparative classification analysis. This selection ensured a diverse representation of geographical regions and sustainable development practices. Each case selected was a sustainable development project implemented within a port, with unique characteristics and contributions to the understanding of different dimensions of sustainability in port operations. The data provided port cases from a range of economic, environmental, and social contexts, enriching the diversity and reliability of the sample (Verweij, 2015).

1. **World Ports Sustainability Program (WPSP) Database:** Provides detailed information on various sustainable development initiatives taken by ports around the world and awards the Sustainable Port Award every year. The WPSP database is crucial in this study because it provides a comprehensive overview of sustainable development practices implemented by ports around the world and is the most important data resource for identifying effective initiatives and benchmarking the performance of ports (WPSP, 2023).

**2. ISL Port Database:** Provides data on port throughput, which is used as an economic indicator for evaluating sustainable development. The ISL Port Database was selected because it is the most comprehensive database on cargo transportation in major ports in the world. It covers nearly 500 ports in 108 countries. The time series for most major seaports dates back to 1980. It is based on data published by ports and statistical authorities around the world and includes information on the structure of cargo transportation, such as cargo types and major bulk commodities. These data are essential for understanding the economic aspects of port sustainability, including the volume of cargo handled and the economic impact on the surrounding area (ISL, 2023).

**3. Environmental Ship Index (ESI):** During the coding process, I evaluated environmental performance based on the port's participation in the ESI program. ESI is an important source of environmental data. Ports participating in ESI must publish emissions data, especially pollution. I believe that participating in ESI shows that ports are committed to reducing their environmental footprint and has great reference value in evaluating the environmental sustainability of ports (IAPH, 2023).

**4. Arcadis Sustainable City Index and Mercer City Ranking:** These indices and city rankings provide a basis for evaluating the social sustainability of ports. These indices were chosen because they all focus on insights into the social aspects of sustainability when ranking cities, such as community engagement, quality of life, and social infrastructure. Ports included in these rankings can be considered to have a broader social impact and have significant achievements in enhancing urban environmental sustainability (Arcadis, 2022; Mercer, 2023).

These materials cover data on the economic, environmental and social aspects of ports, which together serve as an overall evaluation indicator of port sustainability. This comprehensive coverage is essential for a balanced and systematic analysis of port sustainability initiatives. The data are all publicly available and recognized by the industry for their accuracy and reliability. The ISL Port Database and the WPSP Database, for example, are widely used in academic and industry research and provide a solid foundation for this study. The use of standardized indicators from sources such as the ESI and the Arcadis Sustainable Cities Index facilitated the benchmarking and comparison of different ports. The data collection process also involved an extensive document review, qualitative interviews with port authorities and stakeholders, and analysis of sustainability reports. This mixed approach ensured that the data was rich, detailed, and contextually relevant. By combining qualitative insights with quantitative indicators, the study provided a nuanced understanding of how various initiatives impact port sustainability. The collected data was then processed using csQCA to identify patterns and causal relationships, ensuring a rigorous and systematic analysis of the complex interactions between different sustainability initiatives (Verweij, 2013; Verweij, 2015).

# Chapter 4: Data and Analysis

## 4.1 Introduction

This chapter introduces the data collected to study the port's sustainable development initiatives and the process of data analysis. The purpose is to provide a comprehensive overview of the factual information collected rather than jumping to hasty conclusions. The chapter on data can be divided into three parts. The first is to introduce the data source and statistically describe the data. Then there is the data processing process, including data cleaning and data coding. Finally, there is the data analysis section, including the data truth table, identification of necessary conditions and sufficient conditions, and explanation of the reasons for the conclusions.

## 4.2 Data Sources

1. **World Ports Sustainability Program (WPSP) Database**:

The WPSP database provides detailed information on various sustainability initiatives undertaken by ports worldwide. These initiatives are categorized into six main areas: digitalization, environmental caring, community building, sustainable infrastructure, health and safety, and climate and energy. The data includes descriptions of individual projects, their objectives, and outcomes. The database also includes geographic information, allowing for the visualization of the distribution of these initiatives globally.

Additionally, it is important to note that some projects in the WPSP database involve collaboration between multiple ports or span multiple countries. Due to the complexity and difficulty in pinpointing the specific cities and countries involved in these collaborative projects, such initiatives are excluded from the final database used for analysis. This decision ensures clarity and accuracy in attributing specific sustainability efforts to individual ports.

From 2010 to 2023, a comprehensive analysis of 310 port initiatives across six continents reveals significant trends and patterns. Europe leads with 108 cases, followed by North America with 44, Oceania with 40, Asia with 40, South America with 19, and Africa with 13. The cases are distributed across 45 countries and 99 cities, indicating a broad geographical spread. In terms of thematic focus, CB dominates with 121 cases, followed by EC with 115, CE with 106, INF with 57, DIG with 68, and HSS with 53. The most common combination of themes is CB+EC, appearing in 48 cases. This distribution highlights the diversity and complexity of the cases studied, reflecting the global nature of the issues addressed and the interdisciplinary approaches applied.

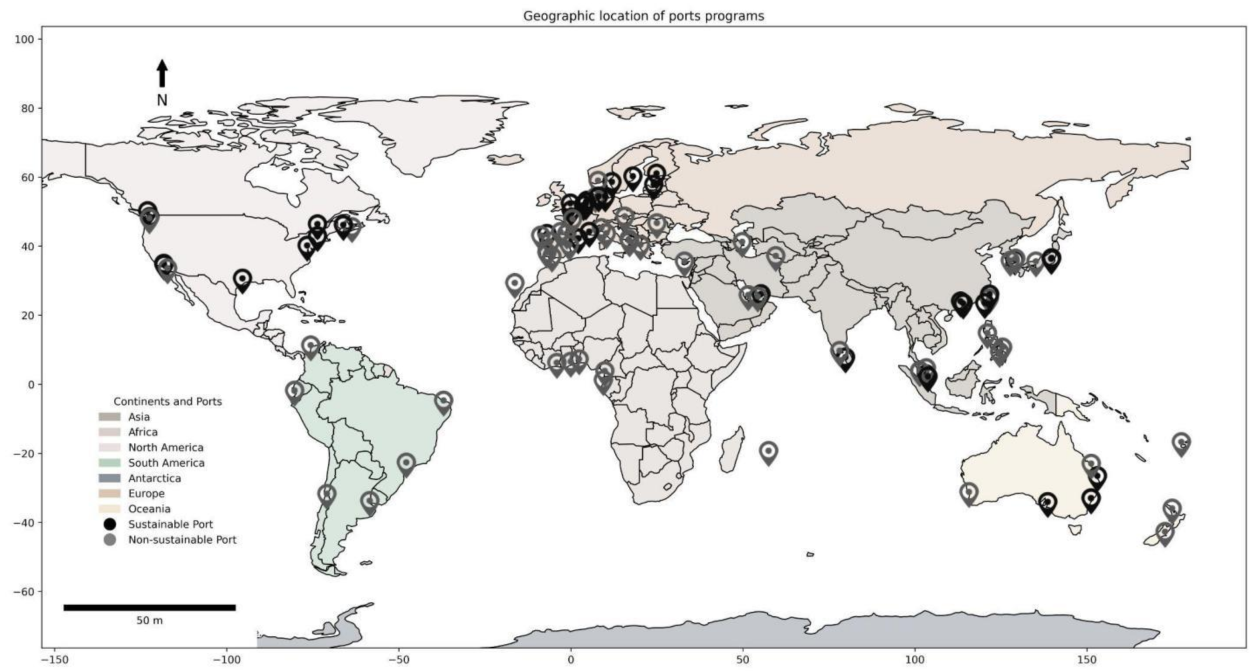


Figure 6: Geographic Distribution of Sustainability Projects from the Final Data-set (Source: Author)

2. **ISL Port Database**:

The ISL Port Database provides comprehensive data on port throughput that can be used as an economic indicator for assessing port sustainability. Its indicators include annual cargo throughput in tons as well as classification of ports based on throughput (above or below 10 million tons). These data help assess the economic performance of ports and their ability to handle large volumes of cargo, which is one of the important aspects of port sustainability. The Port Database is one of the most comprehensive international databases, providing information on cargo traffic in major ports around the world. The database covers nearly 500 ports in 108 countries, with time series for most major seaports dating back to 1980. It contains information on the cargo traffic structure, such as cargo types and major commodities, based on data published by ports and statistical offices around the world. The database covers 489 seaports, records 21 billion tons of cargo and 682 million TEUs, and provides 42 years of time series data.

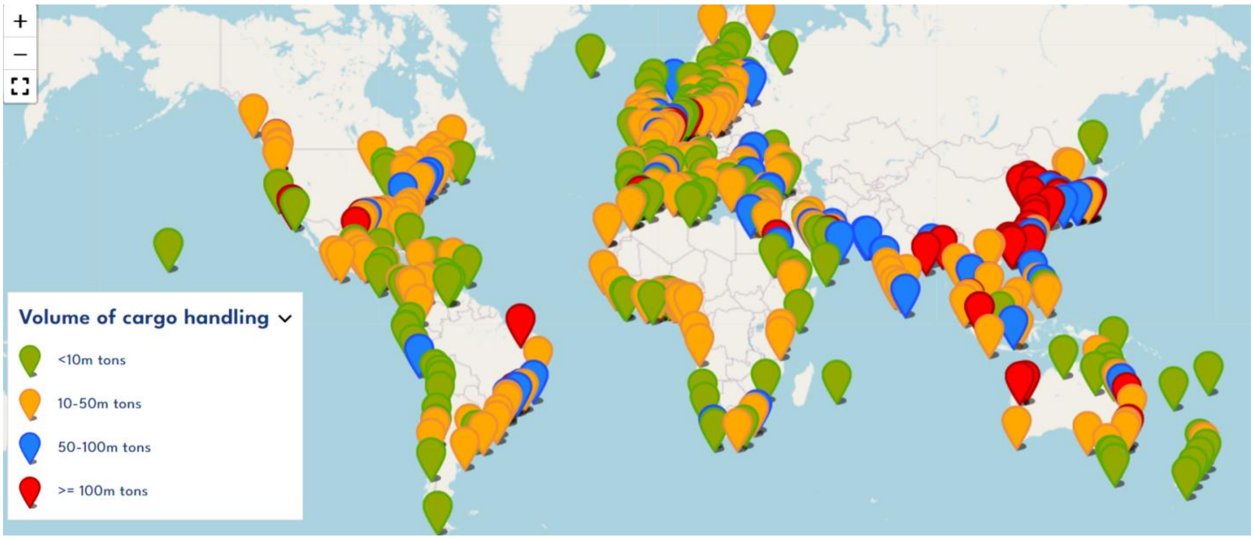


Figure 7: Geographic Distribution of Port Cargo Handling Volumes (Source: ISL Port Database, 2023)

3. **Environmental Ship Index (ESI)**:

The ESI data provides information on ports' participation in the ESI program, which assesses ports' environmental performance based on emissions from ships and can be used as an environmental indicator to assess ports' comprehensive sustainability capabilities (Gibson, 2019). The ESI includes the ports' level of participation in environmental pollution control, environmental performance scores, and emissions reductions achieved through various initiatives. These data help readers understand the impact of port activities on environmental sustainability and the effectiveness of emission reduction measures.


Figure 8: Ports participating in the Environmental Ship Index (ESI) program (Source: IAPH Environmental Ship Index, 2023)

4. **The Arcadis Sustainable Cities Index and Mercer City Ranking**:

The Arcadis Sustainable Cities Index is a comprehensive ranking system that evaluates cities around the world based on their sustainability performance. The index assesses three main pillars of sustainability: People, Planet, and Profit, which correspond to social, environmental, and economic sustainability respectively(Sáez et al., 2020).

- **People:** This pillar focuses on social factors such as health, education, income inequality, crime rates, and work-life balance. It evaluates the quality of life and social equity within cities.
- **Planet:** This pillar assesses environmental sustainability, considering factors such as energy consumption, renewable energy usage, green spaces, waste management, and air pollution. It highlights how cities manage their resources and their environmental impact.
- **Profit:** This pillar examines economic sustainability, looking at metrics such as business environment, economic performance, infrastructure, and ease of

doing business. It measures the economic health and growth potential of cities.

The index combines these pillars to provide an overall ranking that reflects the comprehensive sustainability performance of cities. It helps to identify strengths and weaknesses in different areas, guiding cities towards more sustainable development strategies.


Figure 9: Overall Ranking of Cities in the Arcadis Sustainable Cities Index 2022 (Source: Arcadis Sustainable Cities Index, 2022)

The Mercer City Ranking, specifically known for its Quality of Living Ranking, is another influential index that evaluates cities based on the quality of life they offer. This ranking is widely used by multinational companies and governments to assess the living conditions for expatriates and international employees.

- **Quality of Living Index:** This index measures factors such as political stability, healthcare, education, crime, recreation, housing, and public services. It provides a comprehensive assessment of living conditions in cities around the world.
- **Top 10 Cities for Quality of Living:** Each year, Mercer highlights the top cities that provide the highest quality of living based on their rigorous evaluation criteria.

The Mercer City Ranking is crucial for understanding the social sustainability aspects of port cities, as it directly reflects the living conditions and well-being of the residents.


Figure 10: Top 10 cities for quality of living in 2023 (Source: Mercer Quality of Living City Ranking, 2023)

These indices are vital for evaluating how port activities contribute to the social well-being of the communities they serve. By incorporating these rankings, the study can assess the broader social impact of port sustainability initiatives. The data derived from these sources provides insight into how ports can enhance their contributions to the social fabric of their cities, ensuring that economic and environmental advancements also benefit the community at large.

## 4.3 Data Processing

### 4.3.1 Data coding

4.3.1.1 Condition Assignment

**Digitalization (DIG)**: Ports implementing advanced digital technologies were assigned a value of 1; those not implementing such technologies were assigned a value of 0. The rationale is that digital technologies enhance operational efficiency, reduce environmental impacts, and support sustainable practices (Lam & Notteboom, 2014).

**Environmental Caring (EC)**: Ports adopting green technologies and practices were assigned a value of 1; those not adopting such technologies were assigned a value of 0. This coding reflects the importance of reducing pollution, managing waste, and adopting environmentally friendly practices to achieve sustainability (Poulsen et al., 2018).

**Community Building (CB)**: Ports engaging with local communities to enhance social outcomes were assigned a value of 1; those not engaging with communities were assigned a value of 0. This condition emphasizes the role of ports in fostering community support and improving the quality of life for local residents (Schipper et al., 2017).

