Journal of King Abdulaziz University: Marine Science

Volume 35 | Number 2 Article 4

12-31-2025

A Systematic Literature Review of Sustainable Ports Strategies and Initiatives in the Arabian Gulf Ports – Lessons for Saudi Arabia and UAE

Osayd Helal
Logistics and Operations Management, Cardi Business School, Cardi University, Aberconway Building, Colum Drive, Cardi CF10 3EU, UK, Helaloo1@cardiff.ac.uk

Jane Haider
Logistics and Operations Management, Cardiff Business School, Cardiff University, Aberconway Building, Colum Drive, Cardiff CF10 3EU, UK

Jean-Paul Skeete
Logistics and Operations Management, Cardiff Business School, Cardiff University, Aberconway Building, Colum Drive, Cardiff CF10 3EU, UK

Sehwa Lim
Logistics and Operations Management, Cardiff Business School, Cardiff University, Aberconway Building, Colum Drive, Cardiff CF10 3EU, UK

JOURNAL OF KING ABDULAZIZ UNIVERSITY: MARINE SCIENCES 2025;35:156–170

RESEARCH ARTICLE

A Systematic Literature Review of Sustainable Ports Strategies and Initiatives in the Arabian Gulf Ports – Lessons for Saudi Arabia and UAE

Osayd Helal *, Jane Haider, Jean-Paul Skeete, Sehwa Lim

Logistics and Operations Management, Cardiff Business School, Cardiff University, Aberconway Building, Colum Drive, Cardiff CF10 3EU, UK

ABSTRACT

This systematic review provides a comprehensive evaluation of sustainability strategies in Arabian Gulf ports, focusing on the interplay between technological advancements, green initiatives, and regulatory challenges. While Industry 4.0 technologies—such as automation, artificial intelligence, and electrification—have been integrated to enhance operational efficiency and reduce carbon emissions, the extent to which these innovations align with regional policy frameworks and geopolitical constraints remains insufficiently analysed.

To address this gap, this review synthesises insights from 25 peer-reviewed studies, employing a comparative framework to assess the adoption of sustainability practices in Arabian Gulf ports, focusing on their approaches toward sustainable port development. It is worth noting that while there are many studies on sustainable ports globally, the Gulf context yielded only 25 relevant articles. This highlights that sustainability in the Gulf port context remains underexplored despite the region's global importance in maritime logistics. Moreover, ports in this region are among the best-performing globally in achieving sustainability goals, as reflected in the World Bank's CCPI Index rankings.

The findings indicate that despite significant investments in digitalisation and renewable energy, the large-scale implementation of sustainable port initiatives continues to be hindered by regulatory fragmentation, governance inconsistencies, and geopolitical uncertainties.

This study underscores the urgent need for harmonised governance frameworks, cross-border policy coordination, and standardised sustainability metrics to accelerate the transition toward eco-friendly and resilient maritime logistics in the Gulf region. The review concludes with strategic recommendations for policymakers and port authorities in Saudi Arabia and the UAE—the countries of interest in this study—emphasising the importance of regional cooperation, technological integration, and adaptive regulatory policies to enhance both environmental sustainability and operational efficiency in Saudi and Emirati ports.

Keywords: Port sustainability, Digital ports, Intelligent ports, Green ports, Smart ports, Arabian gulf ports, Saudi Arabia, United Arab Emirates

1. Introduction

Maritime sustainability has received growing attention in recent years, particularly amid global efforts toward carbon neutrality and environmental efficiency. While existing studies have examined the roles of digital transformation, alternative energy, and regulatory frameworks in sustainable ports (Karagkouni & Boile, 2024), research specifically focused on Arabian Gulf ports remains limited.

This study addresses that gap by analysing the distinctive drivers and developments shaping sustainability practices across key Gulf ports. Through an assessment of policy alignment, technological

Received 15 April 2025; revised 10 October 2025; accepted 11 October 2025.
Available online 31 December 2025

* Corresponding author.
E-mail address: helaloo1@cardiff.ac.uk (O. Helal).

https://doi.org/10.64064/1658-4325.1014

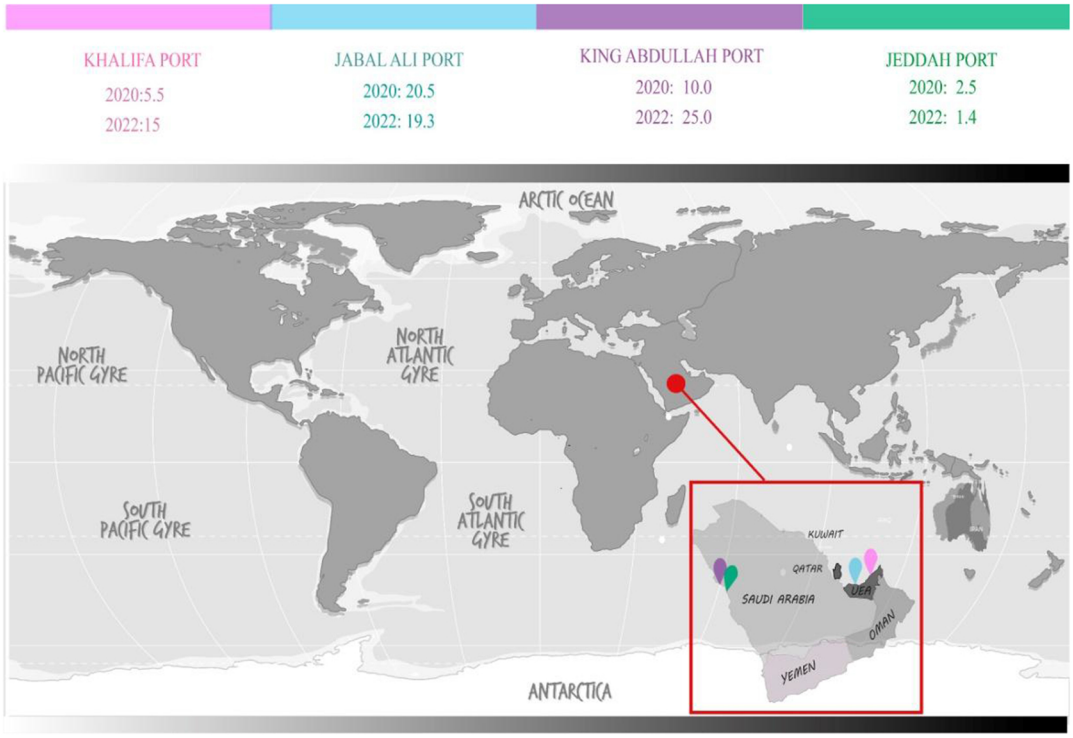

Fig. 1. Strategic seaports and their TEU capacities in Saudi Arabia and the UAE (CPPI 2022).

adoption, and investment strategies, it contributes region-specific insights that enhance both academic discourse and practical port management. These findings also inform sustainable port planning in countries such as Saudi Arabia and the UAE.

Within the Gulf, Saudi Arabia and the UAE are recognised leaders in port sustainability. According to the Container Port Performance Index (CPPI) by the World Bank and S&P Global, several ports from these nations rank among the world's most efficient (World Bank, 2022). Notable examples include Khalifa Port (UAE, 3rd), King Abdullah Port (Saudi Arabia, 17th), Jeddah Islamic Port (29th), and Jebel Ali Port (38th).

Despite these high rankings, sustainability remains an ongoing objective. There is a continuing need to enhance current efforts, especially given the critical role these ports play in global maritime logistics. As shown in Fig. 1, which illustrates key strategic seaports and their TEU capacities, the scale and performance of Saudi and UAE ports underline their importance in shaping global maritime sustainability.

According to the World Bank's 2023 Container Port Performance Index, Jebel Ali Port (UAE) and King Abdullah Port (Saudi Arabia) rank among the top-performing ports globally, with Jebel Ali consistently placed within the top 40 and King Abdullah within the top 20. In comparison, globally renowned ports such as Rotterdam and Singapore occupy similar high-performance categories, underscoring that Gulf ports now operate at comparable levels of efficiency and connectivity. This comparative positioning highlights the region's growing role not only in regional trade but also in shaping global benchmarks for sustainable port performance.

The strategic positioning of Arabian Gulf ports along major global maritime trade routes—linking Asia, Europe, and Africa—offers both opportunities and challenges for advancing sustainability. Their connectivity enhances trade efficiency but also imposes constraints due to the scale and pace of commercial activity.

The geopolitical landscape in the Gulf adds further complexity. Factors such as volatile oil markets, shifting trade alliances, and cross-border regulatory disparities continue to shape the trajectory of sustainability initiatives (Papathanasiou, 2023). While Saudi Arabia and the UAE compete for maritime leadership, sustainable progress depends on collaborative frameworks and joint investment in green infrastructure. Without harmonised governance, fragmented policies risk undermining sustainability goals and weakening regional integration—particularly in light of regional economic interdependence.

According to Lam and Notteboom (2014), the success of sustainable port strategies in the Gulf rests on aligning environmental policy with international trade regulations and broader geopolitical stability. The region's strong reliance on hydrocarbon exports

and its strategic role in global shipping place it in a complex position: balancing economic growth, sustainability commitments, and compliance with international standards.

Tackling these challenges requires enhanced cross-border collaboration, policy standardisation, and the establishment of cohesive regional governance mechanisms to support a unified transition toward sustainable port development.

2. Literature review

This section reviews the existing literature associated with the paper's focus, establishes its scientific foundation, and identifies the main theories that could address the paper's aim.

2.1. Seven key drivers in port sustainability

The literature outlines two main approaches to port sustainability: technology-driven innovations and green port initiatives. The former includes digitalisation, automation, and AI analytics aimed at boosting efficiency and cutting emissions (Mahmud et al., 2023), while the latter integrates renewable energy, pollution control, and eco-friendly infrastructure into port development (Costa et al., 2021).