**Sustainable Infrastructure (INF)**: Ports developing infrastructure projects that prioritize sustainability were assigned a value of 1; those not prioritizing sustainability in infrastructure were assigned a value of 0. Sustainable infrastructure investments are critical for enhancing operational efficiency and reducing environmental impacts (Alamoush et al., 2021).

**Health, Safety, and Security (HSS)**: Ports ensuring the well-being of workers and local communities through robust safety protocols and health initiatives were assigned a value of 1; those not ensuring such protocols were assigned a value of 0. Ensuring health and safety is integral to the social dimension of port sustainability (PSA Singapore, 2024; Dublin Port, 2024).

**Climate and Energy (CE)**: Ports reducing carbon emissions and adopting renewable energy sources were assigned a value of 1; those not adopting these measures were assigned a value of 0. Climate and energy initiatives are essential for ports to contribute to global climate goals (Jansen, 2023).

4.3.1.2 Outcome Determination

A comprehensive assessment of port sustainability mainly includes three dimensions: economic, environmental and social sustainability, emphasizing the importance of balancing economic growth, environmental protection and social equity (Elkington, 1997). The rationale for using these three dimensions is to ensure a comprehensive and balanced assessment of port sustainability.

Cargo throughput is a key indicator of a port’s economic health and its ability to facilitate trade and commerce. The higher the throughput, the greater the economic activity and the ability to generate income and employment. The evaluation is performed using port throughput data from the ISL port database. Ports that handle more than 10 million tons of cargo per year are assigned a score of 1 (sustainable); ports that handle less volume are assigned a score of 0 (unsustainable). The 10 million tons threshold reflects significant economic activity and capacity (Xiao & Lam, 2017).

Environmental performance is critical to sustainable development as it reflects the port’s efforts to minimize its ecological footprint (Hiranandani, 2014b). Participation in the ESI program demonstrates a port’s proactive approach to environmental management and pollution control. Evaluated based on participation in the ESI program. Ports that participate in ESI are assigned 1 (sustainable); ports that do not participate are assigned 0 (unsustainable). Participation in ESI demonstrates a commitment to reducing emissions and improving environmental performance.

Social sustainability encompasses the well-being and quality of life of the communities surrounding the port (MacNeil et al., 2022). A high ranking on the social index indicates that a port's operations contribute positively to local communities through factors such as employment, health, safety and infrastructure. Ranking determined using Arcadis Sustainable Cities Index and Mercer City Ranking. Ports located in cities that appear in either ranking are assigned a value of 1 (sustainable); ports that do not appear in any ranking are assigned a value of 0 (unsustainable). High rankings on these indices reflect strong social infrastructure and quality of life, which are key components of social sustainability (Arcadis, 2022; Mercer, 2023).

In this study, I set a score of 1 for at least two sustainability criteria as the threshold for a sustainable port. A port is classified as sustainable if it meets at least two of the three sustainability criteria (economic, environmental, social). That is, ports with at least two criteria scoring 1 are assigned a final outcome value of 1 (sustainable), and ports with fewer than two criteria scoring 1 are assigned a final outcome value of 0 (unsustainable).

First of all, from the multi-dimensional comprehensive evaluation of sustainable development theory, excellent performance in a single dimension is not enough to fully reflect the sustainable development status of the port. Therefore, by requiring at least two dimensions to meet the criteria, we can more fully assess port sustainability.

Secondly, system theory emphasizes the coordination and balance of the overall system. Setting a threshold of at least two criteria would better reflect the overall sustainability of the port, rather than relying solely on one aspect of performance.

Empirical research and data analysis show that ports that perform well in multiple dimensions have better sustainability performance in long-term operations. For example, by analyzing the data we studied, we found that ports with scores of 1 in at least two dimensions have more balanced and stable performance in terms of economic benefits, environmental protection and social responsibility. Theoretical support is provided by the threshold effect in the multi-criteria decision analysis (MCDA) method. In MCDA, setting reasonable thresholds helps to screen out objects that perform well in multiple key areas and ensures the scientificity and rationality of the decision-making process. Therefore, selecting at least two criteria with scores of 1 as the threshold is a reasonable choice that ensures both rigor and operability.

### 4.3.2 Raw data matrix

The raw data matrix includes several conditions (Community Building (CB), Climate and Energy (CE), Environmental Caring (EC), Digitalization (DIG), Health, Safety, and Security (HSS), and Sustainable Infrastructure (INF) and the outcome variable (sustainability). The total scores covering the whole 6 conditions and outcome assessment are combined into a raw data matrix in table 1 (the complete table in appendix). Due to space limitations, only a selection of representative projects is presented here. For detailed information on the full set of projects and the raw data matrix, please refer to the appendix section.

Each row in the matrix represents a unique combination of these conditions across different cases, with binary values indicating the absence or presence of each condition.

Table 1. Raw Data Matrix for Port Sustainability QCA (part, Source: author)

| Program Name | City | Country | Year | Continent | CB | CE | EC | DIG | HSS | INF | Outcome |
|---|---|---|---|---|---|---|---|---|---|---|---|
| “Port Spot” App | Wilhelmshaven | Germany | 2018 | Europe | 0 | 0 | 0 | 1 | 0 | 0 | 1 |
| “Valparaiso_Puerto Plus” project | Valparaiso | Chile | 2016 | South America | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2nd Generation Cyber Security Operations Center | Los Angeles | United States | 2019 | North America | 0 | 0 | 0 | 0 | 1 | 0 | 1 |
| 3R (Reduce_Reuse_Recycle) Campaign | Honiara | Solomon Islands | 2021 | Oceania | 1 | 1 | 1 | 0 | 0 | 0 | 0 |
| 5G-MoNArch | Hamburg | Germany | 2019 | Europe | 0 | 0 | 0 | 1 | 0 | 0 | 1 |
| Accelerating the transition to low-emission energy | Vancouver | Canada | 2023 | North America | 0 | 1 | 0 | 0 | 0 | 0 | 1 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Aiding schools as part of CSR program | Kota Kinabalu | Malaysia | 2018 | Asia | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| Air Quality Improvement Plan | Barcelona | Spain | 2017 | Europe | 0 | 1 | 1 | 0 | 0 | 0 | 1 |
| Al Dhafrah Region Community Ports Development | Abu Dhabi | United Arab Emirates | 2016 | Asia | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| ALFION project | Igoumenitsa | Greece | 2022 | Europe | 0 | 1 | 0 | 0 | 0 | 1 | 0 |
| Artificial intelligence for environmental monitoring and prediction | Bari | Italy | 2019 | Europe | 0 | 1 | 1 | 1 | 0 | 0 | 0 |
| Automated drones to prevent oil pollution | Antwerp | Belgium | 2020 | Europe | 0 | 0 | 1 | 1 | 1 | 0 | 1 |
| Beneficial reuse of dredge material | Brisbane | Australia | 2019 | Oceania | 1 | 0 | 1 | 0 | 0 | 1 | 1 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Bilbao PortLab | Bilbao | Spain | 2023 | Europe | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| Biohut project | Ivory Coast | Ivory Coast | 2022 | Africa | 0 | 0 | 1 | 0 | 0 | 0 | 0 |
| Brisbane International Cruise Terminal | Brisbane | Australia | 2020 | Oceania | 1 | 0 | 1 | 0 | 0 | 1 | 1 |
| Carbon footprint reduction | Panama City | Panama | 2013 | North America | 0 | 1 | 0 | 0 | 0 | 0 | 1 |

# 4.4 Data Analysis

## 4.4.1 Necessary Conditions Analysis

The raw data matrix was initially utilized to identify necessary conditions for sustainable port outcomes. The conditions with the highest consistency scores were community building (CB) and environment caring (EC). CB had a consistency value of 0.37 and a coverage value of 0.50, while EC had a consistency value of 0.36 and a coverage value of 0.58. Ultimately, no necessary conditions were identified from the raw data matrix.

Table 2. Necessary Conditions for Port Sustainability (Source: author)

| Condition | Consistency | Coverage |
|---|---|---|
| Community Building (CB) | 0.37 | 0.50 |
| Environmental Caring (EC) | 0.36 | 0.58 |

In QCA, the truth table is a vital component because it helps identify which combinations of conditions consistently lead to the expected outcome. In this study, the truth table (Table 2) was employed to uncover patterns and causal relationships between different sustainability initiatives and their outcomes. Analyzing the truth table involves calculating the consistency and coverage for each condition combination. Consistency measures how often a specific combination produces the expected result, while coverage indicates the extent to which the combination explains the expected outcome (Ragin, 1999).

Subsequently, a truth table was constructed using the fsQCA program, listing all significant information. This table showcased all possible condition combinations and their associated outcomes across 310 cases, revealing 32 out of 64 logically possible configurations empirically present. To simplify causal relationships, the frequency threshold was set to 1.00, meaning only condition combinations present in at least one case were included. Configurations with no cases were removed from the truth table. The first 9 rows had a consistency value of 1.00. Rows 10 to 32 had less than perfect consistency scores due to contradictory projects. For example, the configuration ~CB*CE*~EC*~DIG*~HSS*INF had an outcome score of 1.00 in the Korean ‘Piezoelectric System’ case and the Japanese ‘Survey on hydrogen utilization for a carbon neutral port’ case, but a 0.00 outcome score in Fiji’s ‘Inter-island shipping wharf (Muaiwalu 2) carbon-neutral facility’ case.

According to Vis (2009), the gaps in consistency scores indicate where the cut-off should be established. The truth table reveals a distinct gap between 1.00 and 0.67, aligning with logical contradictions and low PRI consistency values. Consequently, the cut-off point is set at 1.00, resulting in the exclusion of cases with consistency scores below 1.00 from the truth table (Ragin, 2008) and their omission from the minimization process. These cases will, however, be revisited in the conclusion. The truth table analysis and minimization, following Ragin's (2008) procedures, produced the complex solution shown in Table 3. Additionally, the parsimonious solution is provided as it is recommended for best practices (Schneider and Wagemann, 2010).

*Table 3. Truth Table for Port Sustainability QCA (Source: author)*

| CB | CE | EC | DIG | HSS | INF | number | outcome | raw consist. | PRI consist. | SYM consist |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0 | 0 | 1 | 0 | 0 | 4 | 1 | 1 | 1 | 1 |
| 0 | 0 | 0 | 1 | 0 | 1 | 4 | 1 | 1 | 1 | 1 |
| 1 | 0 | 0 | 0 | 0 | 1 | 3 | 1 | 1 | 1 | 1 |
| 0 | 1 | 0 | 0 | 1 | 1 | 2 | 1 | 1 | 1 | 1 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 1 | 1 | 1 |
| 0 | 0 | 1 | 0 | 1 | 0 | 1 | 1 | 1 | 1 | 1 |
| 1 | 0 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 |
| 0 | 0 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 |
| 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 0 | 1 | 1 | 1 | 0 | 0 | 3 | 0 | 0.67 | 0.67 | 0.67 |
| 0 | 0 | 0 | 1 | 1 | 0 | 11 | 0 | 0.64 | 0.64 | 0.64 |
| 0 | 1 | 0 | 0 | 0 | 0 | 27 | 0 | 0.63 | 0.63 | 0.63 |
| 0 | 1 | 1 | 0 | 0 | 0 | 24 | 0 | 0.63 | 0.63 | 0.63 |
| 0 | 1 | 0 | 1 | 0 | 0 | 8 | 0 | 0.63 | 0.63 | 0.63 |
| 0 | 1 | 0 | 0 | 0 | 1 | 13 | 0 | 0.54 | 0.54 | 0.54 |
| 0 | 0 | 1 | 0 | 0 | 0 | 16 | 0 | 0.50 | 0.50 | 0.50 |
| 1 | 0 | 1 | 0 | 0 | 1 | 10 | 0 | 0.50 | 0.50 | 0.50 |
| 1 | 0 | 0 | 0 | 1 | 0 | 8 | 0 | 0.50 | 0.50 | 0.50 |
| 1 | 1 | 0 | 0 | 0 | 0 | 6 | 0 | 0.50 | 0.50 | 0.50 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 0 | 1 | 1 | 0 | 0 | 4 | 0 | 0.50 | 0.50 | 0.50 |
| 1 | 1 | 1 | 1 | 0 | 0 | 4 | 0 | 0.50 | 0.50 | 0.50 |
| 0 | 1 | 0 | 0 | 1 | 0 | 2 | 0 | 0.50 | 0.50 | 0.50 |
| 0 | 0 | 1 | 1 | 1 | 0 | 2 | 0 | 0.50 | 0.50 | 0.50 |
| 0 | 1 | 0 | 1 | 0 | 1 | 2 | 0 | 0.50 | 0.50 | 0.50 |
| 1 | 0 | 0 | 0 | 0 | 0 | 52 | 0 | 0.46 | 0.46 | 0.46 |
| 0 | 0 | 0 | 1 | 0 | 0 | 22 | 0 | 0.45 | 0.45 | 0.45 |
| 1 | 1 | 1 | 0 | 0 | 0 | 9 | 0 | 0.44 | 0.44 | 0.44 |
| 0 | 0 | 0 | 0 | 1 | 0 | 25 | 0 | 0.44 | 0.44 | 0.44 |
| 1 | 0 | 1 | 0 | 0 | 0 | 23 | 0 | 0.43 | 0.43 | 0.43 |
| 0 | 0 | 0 | 0 | 0 | 1 | 5 | 0 | 0.40 | 0.40 | 0.40 |
| 0 | 0 | 1 | 0 | 0 | 1 | 13 | 0 | 0.38 | 0.38 | 0.38 |
| 0 | 1 | 1 | 0 | 0 | 1 | 3 | 0 | 0.33 | 0.33 | 0.33 |

### 4.4.2 Sufficient Conditions Analysis

The initial examination of distinct conditions showed that there are no truly necessary conditions for sustainable port construction. However, community building and environmental care came close to being necessary by empirical standards (Ragin, 2008). Further analysis through the truth table (Table 4) reinforced that no single condition is necessary, as none appeared in all five parsimonious paths. Nevertheless, the analysis identified three configurations that significantly contribute to stakeholder satisfaction and are sufficient for the outcome. The conditions within these configurations are INUS conditions: Insufficient but non-redundant parts of a configuration that is Unnecessary but Sufficient for the occurrence of the outcome (Mackie, 1980).