Smart technologies such as AI-based predictive maintenance, IoT-enabled tracking, and blockchain documentation enhance operations and reduce emissions (Mahmud et al., 2023). These tools enable real-time monitoring and improve equipment reliability and data security. While ports like Singapore and Rotterdam have adopted these solutions, Gulf ports lag behind due to infrastructure and regulatory challenges (Bjerkan & Seter, 2019). Targeted digital investment is needed to bridge this gap.

The two strategies are increasingly interlinked, with green initiatives relying on smart technologies for emissions tracking, energy use, and compliance (Lam & Notteboom, 2014). Hamburg and Rotterdam exemplify this integration through AI-led energy and waste systems (Gore, 2022). As such, digitalisation and sustainability are often discussed together, highlighting the need for coordinated governance.

While European and East Asian ports lead in these areas, Gulf ports remain in early stages. Though pilot projects exist, a notable gap persists. Addressing this will require harmonised policies, financial support, and regional cooperation (Bjerkan & Seter, 2019). Meanwhile, ports like Singapore and Rotterdam continue to lead with advanced decarbonisation and automation strategies.

Digital transformation and automation are now central to sustainability. European ports such as Rotterdam and Hamburg have used AI and IoT systems to enhance efficiency and cut emissions (Mahmud et al., 2023). Gulf ports face slower adoption due to continued reliance on fossil fuels. Similarly, while solutions like onshore power and low-emission fuels are common in Scandinavia and East Asia (Costa et al., 2021), they are less developed in the Gulf, hindered by infrastructure and regulatory limitations.

Based on Mahmud et al. (2023), this study identifies seven key drivers linking technology and environmental practices: automation, eco-friendly technologies, pollution control, renewable energy, regulatory compliance, financial incentives, and environmental certifications. Table 1 provides an overview of these drivers and their real-world applications.

As shown in Table 1, automation, digitalisation, and renewable energy adoption appear to be the most actively implemented drivers within Gulf ports, particularly in the UAE where initiatives such as AI-enabled yard management and solar-powered terminals are already operational. However, other drivers—especially environmental certifications, financial incentives, and comprehensive pollution control frameworks—remain comparatively underdeveloped. For instance, while European ports like Rotterdam have advanced emission-based port dues and standardized environmental indices, similar mechanisms are still in early stages in the Arabian Gulf. This highlights the need for more coordinated policy interventions and capacity-building to balance technological advancement with environmental governance in the region.

2.2. The gap in existing literature

Despite extensive research on port sustainability (Lim et al., 2019; Taneja et al., 2021), a significant research gap remains regarding the influence of geopolitical and economic factors on port management and sustainability initiatives. While numerous studies have explored environmental policies, green technologies, and regulatory compliance in ports, limited research has examined how regional political and economic dynamics shape sustainability adoption and investment strategies (Acciaro et al., 2014; Lam & Notteboom, 2014).

This study addresses this gap by investigating sustainable port practices in the Arabian Gulf nations, which are considered regional leaders in port digitalisation and environmental innovation. A recent World Bank (2022) report identified several Arabian Gulf ports among the highest-ranked in sustainability performance. However, geopolitical stability, economic policies, and government-led initiatives continue to play a crucial role in shaping sustainability outcomes.

Table 1. The seven key drivers that integrate sustainable port management practices with technological advancements.

Driver	Category	Description	Noted Examples
Automation & Digitalisation	Technology	Uses IoT, AI, and automation to enhance operational efficiency, optimise cargo handling, and reduce human errors.	IoT-based container tracking and AI-driven port logistics improve operational efficiency and sustainability (Anwar et al., 2019).
Eco-friendly Technologies	Green Initiative	Minimises environmental impact by reducing CO_2 emissions, noise pollution, and energy consumption.	Alternative Marine Power (AMP), electric RTGs, LNG bunkering, and LED lighting significantly reduce emissions in ports (Clarke, 2006; Lawer et al., 2019).
Pollution Control Measures	Environmental Policy	Implements systems to monitor and reduce air, water, and noise pollution at ports.	Port Environmental Review System (PERS), waste and liquid management, and air quality monitoring help mitigate pollution (Adams et al., 2009; Lam & Notteboom, 2014).
Renewable Energy Adoption	Green Initiative	Integrates renewable energy sources such as solar, wind, and biofuels to reduce reliance on fossil fuels.	Solar-powered terminals and hybrid electric port vehicles contribute to sustainability goals (Chen & Pak, 2017; Zhu et al., 2018; Al-Aboosi et al., 2021).
Environmental Regulations	Policy & Regulation	Enforces rules to protect the maritime environment, ensuring compliance with sustainability laws.	Regulations on speed reduction, ballast water treatment, and fuel switching align with IMO standards (An et al., 2021; Pak et al., 2009).
Sustainability Incentives & Pricing	Economic Measure	Encourages sustainable practices through financial incentives or penalties.	Ports implement Environmental Shipping Index (ESI) and emission-based port dues to reward green initiatives (Lawer et al., 2019; Mahmud et al., 2023; Zis et al., 2014).
Compliance & Certifications	Regulation & Standards	Requires ports to adhere to international sustainability standards and best practices.	Ports obtain ISO 14001 (environmental management) and ISO 50001 (energy efficiency) certifications to meet global benchmarks (Badurina et al., 2017; Mahmud et al., 2023).

Notably, disparities persist in policy implementation, funding allocation, and environmental governance—highlighting the need for further research into the region-specific challenges that influence green port development (Villabruna et al., 2024).

2.3. Theoretical framework: Multi-level perspective (MLP) framework

To analyse the factors shaping sustainable port development in the Arabian Gulf, this study adopts the Multi-level Perspective (MLP) framework. Developed by Geels (2002), MLP provides a structured lens for understanding socio-technical transitions through interactions across three interconnected levels: landscape, regime, and niche. The framework is widely applied in sectors facing environmental, technological, and policy change, making it appropriate for exploring Gulf port sustainability.

At the landscape level, external pressures influence strategic port decisions. In the Gulf, these include international regulations (e.g., the IMO 2020 sulphur cap), geopolitical tensions, and global digitalisation trends. These dynamics create both constraints and incentives, supporting Research Questions 1–3, which address the drivers of sustainable port initiatives.

The regime level encompasses established policies, governance structures, and industry norms. Relevant examples include Saudi Vision 2030, the UAE Clean Energy Strategy 2050, and international standards such as ISO 14001 and ISO 9001. These elements inform RQ2, which examines the integration of policy and technology within Gulf port operations.

At the niche level, emerging innovations hold the potential to reshape existing systems. This study focuses on technologies such as cold ironing, AI-driven logistics, blockchain, and energy-efficient infrastructure. Analysing these innovations addresses RQ3, which explores both opportunities and barriers to technological adoption in port sustainability.

By applying MLP, the study synthesises insights from 25 academic sources covering ports across the Gulf. This structured approach identifies the most influential pressures, levels of sustainability commitment, and innovations gaining traction. Although the analysis spans multiple Gulf countries, the findings will inform targeted recommendations for ports in Saudi Arabia and the UAE.

3. Methodology

This section details the research design and procedural methodologies employed to systematically analyse the existing literature on sustainable ports in the SA and UAE.

3.1. Research design

This study adopts an interpretivist paradigm, acknowledging that knowledge is subjectively constructed (Schwandt, 2000). An inductive approach

was used to identify patterns within the collected data (Flynn, 2021). The research follows a mono-qualitative methodology, relying on non-numerical secondary data. This study used a systematic literature review approach where the existing studies matching the inclusion criteria were systematically reviewed focusing on sustainable ports in the Arabian Gulf ports. Thematic analysis (Brew-Sam, 2020) and descriptive quantitative analysis were later utilised to summarise study counts and methodological approaches, and informed the picked lessons learnt applicable to Saudi Arabia and UAE in their quest for improvements in sustainable ports development.

3.2. Procedural methodologies for systematic review

The systematic literature review used in this study follows the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) framework, which is a systematic literature review approach that ensures methodological rigor, transparency, objectivity, and replicability (Page et al., 2020; Page & Moher, 2017; O'dea et al., 2021). The PRISMA process consists of four key stages: (1) identification of relevant studies through database searches, (2) screening of retrieved papers, (3) assessment of eligibility based on predefined inclusion criteria, and (4) final inclusion of selected studies. These stages as adopted in this study are as visually summarised in Fig. 2 below.

Phase 1: Identification of Records Through Database Searching

Prominent databases recognised as authoritative repositories of scholarly information in the academic community of sustainable ports were used. These included Science Direct, Emerald Insight, SCOPUS, Sage Journals, IEEE Explore, EBSCOhost, Springer, ProQuest, and Taylor & Francis. These databases are a significant source for reputable journals, conference proceedings, and research papers, ensuring good coverage of the related literature. The keywords used for searching the subject matter from these databases were "digital ports," "green ports," "smart ports," and "sustainable ports," while the context keywords included "Gulf ports," "Middle East Ports," "Saudi Arabia ports," and "UAE Ports." These keywords were selected to ensure a focused search for information related to the research topic in both subject and context.

Phase 2: Screening Papers

Each study was initially assessed for relevance to the research questions by skimming its title, abstract, and full text to determine its alignment with the present study's focus.

Phase 3: Eligibility Assessment

This phase involved establishing criteria to evaluate the suitability of studies that passed the screening phase for inclusion in the analysis. These predetermined criteria (outlined in Table 2) were established based on the identified research gap to select only studies aligned with this study's scope and focus.