Table 4. Parsimonious Solution from the fsQCA (Source: author)

| Pathway | Raw Coverage | Unique Coverage | Consistency |
|---|---|---|---|
| HSS*INF | 0.018 | 0.012 | 1 |
| CB*~CE*DIG | 0.036 | 0.036 | 1 |
| EC*~DIG*HSS | 0.006 | 0.006 | 1 |
| CB*~EC*INF | 0.018 | 0.018 | 1 |
| ~CE*DIG*INF | 0.036 | 0.030 | 1 |
| solution coverage: 0.109091 | | | |
| solution consistency: 1 | | | |

In fsQCA analysis, the parsimonious solution offers the most straightforward explanation for sustainable port development. The primary robust path identified is HSS*INF. This path signifies that the integration of health, safety, and security measures with enhanced infrastructure is sufficient to improve port sustainability. Specifically, the path points to INF as an INUS condition. This underscores the crucial role of robust port infrastructure systems in elevating operational efficiency, mitigating environmental impacts, and fostering rapid economic growth. Effective infrastructure not only supports smooth port operations but also contributes to the broader sustainability goals by ensuring safety and security, which are essential for long-term viability. Enhanced infrastructure can include advanced logistics networks, energy-efficient systems, and resilient construction that together create a supportive environment for sustainable practices. Therefore, the combination of HSS and INF highlights a holistic approach, addressing both the physical and systemic needs of a port to achieve sustainability. This integrated strategy ensures that ports are not only efficient and economically viable but also environmentally friendly and secure, aligning with broader global sustainability objectives.

In 2021, the Rotterdam Port implemented the “Flood Risk Management Programme”, focusing on HSS, INF, and CE. This program was tailored to the region's specific characteristics, integrating innovative spatial adaptation strategies with emergency response measures(Van Alphen, 2016). This comprehensive approach ensures that the port can effectively and flexibly manage flood risks up to the year 2100. By combining health, safety, and security measures with robust infrastructure and active energy measures, the Rotterdam Port exemplifies how a holistic and adaptive strategy can address long-term sustainability challenges.

In the context of fsQCA analysis for sustainable port development, the second path identified is CB*~CE*DIG, which involves Community Building (CB), the absence of Environmental Caring (~CE), and Digitalization (DIG). An intriguing aspect of this path is the lack of environmental care. While the importance of environmental care cannot be ignored, in some cases, other factors, such as community support and digitalization, may be more critical to sustainable development. This path indicates that when a port project excels in community building and digitalization but lacks environmental care, it can still achieve sustainability. This path underscores the role of community support and technological advancement in driving sustainability, even when environmental measures are insufficient. This scenario may be particularly applicable to ports with limited resources or those needing rapid development. By enhancing community relations and employing digital tools, these ports can still achieve significant sustainability goals.

In 2021, the Shenzhen Shekou Port project focused on community building and digitalization, integrating new-generation information technologies such as 5G communication, the Internet of Things (IoT), big data, and artificial intelligence (AI) into port operations (Wan et al., 2021). This approach facilitated the interconnection of port elements, automated intelligent production operations, and enhanced decision-making and customer service efficiency. By deeply integrating various resources, technologies, services, and management practices, Shekou Port established a modern port pathway characterized by multi-boundary attributes, open sharing, high efficiency, environmental friendliness, and sustainability.

The third path points to ~CE*DIG*INF. This path involves the absence of Environmental Caring (~CE), Digitalization (DIG), and Infrastructure (INF). It indicates that even without environmental care, a port can achieve sustainable development through enhanced digitalization and infrastructure. Digital technologies and robust infrastructure play key roles in optimizing operations, reducing environmental burdens, and promoting economic activities. This analysis underscores the importance of the synergy of multiple factors, especially in resource-limited or rapidly developing environments.

In 2021, the Hamburg Port Authority implemented the "smartBRIDGE Hamburg" project, focusing on digitalization and infrastructure enhancement(Wenner et al., 2022). The Köhlbrand Bridge, a critical traffic artery, was equipped with over 500 sensors to collect real-time data. This data feeds into a digital twin of the bridge, enabling continuous monitoring and predictive maintenance. By integrating traditional inspections with digital diagnostics, the project optimizes operations, extends infrastructure life cycles, reduces costs and $CO_2$ emissions, and improves maintenance efficiency. The success of this project supports sustainable port development through advanced technological integration.

In the fsQCA analysis, examining different paths reveals that while no single necessary condition ensures sustainable port development, various combinations of conditions can achieve this goal. The path HSS*INF indicates that integrating health, safety, security measures with infrastructure enhances port sustainability. The path CB*~CE*DIG highlights the importance of community building and digitalization, even without environmental care. The path ~CE*DIG*INF shows that digitalization and infrastructure improvements can still achieve sustainability without environmental care. The path CB*~EC*INF suggests that community building and infrastructure optimization contribute to social and economic sustainability despite the lack of environmental care. Lastly, the path EC*~DIG*HSS demonstrates that focusing on environmental measures and health, safety, and security can enhance overall sustainability without digitalization.

These paths and actual cases (like projects at Rotterdam, Shenzhen Shekou, and Hamburg ports) illustrate the importance of multiple factors working together for sustainable port development. Utilizing community building, digitalization, and infrastructure improvements enables ports to achieve sustainability goals under different conditions. This highlights that the key to port sustainability lies in the synergy of multiple factors, especially in resource-limited or rapidly developing environments.

### 4.4.3 Summary

The analysis of QCA results provides valuable insights into the necessary and sufficient conditions for achieving port sustainability. The identification of these pathways helps to understand how different combinations of initiatives can lead to sustainable outcomes. This analysis supports the development of targeted strategies for enhancing sustainability in port operations, contributing to the broader goal of sustainable development in maritime logistics and port management. The integration of digitalization, environmental care, community engagement, sustainable infrastructure, health and safety, and climate action into port operations is essential for achieving long-term sustainability.

These findings not only advance academic knowledge but also provide practical recommendations for policymakers and port authorities striving to enhance the sustainability of their operations. By adopting the identified necessary and sufficient conditions, ports can improve their sustainability performance and contribute positively to their local and global environments.

### 4.4.4 Data Analysis: Comparative Regional QCA Results

This section presents the results of the Qualitative Comparative Analysis (QCA) for different regions, including North America, Europe, Oceania, and Asia. The analysis explores the necessary and sufficient conditions for achieving sustainable port outcomes in each region and compares these findings to provide insights into regional variations.

#### 4.4.4.1 North America

1) Data Overview

This section provides an overview of the data collected from North American ports, focusing on sustainability initiatives from 2013 to 2023. The selected cases are representative due to their recent implementation and the variety of initiatives undertaken, offering a comprehensive look at current practices and trends in port sustainability across North America. The cases were chosen based on their ability to provide recent and relevant data, which is crucial for understanding the evolving landscape of port sustainability.

A total of 44 cases were collected, covering a period from 2013 to 2023. The data encompasses various sustainability initiatives implemented across different ports in North America, specifically in the United States, Canada, and Panama. This extensive timeframe allows for an examination of how sustainability practices have developed and been adopted over the years.

The themes identified in the data and their frequency are as follows: Community Building (CB): 24 occurrences, Environmental Caring (CE): 12 occurrences, Economic Contributions (EC): 19 occurrences, Digitalization (DIG): 11 occurrences, Health, Safety, and Security (HSS): 5 occurrences, Sustainable Infrastructure (INFRA): 7 occurrences. Notably, the combination of CB and EC appeared most frequently, with 9 occurrences.

The data covers various locations, including major ports such as Los Angeles, Vancouver, and New York/New Jersey. The distribution reflects a wide geographic spread across North America, encompassing significant ports that play key roles in international trade and logistics. The temporal distribution shows a diverse range of initiatives over the years, with notable peaks in project implementation around 2019 and 2022. This suggests a growing trend towards sustainability in recent years, likely driven by increasing regulatory pressures and public awareness.

Table 5. Truth Table for North America (Source: author)

| CB | CE | EC | DIG | HSS | INF | number | outcome | raw consist. | PRI consist. | SYM consist |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0 | 0 | 0 | 0 | 0 | 9 | 1 | 1 | 1 | 1 |
| 1 | 0 | 1 | 0 | 0 | 0 | 5 | 1 | 1 | 1 | 1 |
| 0 | 1 | 0 | 0 | 0 | 0 | 3 | 1 | 1 | 1 | 1 |
| 0 | 0 | 0 | 1 | 1 | 0 | 3 | 1 | 1 | 1 | 1 |
| 0 | 0 | 1 | 0 | 0 | 0 | 2 | 1 | 1 | 1 | 1 |
| 1 | 0 | 0 | 1 | 0 | 0 | 2 | 1 | 1 | 1 | 1 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0 | 0 | 0 | 0 | 1 | 2 | 1 | 1 | 1 | 1 |
| 1 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 |
| 1 | 1 | 1 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 |
| 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 1 | 1 | 1 |
| 0 | 0 | 1 | 0 | 1 | 0 | 1 | 1 | 1 | 1 | 1 |
| 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 |
| 0 | 1 | 1 | 0 | 0 | 0 | 3 | 0 | 0.67 | 0.67 | 0.67 |
| 0 | 0 | 0 | 1 | 0 | 0 | 2 | 0 | 0.50 | 0.50 | 0.50 |
| 1 | 1 | 1 | 1 | 0 | 0 | 3 | 0 | 0.33 | 0.33 | 0.33 |
| 0 | 0 | 1 | 0 | 0 | 1 | 3 | 0 | 0.33 | 0.33 | 0.33 |
| 0 | 1 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 |
| 1 | 0 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 |

2) Case Examples

**Port of Los Angeles:** Initiatives such as the "Cyber Resilience Center" and the "Zero Emissions Pathway Technology Demonstrations" showcase a strong focus on digitalization and environmental sustainability, highlighting the port's commitment to integrating advanced technologies to enhance security and reduce emissions.

**Port of Vancouver:** Projects like the "International Collaboration on Vessel Emissions Reduction" and the "Accelerating the Transition to Low-Emission Energy" demonstrate significant efforts in environmental caring and international cooperation to address global sustainability challenges.

**Port of Montreal:** The "CargO2ai" initiative reflects an emphasis on digitalization and health and safety, utilizing artificial intelligence to optimize cargo handling while ensuring safety standards. Additionally, the "Grand Quay Development Project" integrates community building and economic contributions, enhancing the port's role in the local economy and community.

These examples illustrate the diverse approaches and priorities in sustainability initiatives across North American ports, emphasizing the integration of technology, environmental stewardship, and community engagement as key factors in driving sustainable development.

3) Analysis and Results

The truth table for North America was generated based on the raw data matrix. The conclusion about the necessary condition cannot be interpreted directly from the raw data matrix. Following the previous analysis, the frequency threshold was also set at 1.00, and the consistency threshold was set at 1.00 (Gerrits & Verweij, 2018a). From the truth table below obtained from the fsQCA analysis, we can find a necessary condition: health, safety and security, with the consistency value of 1 and coverage value at 0.139. Although the consistency value is very high, the coverage value is very low. Therefore, I believe that health safety and security are sufficient conditions for North American ports to develop into sustainable development ports, that is, as long as the initiative promoted by the port government agencies or power agencies includes the theme of health safety and security, the overall sustainable development capacity of the port can be improved to a certain extent.

Projects with this theme are effective because they ensure a safe working environment. This is essential for port operational efficiency and stakeholder confidence. Measures to enhance health and safety could reduce the risk of incidents and minimize disruptions. Innovations in security and automation not only improve the efficiency of cargo and passenger handling but also bolster the resilience of port operations against various threats, including cyber-attacks (AlRukaibi et al., 2020).

Table 6. Necessary Conditions for Port Sustainability in North America (Source: author)

| Condition | Consistency | Coverage |
|---|---|---|
| HSS | 1 | 0.139 |

In the case of North America, there are a total of 7 sufficient paths, among which ~DIG*~INF has the highest coverage value, and the two paths add up to 0.889. This path shows that in the port improvement projects in North America, the lack of digitalization and the lack of infrastructure projects have to some extent guaranteed the overall sustainable development capacity of the port. This conclusion may be difficult to accept at first, but after a careful analysis of the port construction in North America, this result is still easy to understand. Because most of the infrastructure and digitalization construction of the port in this region have been relatively complete, and the focus of port improvement has shifted to environmental care and community care(M. T. Hossain, 2018). This shows to some extent that most of the port projects in North America have relatively good infrastructure support, and it is necessary to further develop more refined thematic projects in the future.

The second path is CB*~EC, involves Community Building (CB) and the absence of Environmental Care (~EC). This path indicates that focusing on community building while neglecting environmental care has contributed to the overall sustainability of North American ports. This may seem counterintuitive, but it highlights the importance of strong community engagement and support in achieving sustainable outcomes(Dooms, 2018). In regions where environmental measures are already well-established, the focus might shift to enhancing social aspects. Ports with strong community support are more likely to gain public approval for their operations and expansion projects, leading to smoother implementation and fewer conflicts.

Table 7. Parsimonious solution for Port Sustainability in North America (Source: author)

| Pathway | Raw Coverage | Unique Coverage | Consistency |
|---|---|---|---|
| ~EC*~DIG | 0.472 | 0.111 | 1 |
| CB*~EC | 0.389 | 0 | 1 |
| ~CE*~DIG*~INF | 0.5 | 0 | 1 |
| CB*~DIG*~INF | 0.44 | 0 | 1 |
| CB*~CE*~INF | 0.44 | 0 | 1 |
| ~CE*EC*~INF | 0.22 | 0 | 1 |
| CB*CE*~DIG | 0.056 | 0 | 1 |
| CB*~CE*DIG | 0.056 | 0 | 1 |
| solution coverage: 0.861111 | | | |
| solution consistency: 1 | | | |

4.4.4.2 Europe

1) Case overview

This section provides an overview of the data collected from European ports, focusing on sustainability initiatives from 2010 to 2023. The selected cases are representative of the latest trends and practices in port sustainability. The focus on recent cases ensures the data reflects the current state of sustainability efforts, technological advancements, and regulatory changes in the maritime industry. This period also captures the increasing momentum towards sustainable development, particularly post-2015, following the adoption of the UN Sustainable Development Goals (SDGs), which have significantly influenced policy and operational shifts in European ports.

A total of 108 cases were collected, encompassing various sustainability initiatives implemented across different ports in Europe. The cases span 13 years, from 2010 to 2023, capturing a range of innovative practices and projects. The data includes information from ports located in 14 countries, reflecting diverse geographical and operational contexts.

The themes identified in the data and their frequency are as follows: Community Building (CB): 35 occurrences, Environmental Caring (CE): 54 occurrences, Economic Contributions (EC): 40 occurrences, Digitalization (DIG): 28 occurrences, Health, Safety, and Security (HSS): 17 occurrences, Sustainable Infrastructure (INFRA): 20 occurrences. Notably, the combination of CE and EC appeared most frequently, with 26 occurrences.

The data spans various locations, including major ports in Germany, the Netherlands, Spain, France, and the United Kingdom. Key projects from well-known ports such as Hamburg, Rotterdam, and Amsterdam are included. The temporal distribution shows a steady increase in sustainability initiatives over the years, with a significant number of projects launched between 2019 and 2023, indicating a growing emphasis on sustainability in recent years.

Table 8. Truth Table for Europe (Source: author)

| CB | CE | EC | DIG | HSS | INF | number | outcome | raw consist. | PRI consist. | SYM consist |
|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 1 | 0 | 6 | 1 | 1 | 1 | 1 |
| 1 | 0 | 1 | 0 | 0 | 0 | 3 | 1 | 1 | 1 | 1 |
| 0 | 0 | 1 | 0 | 0 | 1 | 3 | 1 | 1 | 1 | 1 |
| 0 | 0 | 0 | 1 | 0 | 1 | 3 | 1 | 1 | 1 | 1 |
| 1 | 1 | 0 | 0 | 0 | 0 | 2 | 1 | 1 | 1 | 1 |
| 0 | 0 | 1 | 1 | 0 | 0 | 2 | 1 | 1 | 1 | 1 |
| 0 | 0 | 0 | 1 | 1 | 0 | 2 | 1 | 1 | 1 | 1 |
| 0 | 1 | 0 | 0 | 1 | 1 | 2 | 1 | 1 | 1 | 1 |
| 0 | 0 | 1 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 |
| 1 | 0 | 0 | 1 | 0 | 0 | 1 | 1 | 1 | 1 | 1 |
| 1 | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 1 | 1 | 1 |
| 1 | 1 | 1 | 1 | 0 | 0 | 1 | 1 | 1 | 1 | 1 |
| 0 | 1 | 0 | 0 | 1 | 0 | 1 | 1 | 1 | 1 | 1 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 |
| 1 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 |
| 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 0 | 0 | 0 | 1 | 0 | 0 | 7 | 1 | 0.86 | 0.86 | 0.86 |
| 0 | 1 | 0 | 1 | 0 | 0 | 5 | 1 | 0.80 | 0.80 | 0.80 |
| 0 | 1 | 0 | 0 | 0 | 0 | 14 | 0 | 0.71 | 0.71 | 0.71 |
| 0 | 1 | 1 | 0 | 0 | 0 | 14 | 0 | 0.64 | 0.64 | 0.64 |
| 1 | 1 | 1 | 0 | 0 | 0 | 5 | 0 | 0.60 | 0.60 | 0.60 |
| 1 | 0 | 0 | 0 | 0 | 0 | 16 | 0 | 0.50 | 0.50 | 0.50 |
| 0 | 1 | 1 | 1 | 0 | 0 | 2 | 0 | 0.50 | 0.50 | 0.50 |
| 1 | 0 | 0 | 0 | 1 | 0 | 2 | 0 | 0.50 | 0.50 | 0.50 |
| 0 | 0 | 1 | 1 | 1 | 0 | 2 | 0 | 0.50 | 0.50 | 0.50 |
| 1 | 0 | 1 | 0 | 0 | 1 | 2 | 0 | 0.50 | 0.50 | 0.50 |
| 0 | 1 | 0 | 0 | 0 | 1 | 5 | 0 | 0.40 | 0.40 | 0.40 |
| 0 | 1 | 1 | 0 | 0 | 1 | 3 | 0 | 0.33 | 0.33 | 0.33 |

2) Case Examples

**Port of Amsterdam:** Initiatives like the "Ensuring Safe Distances for Alternative Fuel Bunker Operations" and "Neo Orbis Hydrogen Vessel" reflect a strong focus on environmental caring like the use of alternative energy. This projects also help to drive the transition to cleaner fuels.

**Port of Hamburg:** Projects such as "5G-MoNArch" and "Kreetsand Tidal Zone" showcase Germany advancements in digitalization and environmental sustainability.

**Port of Barcelona:** The "Air Quality Improvement Plan" and "Your Port Opens Up Again" initiatives emphasize environmental and community benefits. These projects have also strengthened the connectivity and integration between the city and the port to a certain extent.

These examples illustrate the diverse approaches and priorities in sustainability initiatives across European ports, emphasizing environmental stewardship, economic contributions, and community engagement as key factors in driving sustainable development.

3) Analysis and Results

From the raw data matrix and the truth table, I cannot conclude the necessary condition for the sustainable port improvement. As usual, the frequency threshold was set at 1.00. For the sake of comprehensive analysis, the consistency threshold was set at 0.80.

I identified a total of nine sufficient pathways, indicating greater diversity and potential in European cases. This diversity is closely related to the varying contexts across Europe, where ports operate under different political, economic, and social conditions. The heterogeneity of development paths highlights the unique nature of sustainable port development in Europe and underscores the value of comparative studies. Such research can yield valuable insights and policy recommendations tailored to the distinct needs and circumstances of each port.

The pathway with the highest coverage value is ~EC*~DIG. This path involves the absence of environmental care (~EC) and the absence of digitalization (~DIG). It suggests that a port in Europe can still achieve sustainable development even without focusing on environmental care and digitalization. This highlights the importance of leveraging existing strengths and focusing on immediate operational efficiencies to support sustainable development (Aarts et al., n.d.). It also underscores the need for a nuanced approach that considers each port's specific circumstances and resource availability.

The second path is ~CB*~EC*HSS. This path involves the absence of community building and environment caring, the presence of health, safety and security. This path highlights that ports can achieve sustainable development by focusing on health, safety, and security measures, even when community engagement and environmental initiatives are lacking. This is particularly relevant in ports where existing community and environmental measures are adequate, pursuing for a focus on enhancing health and safety standards (Carpenter & Lozano, 2020).

Table 9. Parsimonious solution for Port Sustainability in Europe (Source: author)

| **Pathway** | **Raw Coverage** | **Unique Coverage** | **Consistency** |
|---|---|---|---|
| ~EC*~DIG | 0.218 | 0.128 | 1 |
| CB*DIG | 0.05 | 0.026 | 1 |
| ~CB*~CE*~DIG | 0.128 | 0.038 | 1 |
| CB*CE*~EC | 0.026 | 0.026 | 1 |
| ~CE*EC*~HSS*~INF | 0.09 | 0.064 | 1 |

| | | | |
|---|---|---|---|
| ~CB*~DIG*HSS | 0.12 | 0 | 1 |
| ~CB*~EC*HSS | 0.15 | 0 | 1 |
| ~CE*~EC*INF | 0.064 | 0 | 1 |
| CB*~EC*INF | 0.013 | 0 | 1 |
| solution coverage: 0.526 | | | |
| solution consistency: 0.95 | | | |

4.4.4.3 Oceania

1) Case overview

This section provides an overview of the data collected from ports in Oceania, focusing on sustainability initiatives from 2012 to 2023. The selected cases are representative due to their recent implementation, providing up-to-date insights into current practices and trends in port sustainability within the region.

A total of 40 cases were collected, encompassing various sustainability initiatives implemented across different ports in Oceania. The cases span 11 years, from 2012 to 2023, capturing a range of innovative practices and projects. The data includes information from ports located in countries such as Australia, New Zealand, Fiji, and the Solomon Islands, reflecting diverse geographical and operational contexts.

The data spans various locations, including major ports in Australia, New Zealand, and the Pacific Islands. Key projects from well-known ports such as Brisbane, Auckland, and Gladstone are included. The temporal distribution shows a steady increase in sustainability initiatives over the years, with a significant number of projects launched between 2018 and 2023, indicating a growing emphasis on sustainability in recent years.

Table 10. Truth Table for Oceania (Source: author)

| CB | CE | EC | DIG | HSS | INF | number | outcome | raw consist. | PRI consist. | SYM consist |
|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 0 | 1 | 0 | 0 | 0 | 3 | 1 | 1 | 1 | 1 |
| 0 | 0 | 0 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 |
| 1 | 0 | 1 | 0 | 0 | 1 | 4 | 0 | 0.75 | 0.75 | 0.75 |
| 0 | 1 | 0 | 0 | 0 | 1 | 3 | 0 | 0.67 | 0.67 | 0.67 |
| 0 | 1 | 0 | 1 | 0 | 0 | 2 | 0 | 0.50 | 0.50 | 0.50 |
| 1 | 0 | 1 | 0 | 0 | 0 | 3 | 0 | 0.33 | 0.33 | 0.33 |
| 1 | 0 | 0 | 0 | 0 | 0 | 7 | 0 | 0.29 | 0.29 | 0.29 |
| 0 | 0 | 0 | 0 | 1 | 0 | 4 | 0 | 0.25 | 0.25 | 0.25 |
| 0 | 1 | 0 | 0 | 0 | 0 | 5 | 0 | 0.20 | 0.20 | 0.20 |
| 1 | 1 | 1 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 |
| 0 | 0 | 1 | 0 | 0 | 1 | 2 | 0 | 0 | 0 | 0 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 |
| 0 | 1 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 0 |

2) Case Examples

**Port of Brisbane:** In the Brisbane port case, initiatives like the "Beneficial Reuse of Dredge Material" and "Brisbane International Cruise Terminal" emphasize environmental care and infrastructure. Additionally, the Brisbane port has focused on increasing project transparency and improving relationships with stakeholders, including government, researchers, indigenous groups, NGOs, and community members. This effort in stakeholder engagement aligns with the importance of health, safety, and security measures, demonstrating that these factors can drive sustainability.

**Ports of Auckland:** Projects such as the "DC Microgrid Research Project" and "Zero Emissions 2040" showcase advancements in environmental sustainability. This the first port in New Zealand to become a CEMARS certified organisation.

**Gladstone Ports Corporation:** The "Sea Wall Habitat Enhancement" and "Sustainable Sediment Management Project" initiatives emphasize community benefits and sustainable infrastructure.

These examples illustrate the diverse approaches and priorities in sustainability initiatives across Oceania ports, emphasizing the integration of technology, environmental stewardship, and community engagement as key factors in driving sustainable development.

3) Analysis and Results

From the raw data matrix and the truth table, I cannot conclude the necessary condition for the sustainable port improvement. As usual, the frequency threshold was set at 1.00 and the consistency threshold was set at 1.00 I got four paths in the cases of Oceania port projects. Port sustainability can be achieved through various approaches. Strong infrastructure and digitalization are key factors, while clean energy initiatives can also significantly contribute to sustainability, even in the absence of other conditions.

The first path is DIG*INF.  This path involves the combination of digitalization and infrastructure improvement. It suggests that advancements in digital technologies alongside robust infrastructure significantly contribute to port sustainability. The integration of digital systems enhances operational efficiency, data management, and automation, while strong infrastructure ensures the physical and logistical support necessary for smooth port operations (Batalha et al., 2023). Together, these elements foster a resilient and sustainable port environment.

The second path is ~CE*~EC*INF. This pathway combines the absence of Environmental Caring and Clean Energy with Infrastructure. It implies that even without new environmental initiatives, strong infrastructure can maintain port sustainability. This suggests reliance on existing infrastructure to support sustainable operations, highlighting its foundational role in the improvement of port sustainability.

Table 11. Parsimonious solution for Port Sustainability in Oceania (Source: author)

| Pathway | Raw Coverage | Unique Coverage | Consistency |
|---|---|---|---|
| DIG*INF | 0.067 | 0 | 1 |
| ~CE*~EC*INF | 0.067 | 0 | 1 |

| | | | |
|---|---|---|---|
| ~CB*~CE*EC*~INF | 0.2 | 0 | 1 |
| ~CB*~CE*~DIG*~HSS*~INF | 0.2 | 0 | 1 |
| solution coverage: 0.267 | | | |
| solution consistency: 1 | | | |

4.4.4.4 Asia

1) Data overview

This section provides an overview of the data collected from Asian ports, focusing on sustainability initiatives from 2010 to 2023. The selected cases represent a comprehensive and up-to-date sample of the recent practices and trends in port sustainability within the region.

A total of 86 cases were collected, encompassing various sustainability initiatives implemented across different ports in Asia. The cases span 13 years, from 2010 to 2023, capturing a range of innovative practices and projects. The data includes information from ports located in multiple countries, reflecting diverse geographical and operational contexts. The themes identified in the data and their frequency are as follows: Community Building (CB): 29 occurrences, Environmental Caring (CE): 17 occurrences, Economic Contributions (EC): 25 occurrences, Digitalization (DIG): 21 occurrences, Health, Safety, and Security (HSS): 22 occurrences, and Sustainable Infrastructure (INFRA): 10 occurrences. Notably, the combination of CB and EC appeared most frequently, with 9 occurrences.

The data spans various locations, including major ports in the United Arab Emirates, Malaysia, Republic of Korea, China, and Singapore. Key projects from well-known ports such as Abu Dhabi, Johor Bahru, Busan, and Singapore are included. The temporal distribution shows a steady increase in sustainability initiatives over the years, with a significant number of projects launched between 2018 and 2023, indicating a growing emphasis on sustainability in recent years.

Table 12. Truth Table for Asia (Source: author)

| CB | CE | EC | DIG | HSS | INF | number | outcome | raw consist. | PRI consist. | SYM consist |
|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 1 | 1 | 0 | 0 | 0 | 4 | 1 | 1 | 1 | 1 |
| 0 | 1 | 0 | 0 | 0 | 1 | 3 | 1 | 1 | 1 | 1 |
| 1 | 0 | 0 | 1 | 0 | 0 | 1 | 1 | 1 | 1 | 1 |
| 0 | 1 | 1 | 1 | 0 | 0 | 1 | 1 | 1 | 1 | 1 |
| 0 | 0 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 |
| 0 | 1 | 0 | 0 | 0 | 0 | 4 | 0 | 0.75 | 0.75 | 0.75 |
| 1 | 0 | 0 | 0 | 1 | 0 | 4 | 0 | 0.75 | 0.75 | 0.75 |
| 1 | 0 | 1 | 0 | 0 | 1 | 2 | 0 | 0.50 | 0.50 | 0.50 |
| 0 | 1 | 0 | 1 | 0 | 1 | 2 | 0 | 0.50 | 0.50 | 0.50 |
| 0 | 0 | 1 | 0 | 0 | 0 | 5 | 0 | 0.40 | 0.40 | 0.40 |
| 0 | 0 | 0 | 1 | 1 | 0 | 5 | 0 | 0.40 | 0.40 | 0.40 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0 | 0 | 0 | 0 | 0 | 13 | 0 | 0.38 | 0.38 | 0.38 |
| 0 | 0 | 0 | 1 | 0 | 0 | 11 | 0 | 0.27 | 0.27 | 0.27 |
| 0 | 0 | 0 | 0 | 1 | 0 | 12 | 0 | 0.25 | 0.25 | 0.25 |
| 0 | 0 | 0 | 0 | 0 | 1 | 4 | 0 | 0.25 | 0.25 | 0.25 |
| 0 | 0 | 1 | 0 | 0 | 1 | 4 | 0 | 0.25 | 0.25 | 0.25 |
| 1 | 0 | 1 | 0 | 0 | 0 | 7 | 0 | 0.14 | 0.14 | 0.14 |
| 1 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 |
| 1 | 1 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 |
| 0 | 1 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 |

2) Case Examples

**Abu Dhabi Ports:** The "Al Dhafrah Region Community Ports Development" project and "Global Education Programme" reflect a strong focus on community building. As part of this project, Abu Dhabi Ports developed Sir Bani Yas Cruise Beach to create a sustainable cruise destination, which is currently the first and only dedicated cruise beach of its kind in the region, offering visitors an incredible cruise stop adventure experience.