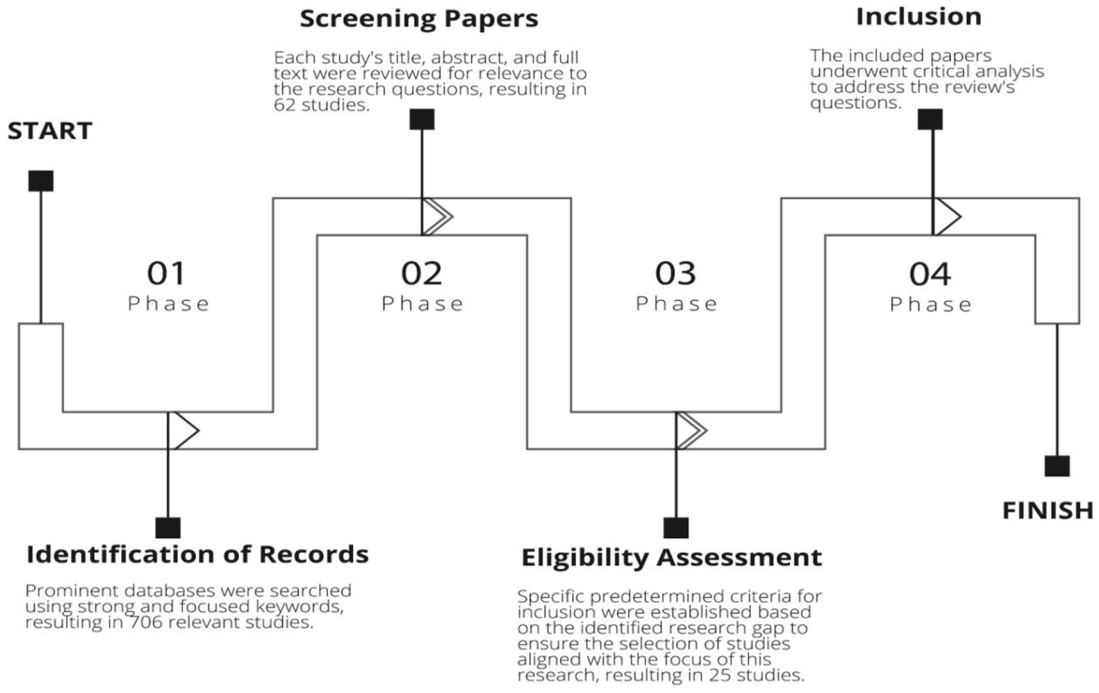

Fig. 2. The review's PRISMA flowchart. (Source: Authors.)

Table 2. The inclusion and exclusion criteria established for the review.

Inclusion Criteria	Exclusion Criteria
i) Studies on environmental sustainability in ports	Studies unrelated to port sustainability (e.g., focused solely on theoretical models)
ii) Research on technological advancements for sustainable port operations	Publications without empirical data or practical applications
iii) Case studies on sustainable port practices	Non-peer-reviewed documents
iv) English publications	Non-English publications

Table 3. Eligible research.

Screening Phase	Related Studies
Initially identified studies	706
Papers meeting all context and subject criteria	87
Excluded after the initial review	62
Included for full-text assessment	25

Adhering to these criteria ensured that only studies meeting the predefined conditions were included to enhance the analysis, reliability, and validity. Table 3 summarises the number of initially identified studies, the number excluded based on these criteria, and the final number of studies deemed eligible for full-text assessment.

Phase 4: Inclusion

In this phase, the included papers underwent a critical analysis to answer the review's questions. This analytical process facilitated extracting valuable insights into the current state of sustainable ports in the Gulf region and identifying gaps and research opportunities.

3.3. Research question formulation

To guide this systematic review, three key research questions were formulated based on identified gaps in the literature and the need for a structured analysis of sustainable port initiatives in the Arabian Gulf Ports as follows:

1. **RQ1:** What are the key drivers of sustainable ports development initiatives in the ports of the Arabian Gulf?
2. **RQ2:** Of the identified drivers, to what extent are technological and policy-driven sustainability initiatives implemented in major ports within these countries?
3. **RQ3:** Of the identified drivers, what opportunities and challenges do they present in the context of Saudi Arabia and UAE sustainable ports initiatives?

4. Findings

This section presents the key findings derived from the systematic literature review, offering an in-depth analysis of sustainable port initiatives in the Arabian Gulf. The findings are structured to first examine the attributes of the reviewed studies, including their methodologies and geographic distribution, before discussing the thematic insights that address the research questions

4.1. Attributes of existing studies on sustainable ports in the arabian gulf

A total of 25 peer-reviewed studies met the inclusion criteria for this systematic review, spanning the years 2009 to 2023. These studies focused primarily on green initiatives, port digitalisation, and regulatory frameworks supporting sustainable ports in the Arabian Gulf. The relatively limited number of studies highlights a notable research gap, given the increasing emphasis on sustainability in global port operations. This gap suggests that further empirical studies are needed to assess how regional sustainability efforts compare to global best practices. Several potential barriers to research development in this area were identified, including limited access to port data, restricted academic collaboration, and an industry focus on operational efficiency over environmental sustainability. These challenges emphasise the contribution of this study in broadening academic discourse on sustainable port management in Gulf nations.

In terms of research methodologies, the review found that quantitative analysis was the most frequently employed approach, comprising 48% of the reviewed studies. This trend suggests that much of the current understanding of port sustainability in the Gulf is shaped by measurable indicators such as emissions, efficiency, and energy use. However, the dominance of quantitative approaches may overlook contextual and behavioural dimensions—such as institutional collaboration, governance culture, and stakeholder perceptions—that are crucial for effective implementation. Incorporating more qualitative methods such as interviews and case studies would provide richer insights into the socio-institutional factors influencing sustainability practices in Gulf ports.

This was followed by qualitative case studies (20%), literature reviews (16%), systematic literature reviews (8%), and mixed-method approaches (8%). The dominance of quantitative research indicates that sustainability assessments in the region have

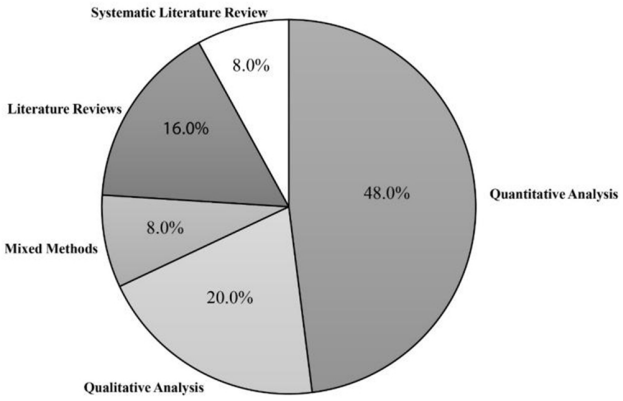

Fig. 3. Methodologies adopted in existing studies by percentage. (Source: Authors.)

largely relied on statistical and economic modelling to measure environmental impact, energy efficiency, and operational performance (Wu et al., 2009; Chen et al., 2019; Liu et al., 2022). However, fewer studies have employed qualitative or mixed-method approaches, which are crucial for capturing stakeholder perspectives, policy implications, and socio-economic barriers to sustainability adoption (Jawad & Ibrahim, 2017; Elnajjar et al., 2021). Fig. 3 illustrates the distribution of these methodologies, emphasising the need for more integrated research approaches that combine both empirical data analysis and qualitative insights.

4.2. Driving factors identified

The literature review identifies distinct sustainability drivers in Arabian Gulf ports, shaped by landscape-level pressures that reflect wider socio-economic and environmental trends. Tables 4 to 6 present the key drivers that emerge in the existing literature at the Landscape, Regime and Niche levels respectively.

One key driver is the implementation of IMO greenhouse gas regulations, which has prompted emission reduction strategies across ports such as Jebel Ali (UAE), Sohar (Oman), and Dammam (Saudi Arabia). These regulations have encouraged cleaner fuel use, improved vessel management, and enhanced environmental monitoring (Gore, 2022; Elnajjar et al., 2021; Balić et al., 2022). In Saudi Arabia, Anser et al. (2020) highlight the challenge of balancing economic growth with environmental degradation, revealing the tension between resource use and sustainability.

Supply chain digitisation also plays a significant role. Ports like Khalifa (UAE) and Sohar (Oman) have adopted digital platforms such as Manara and Silsal, improving logistics transparency and trade efficiency (Rashid et al., 2020; Liu et al., 2022).

Climate change adaptation is emerging as another priority, with Fujairah (UAE) and Hamad Port (Qatar) investing in eco-friendly infrastructure to mitigate weather-related risks (Mustafa et al., 2021). Carbon emissions control, based on carbon-pricing strategies, is also being considered (Anser et al., 2020).

The integration of renewable energy is evident in ports like Jebel Ali and King Abdulaziz, where solar and hybrid systems are reducing reliance on traditional energy sources (Chen et al., 2019). Additionally, wastewater recycling at Sohar and Jubail reflects broader efforts to reduce water use and improve sustainability (Zhao et al., 2021).

Finally, green building standards have been implemented at Khalifa and Jeddah Islamic Port, supporting energy efficiency and emission reduction in port infrastructure (Mustafa et al., 2021). Collectively, these landscape-level factors illustrate how regional ports are responding to rising regulatory expectations and environmental imperatives.

Regime-level drivers exert considerable influence on Arabian Gulf ports through established policies,

Table 4. Landscape-level drivers.

Driver	Ports Implemented	Reference from Analysed Papers
IMO Green-house Gases Regulations – (Carbon monoxide, Carbon dioxide, Hydrocarbons (HCs), Nitrogen Oxide, and Sulphur Oxides)	Jebel Ali Port (UAE), Sohar Port (Oman), Dammam Port (Saudi Arabia)	Gore (2022); Elnajjar et al. (2021); Ghenai et al. (2019)
Supply Chain Digitisation	Jebel Ali Port (UAE), Sohar Port (Oman), Khalifa Port (UAE)	Rashid et al. (2020); Liu et al. (2022); Anser et al. (2020)
Climate Change Adaptation	Port of Fujairah (UAE), Hamad Port (Qatar)	Mustafa et al. (2021); Anser et al. (2020); Balić et al. (2022)
Renewable Energy Integration	Jebel Ali Port (UAE), King Abdulaziz Port (Saudi Arabia)	Chen et al. (2019)
Wastewater Recycling	Port of Sohar (Oman), Jubail Port (Saudi Arabia)	Zhao et al. (2021)
Green Building Standards	Khalifa Port (UAE), Jeddah Islamic Port (Saudi Arabia)	Mustafa et al. (2021); Balić et al. (2022)

Table 5. Regime-level drivers.