**Port of Busan:** Initiatives such as "Reinventing Unused Port Space" and "Recycling of Plastic Waste" showcase advancements in community building and environmental sustainability.

**Port of Guangzhou:** Projects like "Onshore Power Supply Project" and "Improving the Rate and Reliability of Onshore Power Supply" emphasize environmental and economic benefits. In the case of Guangzhou Port, they adopted a series of technical and management measures, and the reliability of port shore power access to ships reached 100%, and the access rate increased from 5.4% to 59.6%.

**Johor Port Authority:** The "Community Empowerment through Science and Research" and "Ship Emission Management System (SEMS)" initiatives highlight community engagement and environmental care.

These examples illustrate the diverse approaches and priorities in sustainability initiatives across Asian ports, emphasizing the integration of technology, environmental stewardship, and community engagement as key factors in driving sustainable development.

3) Analysis and Results

From the raw data matrix and the truth table, I cannot conclude the necessary condition for the sustainable port improvement in Asia either. As usual, the frequency threshold was set at 1.00 and the consistency threshold was set at 1.00 I got five paths in the cases of Asian port projects.

The first path is ~CB*CE*EC. This path shows the absence of community building and the presence of climate and energy and environment caring. The projects in Asia should less emphasize on community building. This may relate to the policy background of the projects. Asian port projects might be influenced by governmental policies that prioritize environmental sustainability and energy efficiency over direct community engagement Governments may implement top-down approaches focusing on broader environmental goals rather than grassroots community initiatives(Cheung & Yip, 2011; Park & Seo, 2016). The second and the third path: CE*~DIG*INF and ~CE*DIG*INF show the same tendency. For future projects, integrating community engagement strategies alongside environmental initiatives could foster more comprehensive and inclusive sustainable development.

Table 13. Parsimonious solution for Port Sustainability in Asia (Source: author)

| Pathway | Raw Coverage | Unique Coverage | Consistency |
|---|---|---|---|
| CB*DIG | 0.028 | 0.028 | 1 |
| ~CB*CE*EC | 0.139 | 0.11 | 1 |
| CE*~DIG*INF | 0.083 | 0.083 | 1 |
| EC*DIG | 0.056 | 0 | 1 |
| ~CE*DIG*INF | 0.09 | 0 | 1 |
| solution coverage: 0.278 | | | |
| solution consistency: 1 | | | |

4.4.4.5 Africa and South America

1) Data Overview

This section provides an overview of the data collected from ports in Africa and South America, focusing on sustainability initiatives from 2010 to 2023. A total of 32 cases were collected, with 19 projects from South America and 13 from Africa. These initiatives span 14 countries, reflecting a wide range of geographical and operational contexts. Over the 13-year period, the data highlights innovative practices in port sustainability. The themes identified and their frequencies are: Community Building (CB): 16 occurrences, Environmental Caring (CE): 6 occurrences, Economic Contributions (EC): 16 occurrences, Digitalization (DIG): 3 occurrences, Health, Safety, and Security (HSS): 4 occurrences, and Infrastructure

(INF): 4 occurrences. Notably, the combination of CB and EC appeared frequently. The data shows a growing emphasis on sustainability in recent years, with many projects launched between 2019 and 2023.

Table 14. Truth Table for Africa and South America (Source: author)

| CB | CE | EC | DIG | HSS | INF | number | outcome | raw consist. | PRI consist. | SYM consist |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0 | 0 | 0 | 0 | 0 | 7 | 0 | 0 | 0 | 0 |
| 0 | 0 | 1 | 0 | 0 | 0 | 5 | 0 | 0 | 0 | 0 |
| 1 | 0 | 1 | 0 | 0 | 0 | 5 | 0 | 0 | 0 | 0 |
| 0 | 1 | 1 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 |
| 0 | 0 | 1 | 1 | 0 | 0 | 2 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 1 | 0 | 2 | 0 | 0 | 0 | 0 |
| 1 | 0 | 0 | 0 | 1 | 0 | 2 | 0 | 0 | 0 | 0 |
| 0 | 1 | 0 | 0 | 0 | 1 | 2 | 0 | 0 | 0 | 0 |
| 0 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 |
| 1 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 0 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 |
| 1 | 0 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 |

2) Case Examples

**Port of Kribi**: Initiatives like the "Socio-economic support program PASEK" and "Integrated Renewable Energy Generation Complex" reflect a strong focus on infrastructure improvement and community construction. These projects tried to further strengthen the relationship between the town and the port.

**Port Dock Sud**: Projects such as "Certification of UN SDGs" and "Solar water heaters from recyclable waste" show Argentina tries to make the energy infrastructure advanced for both port usage and local community and their ambition to realize SDGs.

**Port of Açu**: The "Protecting Sea Turtles" and "Mangrove Reforestation Project" initiatives emphasize environmental and community benefits. The programs aim to leave a legacy for the world showing that it is possible to develop port operations in a sustainable manner providing educational outreach and positive impacts on the environment.

These examples illustrate the diverse approaches and priorities in sustainability initiatives across Africa and South America ports, emphasizing the integration of infrastructure building, environmental stewardship, and community engagement as key factors in driving sustainable port construction.

3) Analysis and Results

The QCA analysis for Africa and South America revealed several challenges due to the limited data available. As a result, the analysis did not identify any necessary or sufficient conditions for achieving port sustainability in these regions. However, from the raw data matrix and the truth table, I observed that port projects in Africa and South America tend to focus more on improving relationships between ports and local communities. This emphasis on community relations might be related to human rights and racial issues, highlighting the importance of addressing social justice and inclusivity within port sustainability initiatives (Ayesu et al., 2023; Saidi et al., 2020). Additionally, these port projects also place a strong emphasis on protecting and improving the natural environment, which differs from other regions that focus more on reducing pollution emissions from ports. Moreover, I found that ports in Africa and South America generally do not prioritize digitalization and health and safety issues. This could be due to slow economic development and technological limitations. For local governments and port authorities, these areas should be the focus and direction for future port development.

# Chapter 5: Conclusion reflection

## 5.1 Pathways to Port Sustainability

The research on global port sustainability initiatives using Crisp-Set Qualitative Comparative Analysis (csQCA) provides valuable insights into the necessary and sufficient conditions for achieving sustainable port operations. This study underscores the complexity of port sustainability, emphasizing that no single condition is universally necessary. Instead, multiple pathways involving different combinations of digitalization, environmental care, community building, sustainable infrastructure, health and safety, and climate measures can lead to sustainable outcomes.

Various sustainability themes can be effectively combined to promote overall port sustainability. The study identifies three primary configurations that are sufficient for achieving sustainable outcomes: HSS*INF, CB*~CE*DIG, and ~CE*DIG*INF. These findings validate the theoretical frameworks used in the study, including the Triple Bottom Line (TBL) framework, Sustainable Development Goals (SDGs), stakeholder theory, and the resource-based view (RBV). These theories provide a robust foundation for understanding the multifaceted nature of port sustainability and for developing comprehensive evaluation criteria.

## 5.2 Regional Contexts Analysis in Port Sustainability

The study demonstrates the utility of csQCA as a methodological tool for analyzing complex cause-effect relationships in sustainability research. The identification of multiple pathways to sustainability underscores the importance of a nuanced approach that considers the interplay of various conditions.

Key findings highlight that regional contexts significantly influence the effectiveness of sustainability initiatives. For instance, ports in Europe and North America generally exhibit higher sustainability performance due to better economic conditions, stringent environmental regulations, and advanced technological infrastructure. In contrast, ports in developing regions such as Asia, Africa, and South America face challenges related to slower economic development and technological limitations, affecting their sustainability outcomes.

## 5.3 Recommendations for Enhancing Port Sustainability

The study provides several practical recommendations for policymakers and port authorities to enhance sustainability in port operations:

1. Tailored Strategies: Develop context-specific sustainability strategies that consider regional economic, regulatory, and technological conditions. This approach ensures that initiatives are relevant and effective within the local context.

2. Integrated Approach: Promote an integrated approach combining economic, social, and environmental aspects of sustainability. This includes initiatives that simultaneously address digitalization, environmental care, community engagement, and infrastructure development.

3. Focus on Key Conditions: Prioritize conditions such as digitalization and community building, which have been identified as critical components in multiple successful pathways to sustainability. Investments in these areas can yield significant improvements in port operations.

4. Data Collection and Sharing: Enhance data collection efforts and promote the sharing of best practices across regions. Comprehensive and accurate data is crucial for evaluating the effectiveness of sustainability initiatives and for making informed decisions.

By understanding and applying these findings, policymakers and port authorities can better navigate the complexities of port sustainability, ultimately leading to more effective and enduring sustainable practices.

# Chapter 6：Reflection for future research

## 6.1 Comprehensiveness of the Assessment Indicator

While this study’s evaluation system strives for balance, it falls short in comprehensiveness, with relatively simple indicator selection. Although the consideration of balance ensures consistency and fairness across different fields, this approach might overlook some crucial indicators that fully reflect ports' sustainable development capabilities. For instance, single indicators in environmental protection, energy efficiency, community impact, and digital transformation may not fully cover the actual performance of ports in these areas. Such limitations can lead to one-sided evaluation results, failing to achieve the study's original goal of comprehensively evaluating ports' sustainable development capabilities. Future research should diversify and expand indicators to fully reflect ports' sustainable development levels, improving research accuracy and providing more comprehensive decision-making support for policymakers.

## 6.2 Comprehensiveness of the Database

The study's database lacks comprehensiveness, as the WPSP database excludes four of the world's top ten ports by throughput, including Shanghai Port, Ningbo-Zhoushan Port, Qingdao Port, and Tianjin Port. These ports are vital global shipping hubs whose sustainability measures and effects hold significant representativeness and reference value. Therefore, the lack of data on these ports may bias the research results and affect the general applicability of the conclusions. Future research should expand the database to include more representative ports and consider combining other data sources for data supplementation and verification to improve research reliability and accuracy.

## 6.3 Lack of In-Depth Interviews

Due to time and space constraints, this study lacks in-depth interviews with port authorities and other stakeholders, limiting understanding of the causal relationships in sustainable port development. Existing research primarily relies on macro and general level data, which cannot fully capture the uniqueness and complexity of each case. This limitation weakens the qualitative research attributes of the QCA method and fails to show the unique paths and strategies of different ports in sustainable development. Future research should incorporate more in-depth exchanges and interviews with relevant stakeholders to obtain first-hand information, enriching data sources and providing a more detailed and in-depth basis for interpreting research results.

## 6.4 Future Research Directions

1. Improvement of the Evaluation System: Increase the diversity and representativeness of evaluation indicators to comprehensively cover key areas such as environmental protection, energy efficiency, community impact, and digital transformation. Introducing more comprehensive indicators will more accurately reflect ports' actual sustainable development levels, enhancing the comprehensiveness and representativeness of evaluation results.

2. Expansion of the Database: Expand the research database to cover more representative ports, particularly those missing in the current study. Additionally, combine multiple data sources to supplement and cross-validate data, improving data comprehensiveness and accuracy. This will enhance the universality and credibility of research results.

3. Increase in In-Depth Interviews: Conduct more in-depth interviews with port management authorities and other stakeholders to obtain first-hand information, enhancing understanding of each case's uniqueness and complexity. This approach will better capture ports' unique paths and strategies in sustainable development,

reinforcing the qualitative research attributes of the QCA method and providing more detailed support for research conclusions.

Through these improvements, future research will be better positioned to comprehensively and accurately evaluate ports' sustainable development capabilities, providing stronger support and guidance for theoretical research and practical applications in related fields.