Driver	Ports Implemented	Reference from Analysed Papers
Cold Ironing (Shore Power)	Jebel Ali Port (UAE), King Abdullah Port (Saudi Arabia), Port of Sohar (Oman)	Gore (2022); Elnajjar et al. (2021);
ISO 14001 Certification	Sohar Port (Oman), Jeddah Islamic Port (Saudi Arabia)	Chen et al. (2019); Shadi et al. (2018)
ISO 9001 Certification	Hamad Port (Qatar), King Abdulaziz Port (Saudi Arabia)	Mustafa et al. (2021)
OHSAS 18001 Certification	Sohar Port (Oman), Jubail Port (Saudi Arabia)	Alzahrani et al. (2021)
AI-Driven Logistics	Port Sohar (Oman), Jebel Ali Port (UAE) – Smart yard management systems	Rashid et al. (2020)
Smart Port Infrastructure and efficiency measurement modelling	Khalifa Port (UAE), Dammam Port (Saudi Arabia)	Liu et al. (2022); Gholizadeh et al. (2020); Wu et al. (2009); XU et al. (2021); Alves and Meza (2023); Miller and Hyodo (2022)

Table 6. Niche-level drivers.

Driver	Ports Implemented	Reference from Analysed Papers
Marine Life and Marine Ecosystem Protection	Port of Jeddah (Saudi Arabia), Sohar Port (Oman), Lengeh Port (Iran)	Jawad and Ibrahim (2017); Haidari et al. (2013)
Air Quality Monitoring Systems Noise Pollution Control	Port of Fujairah (UAE), Sohar Port (Oman), King Abdulaziz Port (Saudi Arabia)	Zhao et al. (2021); Bjerkan and Seter (2019); De La Peña Zarzuelo et al. (2020)
Waste Management Systems	Port Zayed (UAE), Jeddah Port (Saudi Arabia)	Mustafa et al. (2021)
Green energy, Solar and LED Initiatives	Khalifa Port (UAE), Jebel Ali Port (UAE), Sohar Port (Oman)	Chen et al. (2019); Khalid and Al-Mamery (2019); Szaruga et al. (2021)
Blockchain for Logistics	Sohar Port (Oman), Khalifa Port (UAE)	Liu et al. (2022)
Use of Biometrics	Passenger ports in Kuwait	Al-Alawi et al. (2016)
Simulation Technologies	Hamad Port (Qatar), Sohar Port (Oman)	Gore (2022)
Electronic Vehicles (EVs)	Jebel Ali Port (UAE), King Abdulaziz Port (Saudi Arabia)	Mustafa et al. (2021)

certifications, and national sustainability frameworks. One example is the adoption of cold ironing (shore power) at Jebel Ali (UAE), King Abdullah (Saudi Arabia), and Sohar (Oman), where vessels connect to onshore electrical power to reduce emissions while docked (Gore, 2022; Elnajjar et al., 2021).

Environmental and quality certifications play a major role in formalising sustainability efforts. ISO 14001 has been adopted in Sohar and Jeddah Islamic Port, reflecting a commitment to environmental standards and supported by Shadi et al. (2018), who report measurable improvements in safety, productivity, and environmental protection (Chen et al., 2019). ISO 9001, which promotes quality management systems, is in use at Hamad Port (Qatar) and King Abdulaziz Port (Saudi Arabia) (Mustafa et al., 2021), while OHSAS 18001 for occupational safety has been implemented in Sohar and Jubail (Alzahrani et al., 2021).

Technological innovation also characterises regime-level change. AI-driven logistics and smart yard systems are increasingly adopted in Sohar and Jebel Ali (Rashid et al., 2020), while Khalifa (UAE) and Dammam (Saudi Arabia) have introduced data-driven monitoring and resource optimisation platforms (Liu et al., 2022). Regionally, Gwadar Port (China) and Chabahar Port (Iran) have also pursued joint sustainability projects under the Belt and Road Initiative (BRI) (Gholizadeh et al., 2020).

From an analytical perspective, scholars have advanced performance measurement tools for sustainable port operations. Wu et al. (2009) and Alves and Meza (2023) highlight the role of Data Envelopment Analysis (DEA), while XU et al. (2021) use regression modelling with panel data to assess seaport efficiency. These approaches focus on operational indicators such as berth length and Ship-to-Shore (STS) gantry cranes, which correlate closely with port performance (Miller & Hyodo, 2022). Together, these regime-level initiatives reflect a growing regional commitment to compliance, safety, and technology-led sustainability.

Niche-level innovations are increasingly contributing to sustainable port development in the Arabian Gulf, though adoption levels vary. Marine life and ecosystem protection have gained attention in ports such as Jeddah (Saudi Arabia) and Sohar (Oman), where biodiversity monitoring initiatives are in place (Jawad & Ibrahim, 2017). At Lengeh Port in Iran, biomonitoring using oysters has been employed to assess nickel and vanadium contamination (Haidari et al., 2013).