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# Appendix - Original Raw Data Matrix

| Program Name | City | Country | Year | Continent | CB | CE | EC | DIG | HSS | INF | Outcome |
|---|---|---|---|---|---|---|---|---|---|---|---|
| "Port Spot" App | Wilhelmshaven | Germany | 2018 | Europe | 0 | 0 | 0 | 1 | 0 | 0 | 1 |
| "Valparaiso_Puerto Plus" project | Valparaiso | Chile | 2016 | South America | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2nd Generation Cyber Security Operations Center | Los Angeles | United States | 2019 | North America | 0 | 0 | 0 | 0 | 1 | 0 | 1 |
| 3R (Reduce_Reuse_Recycle) Campaign | Honiara | Solomon Islands | 2021 | Oceania | 1 | 1 | 1 | 0 | 0 | 0 | 0 |
| 5G-MoNArch | Hamburg | Germany | 2019 | Europe | 0 | 0 | 0 | 1 | 0 | 0 | 1 |

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|---|---|---|---|---|---|---|---|---|---|---|---|
| AbrAÇU Volunteer Project | São João da Barra | Brazil | 2016 | South America | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| Accelerating the transition to low-emission energy | Vancouver | Canada | 2023 | North America | 0 | 1 | 0 | 0 | 0 | 0 | 1 |
| Addressing Port congestion during the 2020 Tokyo Olympics | Tokyo | Japan | 2018 | Asia | 1 | 0 | 1 | 0 | 0 | 0 | 1 |
| Aiding schools as part of CSR program | Kota Kinabalu | Malaysia | 2018 | Asia | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| Air Quality Improvement Plan | Barcelona | Spain | 2017 | Europe | 0 | 1 | 1 | 0 | 0 | 0 | 1 |
| Al Dhafrah Region Community Ports Development | Abu Dhabi | United Arab Emirates | 2016 | Asia | 1 | 0 | 0 | 0 | 0 | 0 | 0 |

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|---|---|---|---|---|---|---|---|---|---|---|---|
| ALFION project | Igoumenitsa | Greece | 2022 | Europe | 0 | 1 | 0 | 0 | 0 | 1 | 0 |
| Applying the OECD Guidance for Responsible Business Conduct | Rotterdam | The Netherlands | 2019 | Europe | 1 | 0 | 0 | 0 | 0 | 0 | 1 |
| Artificial intelligence for environmental monitoring and prediction | Bari | Italy | 2019 | Europe | 0 | 1 | 1 | 1 | 0 | 0 | 0 |
| Automated drones to prevent oil pollution | Antwerp | Belgium | 2020 | Europe | 0 | 0 | 1 | 1 | 1 | 0 | 1 |
| Beneficial reuse of dredge material | Brisbane | Australia | 2019 | Oceania | 1 | 0 | 1 | 0 | 0 | 1 | 1 |
| Bilbao PortLab | Bilbao | Spain | 2023 | Europe | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| BilbOPS | Bilbao | Spain | 2022 | Europe | 0 | 1 | 1 | 0 | 0 | 1 | 0 |

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|---|---|---|---|---|---|---|---|---|---|---|---|
| Biohut project | Ivory Coast | Ivory Coast | 2022 | Africa | 0 | 0 | 1 | 0 | 0 | 0 | 0 |
| Brisbane International Cruise Terminal | Brisbane | Australia | 2020 | Oceania | 1 | 0 | 1 | 0 | 0 | 1 | 1 |
| Carbon footprint reduction | Panama City | Panama | 2013 | North America | 0 | 1 | 0 | 0 | 0 | 0 | 1 |
| Carbon footprint, energy optimization and sustainability reporting | Stockholm | Sweden | 2018 | Europe | 1 | 1 | 1 | 0 | 0 | 0 | 1 |
| Carbon Neutral Port 2035 | Helsinki | Finland | 2019 | Europe | 0 | 1 | 0 | 0 | 0 | 0 | 1 |
| Care towards flood victims | Johor Bahru | Malaysia | 2021 | Asia | 1 | 0 | 0 | 0 | 1 | 0 | 1 |
| CargO2ai | Montreal | Canada | 2020 | North America | 0 | 0 | 0 | 1 | 1 | 0 | 1 |

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|---|---|---|---|---|---|---|---|---|---|---|---|
| Caruara Reserve; biodiversity for all | São João da Barra | Brazil | 2022 | South America | 1 | 0 | 1 | 0 | 0 | 0 | 0 |
| Certification of UN SDGs | Buenos Aires | Argentina | 2023 | South America | 1 | 0 | 1 | 0 | 0 | 1 | 0 |
| Channel Optimization with DUKC® | Ras Al Khaimah | United Arab Emirates | 2020 | Asia | 0 | 1 | 0 | 1 | 0 | 1 | 0 |
| CinfraCap Carbon Infrastructure Capture | Gothenburg | Sweden | 2020 | Europe | 0 | 1 | 0 | 0 | 0 | 1 | 1 |
| Clean Coast / Beach Project | Tema | Ghana | 2019 | Africa | 0 | 0 | 1 | 0 | 0 | 0 | 0 |
| Clean Up Campaigns | Abu Dhabi | United Arab Emirates | 2022 | Asia | 1 | 0 | 1 | 0 | 0 | 0 | 0 |
| Clean Vessel Incentive | New York and | United States | 2019 | North | 1 | 1 | 0 | 0 | 0 | 0 | 1 |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (CVI) Program | New Jersey | | | America | | | | | | | | |
| Climate Adaptation Strategy | Adelaide | Australia | 2021 | Oceania | 0 | 1 | 0 | 0 | 0 | 1 | 1 |
| Climate Change Adaptation & Stormwater Treatment | Baltimore | United States | 2016 | North America | 0 | 0 | 0 | 0 | 0 | 1 | 1 |
| Climate Resilience | São João da Barra | Brazil | 2022 | South America | 0 | 1 | 0 | 0 | 0 | 1 | 0 |
| Climate Strategy 2035 | Baku | Azerbaijan | 2021 | Asia | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| CODEX Port Community System | Tuticorin | India | 2022 | Asia | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| Community awareness programs | Colombo | Sri Lanka | 2019 | Asia | 1 | 0 | 0 | 0 | 0 | 0 | 1 |

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|---|---|---|---|---|---|---|---|---|---|---|---|
| Community Empowerment through Science and Research | Johor Bahru | Malaysia | 2021 | Asia | 1 | 0 | 0 | 0 | 0 | 0 | 1 |
| Community Outreach Program | Yeosu and Gwangyang | Republic of Korea | 2019 | Asia | 1 | 0 | 1 | 0 | 0 | 0 | 0 |
| Conservation hand in hand with communities | São João da Barra | Brazil | 2010 | South America | 1 | 0 | 1 | 0 | 0 | 0 | 0 |
| Container Fast Pass (CONPAS) | Yokohama | Japan | 2017 | Asia | 0 | 0 | 0 | 1 | 0 | 0 | 1 |
| Converting Waste into Value | São João da Barra | Brazil | 2022 | South America | 0 | 0 | 1 | 0 | 0 | 0 | 0 |
| CORE Center of Operations and Response to Emergencies | São João da Barra | Brazil | 2021 | South America | 0 | 0 | 0 | 0 | 1 | 0 | 0 |

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|---|---|---|---|---|---|---|---|---|---|---|---|
| Covid19 outreach | Kota Kinabalu | Malaysia | 2020 | Asia | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| Covid19 Response | Busan | Republic of Korea | 2020 | Asia | 0 | 0 | 0 | 0 | 1 | 0 | 1 |
| C-PORT Zero Emissions Demonstration Project | Long Beach | United States | 2019 | North America | 0 | 1 | 0 | 0 | 0 | 0 | 1 |
| Cruise Terminal Development | Panama City | Panama | 2019 | North America | 1 | 0 | 0 | 0 | 0 | 1 | 1 |
| CSR assessment framework in contracts with customers | Amsterdam | The Netherlands | 2022 | Europe | 1 | 1 | 0 | 0 | 0 | 0 | 1 |
| Cyber Resilience Center | Los Angeles | United States | 2022 | North America | 0 | 0 | 0 | 1 | 1 | 0 | 1 |
| Cyber Resilience Center | Los Angeles | United States | 2022 | North | 0 | 0 | 0 | 1 | 1 | 0 | 1 |

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|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | America | | | | | | | |
| Data collaboration with MarineTraffic | Surigao | Philippines | 2022 | Asia | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| Data Enhancement Framework 2 (DEF2) | Halifax | Canada | 2023 | North America | 0 | 1 | 0 | 1 | 0 | 0 | 0 |
| DC Microgrid Research Project | Auckland | New Zealand | 2018 | Oceania | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| Debris Free Fundy / Rope Recycling | Saint John | Canada | 2020 | North America | 1 | 0 | 1 | 0 | 0 | 0 | 1 |
| Decarbonization initiatives | Owendo | Gabon | 2022 | Africa | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| Digital Port Ecosystem | Singapore | Singapore | 2020 | Asia | 0 | 0 | 0 | 1 | 1 | 0 | 1 |
| Digitalization initiative | Lautoka | Fiji | 2019 | Oceania | 0 | 0 | 0 | 1 | 0 | 0 | 0 |

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|---|---|---|---|---|---|---|---|---|---|---|---|
| Disaster Avoidance and Resiliency | Abu Dhabi | United Arab Emirates | 2015 | Asia | 0 | 0 | 0 | 1 | 1 | 0 | 0 |
| Dradenau logistics area | Hamburg | Germany | 2022 | Europe | 0 | 0 | 1 | 0 | 0 | 1 | 1 |
| Dugong, Otter and Seahorse Habitat Study | Johor Bahru | Malaysia | 2021 | Asia | 0 | 0 | 1 | 0 | 0 | 0 | 1 |
| Duwamish River Community Hub | Seattle | United States | 2023 | North America | 1 | 0 | 0 | 0 | 0 | 0 | 1 |
| Duwamish River People's Park and Shoreline Habitat | Seattle | United States | 2022 | North America | 1 | 0 | 1 | 0 | 0 | 0 | 1 |
| Duwamish Valley Community Benefits Commitment | Seattle | United States | 2019 | North America | 1 | 0 | 1 | 0 | 0 | 0 | 1 |
| ECO-Bulk Cargo | Kuantan | Malaysia | 2020 | Asia | 0 | 0 | 1 | 0 | 0 | 1 | 0 |

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|---|---|---|---|---|---|---|---|---|---|---|---|
| Ecosystem | | | | | | | | | | | |
| Ecological recovery project | Huelva | Spain | 2016 | Europe | 1 | 0 | 1 | 0 | 0 | 1 | 0 |
| ECOncrete Coastalock Blue Economy Pilot Project | San Diego | United States | 2021 | North America | 0 | 0 | 1 | 0 | 0 | 1 | 0 |
| Eco-resilient Future | Taipei | Taiwan （China） | 2020 | Asia | 0 | 1 | 0 | 1 | 0 | 1 | 1 |
| e-ISLAND Sustainable Electric Mobility Plan | Santa Cruz de Tenerife | Spain | 2016 | Europe | 0 | 1 | 1 | 0 | 0 | 0 | 0 |
| Electric Prime Movers | Guangzhou | China | 2020 | Asia | 0 | 1 | 0 | 0 | 0 | 0 | 1 |
| Emergency Notification System | Wilhelmshaven | Germany | 2016 | Europe | 0 | 0 | 0 | 0 | 1 | 0 | 1 |

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|---|---|---|---|---|---|---|---|---|---|---|---|
| Emergency Preparedness Project | São João da Barra | Brazil | 2019 | South America | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| Employability Network | São João da Barra | Brazil | 2014 | South America | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| Energy recovery from cruise ships' wastewater | Marseille | France | 2020 | Europe | 0 | 1 | 1 | 0 | 0 | 0 | 1 |
| Energy transition: decoupling growth from carbon emissions | London | United Kingdom | 2010 | Europe | 0 | 1 | 0 | 0 | 0 | 0 | 1 |
| Enhancing Port Security and Safety | Cagayan de Oro | Philippines | 2014 | Asia | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| Enhancing safety performance | Gladstone | Australia | 2021 | Oceania | 0 | 0 | 0 | 0 | 1 | 0 | 0 |

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| Ensuring Safe Distances for Alternative Fuel Bunker Operations | Amsterdam | The Netherlands | 2023 | Europe | 0 | 1 | 0 | 0 | 1 | 0 | 1 |
| Ensuring sustainable mega port development | Doha | Qatar | 2017 | Asia | 1 | 0 | 1 | 0 | 0 | 0 | 0 |
| Environmental Action Plan | Tacoma | United States | 2022 | North America | 0 | 1 | 1 | 0 | 0 | 0 | 0 |
| Environmental Innovation through Blue Economy Incubator Program | San Diego | United States | 2019 | North America | 1 | 0 | 1 | 0 | 0 | 1 | 0 |
| Environmental Measures in Reclamation Projects | Kobe | Japan | 2018 | Asia | 1 | 0 | 1 | 0 | 0 | 1 | 0 |
| ESG Implementation Roadmap | Keelung | Taiwan（China） | 2022 | Asia | 1 | 0 | 0 | 0 | 1 | 0 | 1 |

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| Expanding Passive Litter Collection on the Thames | London | United Kingdom | 2019 | Europe | 1 | 0 | 1 | 0 | 0 | 0 | 1 |
| Expanding wetland fringes along the estuary | London | United Kingdom | 2019 | Europe | 1 | 0 | 1 | 0 | 0 | 1 | 1 |
| Expansion of community parklands | Gladstone | Australia | 2020 | Oceania | 1 | 0 | 1 | 0 | 0 | 0 | 0 |
| Fairy Tern Conservation Sanctuary | Fremantle | Australia | 2013 | Oceania | 1 | 0 | 1 | 0 | 0 | 0 | 0 |
| Feasibility Study for Onshore Power Supply | Port Louis | Mauritius | 2022 | Africa | 0 | 1 | 1 | 0 | 0 | 0 | 0 |
| Fighting food insecurity | Saint John | Canada | 2020 | North America | 1 | 0 | 0 | 0 | 0 | 0 | 1 |
| First free university in a DP | Posorja | Ecuador | 2022 | South | 1 | 0 | 0 | 0 | 0 | 0 | 0 |

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| World facility | | | | America | | | | | | | |
| Flood Risk Management Programme | Rotterdam | The Netherlands | 2021 | Europe | 0 | 1 | 0 | 0 | 1 | 1 | 1 |
| Flow Pass | Marseille | France | 2020 | Europe | 0 | 0 | 1 | 1 | 0 | 0 | 1 |
| Free Wi-Fi for Seafarers | Saint John | Canada | 2020 | North America | 1 | 0 | 0 | 1 | 0 | 0 | 1 |
| Friend Ship Solution | Marseille | France | 2020 | Europe | 0 | 1 | 0 | 1 | 0 | 0 | 1 |
| Fritzy and friends | Amsterdam | The Netherlands | 2019 | Europe | 0 | 0 | 0 | 1 | 0 | 1 | 1 |
| From zero to hero mentor-mentee program | Port Klang | Malaysia | 2022 | Asia | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| Frontrunner on Onshore | Gothenburg | Sweden | 2021 | Europe | 0 | 1 | 1 | 0 | 0 | 0 | 1 |

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| Power Supply for vessels | | | | | | | | | | | |
| Future Proof Governance Program | Amsterdam | The Netherlands | 2022 | Europe | 1 | 0 | 0 | 0 | 0 | 0 | 1 |
| Gender equality; “Train for Work” program | Buenos Aires | Argentina | 2023 | South America | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| Gender Equity Initiatives | Panama City | Panama | 2013 | North America | 1 | 0 | 0 | 0 | 0 | 0 | 1 |
| Ghetto Games street sports and culture movement | Riga | Latvia | 2020 | Europe | 1 | 0 | 0 | 0 | 0 | 0 | 1 |
| GHG Emission Reduction Pathway | Auckland | New Zealand | 2018 | Oceania | 1 | 1 | 1 | 0 | 0 | 0 | 0 |
| GHG emission reduction | Colombo | Sri Lanka | 2021 | Asia | 0 | 1 | 0 | 0 | 0 | 0 | 1 |

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| project | | | | | | | | | | | |
| Global Education Programme | Dubai | United Arab Emirates | 2016 | Asia | 1 | 0 | 0 | 0 | 0 | 0 | 1 |
| Grand Quay development project | Montreal | Canada | 2019 | North America | 1 | 1 | 1 | 0 | 0 | 0 | 1 |
| Green Bay | Vigo | Spain | 2020 | Europe | 1 | 1 | 1 | 0 | 0 | 0 | 0 |
| Green mobile energy for reefer containers | Marseille | France | 2020 | Europe | 0 | 1 | 0 | 0 | 0 | 0 | 1 |
| Green Port Initiative | Lautoka | Fiji | 2019 | Oceania | 0 | 1 | 1 | 0 | 0 | 0 | 0 |
| Green Port Policy and Program | Kota Kinabalu | Malaysia | 2017 | Asia | 1 | 1 | 0 | 0 | 0 | 0 | 0 |
| Green Ports Project | Honiara | Solomon | 2019 | Oceania | 0 | 1 | 0 | 0 | 0 | 0 | 0 |

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| | | Islands | | | | | | | | | |
| Greening Project | Batangas | Philippines | 2015 | Asia | 1 | 1 | 1 | 0 | 0 | 0 | 0 |
| GuideMeMarseille | Marseille | France | 2019 | Europe | 1 | 0 | 1 | 1 | 0 | 0 | 1 |
| H2Ports / Fuel Cells and Hydrogen in Ports | Valencia | Spain | 2019 | Europe | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| Hamburg Sustainable Fleet | Hamburg | Germany | 2017 | Europe | 0 | 1 | 1 | 0 | 0 | 0 | 1 |
| Hector’s dolphin acoustic monitoring programme | Christchurch | New Zealand | 2023 | Oceania | 0 | 0 | 1 | 0 | 0 | 1 | 0 |
| Helping those in need during the COVID19 pandemic | Johor Bahru | Malaysia | 2020 | Asia | 1 | 0 | 0 | 0 | 1 | 0 | 1 |

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| Heroes of Hope | Abu Dhabi | United Arab Emirates | 2022 | Asia | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| homePORT | Hamburg | Germany | 2020 | Europe | 1 | 0 | 0 | 0 | 0 | 0 | 1 |
| HSE Culture Building Program | Abu Dhabi | United Arab Emirates | 2014 | Asia | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| HyAMMED | Marseille | France | 2019 | Europe | 0 | 1 | 0 | 0 | 0 | 0 | 1 |
| Hydrogen Highway project | London | United Kingdom | 2021 | Europe | 0 | 1 | 0 | 0 | 1 | 1 | 1 |
| Hydrogen production facility and filling station | Gothenburg | Sweden | 2021 | Europe | 0 | 1 | 0 | 0 | 0 | 1 | 1 |
| Hydrogen Supply Chain Joint Study | Yokohama | Japan | 2021 | Asia | 0 | 1 | 0 | 0 | 0 | 1 | 1 |

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| Hydroturbine | Antwerp | Belgium | 2019 | Europe | 0 | 1 | 0 | 0 | 0 | 0 | 1 |
| Implementing a comprehensive safety framework | Ulsan | Republic of Korea | 2022 | Asia | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| Improving operational efficiency through transparent information exchange | Houston | United States | 2020 | North America | 1 | 0 | 0 | 1 | 0 | 0 | 1 |
| Improving the Rate and Reliability of Onshore Power Supply | Guangzhou | China | 2018 | Asia | 0 | 1 | 1 | 0 | 0 | 0 | 1 |
| Incentive scheme for climate-friendly shipping | Rotterdam | The Netherlands | 2019 | Europe | 0 | 1 | 0 | 0 | 0 | 0 | 1 |
| Increasing resilience to | Valencia | Spain | 2019 | Europe | 0 | 1 | 0 | 0 | 0 | 1 | 0 |

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| climate change | | | | | | | | | | | |
| Incredible Parks Want Incredible Names | Seattle | United States | 2020 | North America | 1 | 0 | 1 | 0 | 0 | 0 | 1 |
| Indigenous Affairs Strategy | Gladstone | Australia | 2012 | Oceania | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| Indigenous Empowerment and Partnership | Gladstone | Australia | 2014 | Oceania | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| Innovation Partnership project | Yeosu/Gwangya ng | Republic of Korea | 2022 | Asia | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| Innovation Prospers Sustainability | Shenzhen | China | 2021 | Asia | 1 | 0 | 0 | 1 | 0 | 0 | 1 |
| Innovative intelligent lighting system | Emden | Germany | 2017 | Europe | 0 | 1 | 0 | 0 | 0 | 0 | 0 |

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| Integrated Green Energy Solutions (IGES) | Amsterdam | The Netherlands | 2018 | Europe | 0 | 1 | 0 | 0 | 0 | 0 | 1 |
| Integrated Management System certification | Lautoka | Fiji | 2023 | Oceania | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| Integrated Platform for Port Logistics Information | Busan | Republic of Korea | 2023 | Asia | 0 | 0 | 0 | 1 | 0 | 0 | 1 |
| Integrated Renewable Energy Generation Complex | Kribi | Cameroon | 2022 | Africa | 0 | 1 | 0 | 0 | 0 | 1 | 0 |
| INTER-IoT | Valencia | Spain | 2018 | Europe | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| Inter-island shipping wharf (Muaiwalu 2) carbon-neutral facility | Lautoka | Fiji | 2023 | Oceania | 0 | 1 | 0 | 0 | 0 | 1 | 0 |

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| International Collaboration on Vessel Emissions Reduction | Vancouver | Canada | 2017 | North America | 1 | 1 | 1 | 1 | 0 | 0 | 1 |
| Investing in Community | Sydney | Australia | 2023 | Oceania | 1 | 0 | 0 | 0 | 0 | 0 | 1 |
| IoT4Control | Marseille | France | 2020 | Europe | 0 | 0 | 0 | 1 | 1 | 0 | 1 |
| Journey towards HSE excellence | Port Klang | Malaysia | 2020 | Asia | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| Jupiter 1000 | Marseille | France | 2019 | Europe | 0 | 1 | 0 | 0 | 0 | 0 | 1 |
| Kakao Talk Chatbot for Port Statistics Monitoring | Busan | Republic of Korea | 2020 | Asia | 0 | 0 | 0 | 0 | 0 | 1 | 1 |
| Kal Ki Kaksha (The Classroom of Tomorrow) | Mundra | India | 2017 | Asia | 1 | 0 | 0 | 0 | 0 | 0 | 0 |

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| Keeping port workers healthy | Yeosu/Gwangyang | Republic of Korea | 2022 | Asia | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| KPA e-Citizen platform | Mombasa | Kenya | 2022 | Africa | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| KPA Fishermen Compensation program | Mombasa | Kenya | 2023 | Africa | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| Kreetsand tidal zone | Hamburg | Germany | 2023 | Europe | 0 | 0 | 1 | 0 | 0 | 1 | 1 |
| Kribi Port Eco-sustain Project | Kribi | Cameroon | 2022 | Africa | 0 | 0 | 1 | 1 | 0 | 0 | 0 |
| Kribi Port Eco-sustain Project | Kribi | Cameroon | 2022 | Africa | 0 | 0 | 1 | 1 | 0 | 0 | 0 |
| Large scale planting of eelgrass meadows | Gothenburg | Sweden | 2018 | Europe | 0 | 1 | 1 | 0 | 0 | 0 | 1 |

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| Leader in Maritime Safety | Busan | Republic of Korea | 2021 | Asia | 0 | 0 | 0 | 0 | 1 | 0 | 1 |
| Living Ports | Vigo | Spain | 2021 | Europe | 0 | 1 | 1 | 0 | 0 | 1 | 0 |
| Livorno Open Port project | Livorno | Italy | 2015 | Europe | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| LNG bunkering | Yokohama | Japan | 2016 | Asia | 0 | 0 | 1 | 0 | 0 | 0 | 1 |
| LNG dual-fuel tugs | Singapore | Singapore | 2019 | Asia | 0 | 1 | 1 | 0 | 0 | 0 | 1 |
| Lower Wapato Creek Habitat Project | Tacoma | United States | 2021 | North America | 0 | 0 | 1 | 0 | 0 | 1 | 0 |
| Maiden visit to Saint John | Saint John | Canada | 2022 | North America | 1 | 0 | 0 | 0 | 0 | 0 | 1 |
| Maiden visit to Saint John | Saint John | Canada | 2022 | North | 1 | 0 | 0 | 0 | 0 | 0 | 1 |

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| Mangrove Reforestation Project | Posorja | Ecuador | 2020 | South America | 0 | 1 | 1 | 0 | 0 | 0 | 0 |
| Maplewood Marine Restoration Project | Vancouver | Canada | 2021 | North America | 0 | 0 | 1 | 0 | 0 | 1 | 1 |
| Maqta Airfreight Services (MAS) | Abu Dhabi | United Arab Emirates | 2023 | Asia | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| Marine Cadetship Program for Women | Brisbane | Australia | 2018 | Oceania | 1 | 0 | 0 | 0 | 0 | 0 | 1 |
| Marine Conservation Research | Kota Kinabalu | Malaysia | 2017 | Asia | 1 | 0 | 1 | 0 | 0 | 0 | 0 |
| Marine Plastic Collection and Utilization Network | Yeosu/Gwangyang | Republic of Korea | 2020 | Asia | 0 | 0 | 1 | 0 | 0 | 0 | 0 |

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| Marine Resource Management System | Johor Bahru | Malaysia | 2022 | Asia | 0 | 0 | 0 | 1 | 0 | 0 | 1 |
| Maritime Cluster | Abu Dhabi | United Arab Emirates | 2022 | Asia | 0 | 1 | 0 | 0 | 1 | 0 | 0 |
| Maritime Innovation Center | Seattle | United States | 2023 | North America | 1 | 0 | 0 | 0 | 0 | 1 | 1 |
| Maritime Trail | Perth | Australia | 2019 | Oceania | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| Market Slip Collaboration for Recreational Boaters | Saint John | Canada | 2020 | North America | 1 | 0 | 0 | 0 | 0 | 0 | 1 |
| Master Plan 2017-2021 | Kaohsiung | Taiwan （China） | 2021 | Asia | 1 | 0 | 1 | 0 | 0 | 1 | 1 |
| Mercy Ships | Antwerp | Belgium | 2021 | Europe | 1 | 0 | 0 | 0 | 1 | 0 | 1 |

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| Migratory Shorebird Monitoring | Brisbane | Australia | 2017 | Oceania | 1 | 0 | 1 | 0 | 0 | 0 | 1 |
| MOBI platform | Amsterdam | The Netherlands | 2019 | Europe | 0 | 0 | 0 | 0 | 1 | 0 | 1 |
| Moving towards Smart Port status | Adelaide | Australia | 2020 | Oceania | 0 | 0 | 0 | 1 | 0 | 1 | 1 |
| mPCS Project | Abu Dhabi | United Arab Emirates | 2014 | Asia | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| mUnity | Abu Dhabi | United Arab Emirates | 2022 | Asia | 0 | 0 | 0 | 1 | 1 | 0 | 0 |
| NCOS Online | Brisbane | Australia | 2019 | Oceania | 0 | 1 | 0 | 1 | 0 | 0 | 1 |
| Neeshan HSE Awards | Abu Dhabi | United Arab Emirates | 2022 | Asia | 0 | 0 | 0 | 0 | 1 | 0 | 0 |

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| Neo Orbis hydrogen vessel | Amsterdam | The Netherlands | 2023 | Europe | 0 | 1 | 0 | 0 | 0 | 0 | 1 |
| Net Zero Emissions (Scope 1 & 2) | Brisbane | Australia | 2023 | Oceania | 0 | 1 | 0 | 0 | 0 | 0 | 1 |
| Network of Fire Services | Antwerp | Belgium | 2021 | Europe | 0 | 0 | 0 | 0 | 1 | 0 | 1 |
| Occupational health and safety certification | Lautoka | Fiji | 2023 | Oceania | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| Ocean Acidification Action Plan | Seattle | United States | 2020 | North America | 0 | 1 | 1 | 0 | 0 | 0 | 1 |
| Offshore wind energy hub | Sydney | Australia | 2023 | Oceania | 0 | 1 | 0 | 0 | 0 | 1 | 1 |
| Offsite Stormwater management | Brisbane | Australia | 2019 | Oceania | 1 | 0 | 1 | 0 | 0 | 1 | 1 |

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| Online monitoring of water quality | Anzali | Iran | 2015 | Asia | 1 | 0 | 1 | 0 | 0 | 0 | 0 |
| Onshore Power Supply (OPS) | Hamburg | Germany | 2020 | Europe | 0 | 1 | 1 | 0 | 0 | 1 | 1 |
| Onshore Power Supply Project | Guangzhou | China | 2017 | Asia | 0 | 1 | 1 | 0 | 0 | 0 | 1 |
| Onshore Power Supply to vessels | Genoa | Italy | 2019 | Europe | 0 | 1 | 1 | 0 | 0 | 0 | 0 |
| Open Port exhibition center | Taranto | Italy | 2023 | Europe | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| Optimal Infrastructure and Services | Batangas | Philippines | 2010 | Asia | 0 | 0 | 0 | 0 | 0 | 1 | 0 |
| PACT project | Amsterdam | The | 2019 | Europe | 0 | 0 | 0 | 1 | 0 | 0 | 1 |

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| | | Netherlands | | | | | | | | | |
| Panama Maritime Single Window | Cristobal | Panama | 2016 | North America | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| Panama Maritime Single Window | Balboa | Panama | 2016 | North America | 0 | 0 | 0 | 1 | 0 | 0 | 1 |
| Pathway towards Smart & Green Port | Lautoka | Fiji | 2023 | Oceania | 0 | 1 | 0 | 1 | 0 | 0 | 0 |
| Piezoelectric System | Busan | Republic of Korea | 2023 | Asia | 0 | 1 | 0 | 0 | 0 | 1 | 1 |
| Pilot scheme for emission-free construction sites | Gothenburg | Sweden | 2021 | Europe | 1 | 1 | 0 | 0 | 0 | 0 | 1 |
| PIN Project | Antwerp | Belgium | 2014 | Europe | 0 | 0 | 0 | 0 | 1 | 0 | 1 |

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| Plaza Major Cartagena and Port Window projects | Cartagena | Spain | 2021 | Europe | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| Pop-Up Cruise Market | Busan | Republic of Korea | 2019 | Asia | 1 | 0 | 0 | 0 | 0 | 0 | 1 |
| Port Community Care Project | Baku | Azerbaijan | 2021 | Asia | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| Port Energy Consumption Management Tool | Wilhelmshaven | Germany | 2018 | Europe | 0 | 1 | 0 | 1 | 0 | 0 | 1 |
| Port environmental monitoring platform for invasive species (PPSE) | Cotonou | Benin | 2023 | Africa | 0 | 0 | 1 | 0 | 0 | 0 | 0 |
| Port Festival 2019 | Baku | Azerbaijan | 2019 | Asia | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| Port Health, Safety & | Saint John | Canada | 2022 | North | 0 | 0 | 1 | 0 | 1 | 0 | 1 |

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| Environment Engagement Committee | | | | America | | | | | | | |
| Port immersion vocational training (PIVOT) | Valencia | Spain | 2023 | Europe | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| Port Links | Barcelona | Spain | 2016 | Europe | 1 | 1 | 1 | 1 | 0 | 0 | 1 |
| Port Management and Information System (PMIS) | Baku | Azerbaijan | 2019 | Asia | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| Port Management Information System (PMIS) | Baku | Azerbaijan | 2020 | Asia | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| Port Pod | Saint John | Canada | 2022 | North America | 1 | 0 | 0 | 0 | 0 | 0 | 1 |
| Port to Park community event | Gladstone | Australia | 2021 | Oceania | 1 | 0 | 0 | 0 | 0 | 0 | 0 |

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| PortXchange | Algeciras | Spain | 2020 | Europe | 0 | 1 | 0 | 1 | 0 | 0 | 0 |
| PortXchange Pronto | Rotterdam | The Netherlands | 2019 | Europe | 0 | 1 | 0 | 1 | 0 | 0 | 1 |
| Posidonia Oceanica marine forest | Cartagena | Spain | 2022 | Europe | 0 | 1 | 1 | 0 | 0 | 0 | 0 |
| Project Shamal | Abu Dhabi | United Arab Emirates | 2023 | Asia | 0 | 0 | 0 | 0 | 0 | 1 | 0 |
| Protecting habitats and enhancing biodiversity | Abu Dhabi | United Arab Emirates | 2022 | Asia | 0 | 0 | 1 | 0 | 0 | 1 | 0 |
| Protecting Sea Turtles | São João da Barra | Brazil | 2021 | South America | 1 | 0 | 1 | 0 | 0 | 0 | 0 |
| Protecting the Coral Reefs | Abu Dhabi | United Arab Emirates | 2010 | Asia | 0 | 0 | 1 | 0 | 0 | 0 | 0 |

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| Provision of Onshore Power Supply | Marseille | France | 2019 | Europe | 0 | 1 | 1 | 0 | 0 | 0 | 1 |
| Provision of Onshore Power Supply (OPS) | Santa Cruz de Tenerife | Spain | 2019 | Europe | 0 | 1 | 1 | 0 | 0 | 0 | 0 |
| Recycling of aggregates for construction | Busan | Republic of Korea | 2023 | Asia | 0 | 0 | 1 | 0 | 0 | 1 | 1 |
| Recycling of Plastic Waste | Busan | Republic of Korea | 2021 | Asia | 0 | 1 | 1 | 0 | 0 | 0 | 1 |
| Reinventing unused port space | Busan | Republic of Korea | 2017 | Asia | 1 | 0 | 0 | 0 | 0 | 0 | 1 |
| Relocation of corals located in limit of development plan | Chabahar | Iran | 2011 | Asia | 0 | 0 | 1 | 0 | 0 | 1 | 0 |

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| Remote surveying of vessels | Singapore | Singapore | 2020 | Asia | 0 | 0 | 0 | 1 | 1 | 0 | 1 |
| Renewable Energy for a Sustainable Community | Honiara | Solomon Islands | 2021 | Oceania | 1 | 1 | 0 | 0 | 0 | 0 | 0 |
| Renewing, greening and optimizing the port's fleet | Antwerp | Belgium | 2021 | Europe | 0 | 1 | 1 | 0 | 0 | 0 | 1 |
| Responding to storm and flood | Port Klang | Malaysia | 2021 | Asia | 1 | 0 | 0 | 0 | 1 | 0 | 0 |
| Response to the pandemic | Colombo | Sri Lanka | 2020 | Asia | 0 | 0 | 0 | 0 | 1 | 0 | 1 |
| River Cooling | Marseille | France | 2020 | Europe | 0 | 1 | 1 | 1 | 0 | 0 | 1 |
| Routescanner | Rotterdam | The Netherlands | 2022 | Europe | 0 | 0 | 0 | 1 | 0 | 0 | 1 |

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| SAFE SECA project | Le Havre | France | 2014 | Europe | 0 | 1 | 1 | 0 | 0 | 0 | 1 |
| Safety in the Heat Campaign | Abu Dhabi | United Arab Emirates | 2023 | Asia | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| Sea Turtle Conservation Program | Tema | Ghana | 2018 | Africa | 0 | 0 | 1 | 0 | 0 | 0 | 0 |
| Sea wall habitat enhancement | Gladstone | Australia | 2021 | Oceania | 0 | 0 | 1 | 0 | 0 | 1 | 0 |
| SeaClear project | Hamburg | Germany | 2020 | Europe | 0 | 0 | 1 | 1 | 0 | 0 | 1 |
| Seafarer Vaccination Program | Sydney | Australia | 2022 | Oceania | 0 | 0 | 0 | 0 | 1 | 0 | 1 |
| Seagrass relocation | Kota Kinabalu | Malaysia | 2018 | Asia | 1 | 0 | 1 | 0 | 0 | 0 | 0 |

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| Searoutes | Marseille | France | 2019 | Europe | 0 | 1 | 0 | 1 | 0 | 0 | 1 |
| Secure Truck Parking | Hamburg | Germany | 2018 | Europe | 1 | 0 | 1 | 1 | 1 | 0 | 1 |
| SeePort Festival and Concert | Auckland | New Zealand | 2020 | Oceania | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| SENYAR HSE Application | Abu Dhabi | United Arab Emirates | 2020 | Asia | 0 | 0 | 0 | 1 | 1 | 0 | 0 |
| Ship Emission Management System (SEMS) | Johor Bahru | Malaysia | 2017 | Asia | 0 | 1 | 1 | 1 | 0 | 0 | 1 |
| Shipping Container Community Village | Saint John | Canada | 2021 | North America | 1 | 0 | 0 | 0 | 0 | 0 | 1 |
| Shore power supply for cruise ships | Kristiansand | Norway | 2018 | Europe | 0 | 1 | 1 | 0 | 0 | 0 | 0 |

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| Singapore's Next Generation Tuas Port Project | Singapore | Singapore | 2019 | Asia | 0 | 0 | 1 | 1 | 0 | 1 | 1 |
| Smart Bollard | Rotterdam | The Netherlands | 2019 | Europe | 0 | 0 | 0 | 1 | 1 | 1 | 1 |
| Smartbolt digital cargo seal | Marseille | France | 2020 | Europe | 0 | 0 | 0 | 0 | 1 | 0 | 1 |
| smartBRIDGE Hamburg | Hamburg | Germany | 2021 | Europe | 0 | 0 | 0 | 1 | 0 | 1 | 1 |
| Socio-economic support program PASEK | Kribi | Cameroon | 2020 | Africa | 1 | 0 | 0 | 0 | 1 | 0 | 0 |
| Solar Park | Ghent | Belgium, The Netherlands | 2021 | Europe | 0 | 1 | 0 | 0 | 0 | 0 | 1 |
| Solar Powered Automatic | Brisbane | Australia | 2021 | Oceania | 0 | 0 | 1 | 0 | 0 | 0 | 1 |

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| River Cleaner trial | | | | | | | | | | | |
| Solar water heaters from recyclable waste | Buenos Aires | Argentina | 2023 | South America | 1 | 1 | 0 | 0 | 0 | 0 | 0 |
| Spot the robot dog, our assistant bridge inspector | Hamburg | Germany | 2022 | Europe | 0 | 0 | 0 | 1 | 0 | 0 | 1 |
| Start-up to Grow-up Onestop Platform | Ulsan | Republic of Korea | 2022 | Asia | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| STEAM project | Limassol | Cyprus | 2019 | Europe | 0 | 0 | 1 | 1 | 1 | 0 | 0 |
| StoryBike | Marseille | France | 2020 | Europe | 1 | 0 | 0 | 0 | 0 | 0 | 1 |
| Strategy towards zero emissions by 2030 | Valencia | Spain | 2020 | Europe | 0 | 1 | 0 | 0 | 0 | 1 | 0 |
| Study on Cruise Activity | Barcelona | Spain | 2014 | Europe | 1 | 0 | 0 | 0 | 0 | 0 | 1 |

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| Submarine Cable Landing “Plug” | Marseille | France | 2019 | Europe | 0 | 0 | 0 | 1 | 0 | 1 | 1 |
| Sunset Dock Project | Vigo | Spain | 2019 | Europe | 1 | 1 | 1 | 0 | 0 | 0 | 0 |
| Survey on hydrogen utilization for a carbon neutral port | Yokohama | Japan | 2023 | Asia | 0 | 1 | 0 | 0 | 0 | 1 | 1 |
| Sustainability Governance | Vancouver | Canada | 2018 | North America | 1 | 0 | 0 | 0 | 0 | 0 | 1 |
| Sustainability, Equilibrium and Respect Program | Itaguaí | Brazil | 2022 | South America | 1 | 0 | 1 | 0 | 0 | 0 | 0 |
| Sustainable anchoring practices | Sydney | Australia | 2022 | Oceania | 0 | 0 | 1 | 0 | 0 | 0 | 1 |
| Sustainable anchoring | Sydney | Australia | 2022 | Oceania | 0 | 0 | 1 | 0 | 0 | 0 | 1 |

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| practices | | | | | | | | | | | |
| Sustainable Cruise Tourism | Saint John | Canada | 2020 | North America | 1 | 0 | 1 | 0 | 0 | 0 | 1 |
| Sustainable Office Building | Johor Bahru | Malaysia | 2022 | Asia | 0 | 1 | 0 | 0 | 0 | 0 | 1 |
| Sustainable Port Development | Abu Dhabi | United Arab Emirates | 2022 | Asia | 0 | 0 | 0 | 0 | 0 | 1 | 0 |
| Sustainable Sediment Management Project | Gladstone | Australia | 2018 | Oceania | 1 | 0 | 1 | 0 | 0 | 1 | 0 |
| Taking Action / Creating Values | Hamburg | Germany | 2018 | Europe | 1 | 0 | 0 | 0 | 0 | 0 | 1 |
| Tenerife Port ZERO | Santa Cruz de Tenerife | Spain | 2023 | Europe | 0 | 1 | 0 | 0 | 0 | 0 | 0 |

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| Thames Vision 2035 | London | United Kingdom | 2019 | Europe | 1 | 0 | 1 | 0 | 0 | 0 | 1 |
| The “Cohesion Factory” port-city initiative | Tenerife | Spain | 2016 | Europe | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| The Digital Route | Baku | Azerbaijan | 2019 | Asia | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| The ECHO Program | Vancouver | Canada | 2021 | North America | 0 | 0 | 1 | 0 | 0 | 0 | 1 |
| The Livorno “Public debate” | Livorno | Italy | 2016 | Europe | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| The MeRS project | Marseille | France | 2019 | Europe | 0 | 0 | 0 | 1 | 1 | 0 | 1 |
| The PIER living lab | Halifax | Canada | 2023 | North America | 1 | 1 | 1 | 1 | 0 | 0 | 0 |

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| The PIER living lab | Halifax | Canada | 2023 | North America | 1 | 1 | 1 | 1 | 0 | 0 | 0 |
| The Port as a Functioning Part of the City | Helsinki | Finland | 2010 | Europe | 1 | 0 | 1 | 0 | 0 | 0 | 1 |
| The Seabin Project | Wilhelmshaven | Germany | 2019 | Europe | 0 | 0 | 1 | 0 | 0 | 0 | 1 |
| The Unique Dispatcher Software | Baku | Azerbaijan | 2019 | Asia | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| Tidal Energy Demonstration | Gladstone | Australia | 2018 | Oceania | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| Together in the fight against Covid-19 | São João da Barra | Brazil | 2020 | South America | 1 | 0 | 0 | 0 | 1 | 0 | 0 |
| Tranzero Initiative | Gothenburg | Sweden | 2021 | Europe | 1 | 1 | 1 | 0 | 0 | 0 | 1 |

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| Tunahusika Corporate Social Investment program | Mombasa | Kenya | 2018 | Africa | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| UN SDGs integration in port sustainability strategy | Cartagena | Spain | 2020 | Europe | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| Upcycle Factory | Amsterdam | The Netherlands | 2020 | Europe | 0 | 1 | 1 | 0 | 0 | 0 | 1 |
| Vessel Traffic Management System | Lautoka | Fiji | 2022 | Oceania | 0 | 0 | 0 | 1 | 1 | 0 | 0 |
| Vila da Terra project | São João da Barra | Brazil | 2012 | South America | 1 | 0 | 1 | 0 | 0 | 0 | 0 |
| Virtual Maritime Museum and Heritage Project | Riga | Latvia | 2023 | Europe | 1 | 0 | 0 | 1 | 0 | 0 | 1 |
| Virtual Reality for model- | Hamburg | Germany | 2017 | Europe | 0 | 0 | 0 | 1 | 0 | 0 | 1 |

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| based port infrastructure management | | | | | | | | | | | |
| Vision on responsible supply chains | Amsterdam | The Netherlands | 2018 | Europe | 1 | 0 | 0 | 0 | 0 | 0 | 1 |
| WASh2Emden project | Emden | Germany | 2019 | Europe | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| Water Bank System | Hualien | Taiwan（China） | 2018 | Asia | 0 | 0 | 1 | 0 | 0 | 0 | 0 |
| Water quality programs result in port biodiversity | Long Beach | United States | 2023 | North America | 0 | 0 | 1 | 0 | 0 | 0 | 1 |
| Water Treatment and Reuse System | Itaguaí | Brazil | 2023 | South America | 0 | 0 | 1 | 0 | 0 | 1 | 0 |
| Wearable device program | Antwerp | Belgium | 2019 | Europe | 0 | 0 | 0 | 0 | 1 | 0 | 1 |

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| Welfare Committee | Vigo | Spain | 2022 | Europe | 1 | 0 | 0 | 0 | 1 | 0 | 0 |
| Wetland at Torsviken | Gothenburg | Sweden | 2020 | Europe | 0 | 0 | 1 | 0 | 0 | 1 | 1 |
| Your port opens up again | Barcelona | Spain | 2022 | Europe | 1 | 0 | 0 | 0 | 0 | 1 | 1 |
| Zero Emission Services | Rotterdam | The Netherlands | 2020 | Europe | 1 | 1 | 1 | 0 | 0 | 0 | 1 |
| Zero Emissions 2040 | Auckland | New Zealand | 2017 | Oceania | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| Zero Emissions Pathway Technology Demonstrations | Los Angeles | United States | 2019 | North America | 0 | 1 | 1 | 0 | 0 | 0 | 1 |