Air quality monitoring systems designed to track and mitigate airborne pollutants have been adopted at the Port of Fujairah (UAE), Sohar (Oman), and King Abdulaziz Port (Saudi Arabia) (Zhao et al., 2021; De La Peña Zarzuelo et al., 2020). Bjerkan and Seter (2019) offer a broader evaluation of sustainable port tools, highlighting the integration of low-emission technologies such as yard equipment electrification in concession criteria.

Circular waste management strategies are in use at Port Zayed (UAE) and Jeddah Port (Saudi Arabia), supporting enhanced recycling and landfill reduction (Mustafa et al., 2021). Similarly, solar and LED energy solutions have been introduced at Khalifa (UAE), Jebel Ali (UAE), and Sohar (Oman), contributing to lower carbon emissions (Chen et al., 2019). The strategic location of Sohar Port outside the Strait of Hormuz has also been identified as a factor in its success (Khalid & Al-Mamery, 2019), with further evidence linking energy delivery and economic growth from a port sustainability perspective (Szaruga et al., 2021).

Innovative technologies such as blockchain are being used in Sohar (Oman) and Khalifa Port (UAE) to improve trade transparency (Liu et al., 2022). In parallel, biometric systems have been implemented at Kuwait's passage ports to enhance security checks (Al-Alawi et al., 2016). Simulation technologies for vessel scheduling have also been deployed at Hamad (Qatar) and Sohar (Oman) to reduce congestion (Gore, 2022). Additionally, electronic vehicles (EVs) are being introduced in Jebel Ali (UAE) and King Abdulaziz Port (Saudi Arabia) to reduce logistics-related emissions (Mustafa et al., 2021).

While these niche innovations reflect growing momentum toward sustainability, many remain in the pilot stage and require continued investment and scaling.

4.3. Comparative analysis of drivers' impact

Among the key sustainability drivers, IMO greenhouse gas regulations, supply chain digitisation, and renewable energy integration stand out for their broad implementation across major Arabian Gulf ports such as Jebel Ali, Sohar, and King Abdulaziz (Gore, 2022; Rashid et al., 2020; Chen et al., 2019; Ghenai et al., 2019). Their impact is largely due to alignment with international regulations and trade efficiency goals.

ISO certifications and AI-based logistics have also seen strong uptake, particularly in Jeddah, Sohar, and Dammam, improving environmental, operational, and safety standards (Mustafa et al., 2021; Alzahrani et al., 2021; Liu et al., 2022). By contrast, cold ironing, blockchain, and marine ecosystem initiatives remain limited in application, pointing to early-stage adoption and a need for greater infrastructure and policy support (Gore, 2022; Jawad & Ibrahim, 2017).

While niche innovations offer long-term potential, landscape-level drivers—especially IMO regulations and digitisation—currently exert the most immediate influence across the region.

5. Discussion of findings

The findings of this systematic literature review provide critical insights into the state of sustainability in Arabian Gulf ports, addressing key drivers, technological advancements, and policy initiatives while evaluating their implementation across the region. The following discussion synthesizes the study's key themes by aligning them with the research questions, providing a deeper analysis of challenges, opportunities, and policy implications.

5.1. What are the unique key drivers of sustainable ports development initiatives in the ports of the Arabian Gulf?

The analysis reveals that sustainable port development in the Arabian Gulf is driven by a combination of landscape, regime, and niche-level factors. Key landscape-level pressures such as the IMO 2020 sulfur regulations and supply chain digitalisation have exerted a strong influence across regional ports, prompting ports like Jebel Ali (UAE), Sohar (Oman), and Dammam (Saudi Arabia) to implement stricter environmental controls and adopt digital systems to improve trade efficiency (Gore, 2022; Rashid et al., 2020). Economic pressures have similarly driven ports to modernise operations, seen in the increased adoption of renewable energy solutions at King Abdulaziz Port (Saudi Arabia) and Jebel Ali Port (UAE) (Chen et al., 2019). Ports in countries like Oman and Qatar have also responded to geopolitical risks and climate-related vulnerabilities by investing in eco-friendly infrastructure and wastewater recycling systems (Mustafa et al., 2021; Zhao et al., 2021).

At the regime level, international certifications such as ISO 14001 and ISO 9001, along with national strategies like Saudi Vision 2030 and the UAE Clean Energy Strategy 2050, have helped formalise sustainability efforts in ports such as Sohar, Jeddah, and Khalifa. These institutional drivers promote environmental compliance while enhancing operational efficiency and workplace safety (Chen et al., 2019; Alzahrani et al., 2021).

Collectively, these drivers demonstrate that Arabian Gulf ports are increasingly integrating sustainability strategies, blending regulatory compliance, environmental considerations, and technological advancements. However, their implementation varies across countries, with some ports advancing faster due to stronger financial backing and government incentives.

5.2. To what extent are technological and policy-driven sustainability initiatives implemented in major ports within these countries?

Technological and policy-driven initiatives have been integrated to varying degrees across Arabian Gulf ports, with notable progress in some areas and emerging gaps in others. Cold ironing has seen partial adoption, with ports such as Jebel Ali (UAE), King Abdullah (Saudi Arabia), and Sohar (Oman) integrating onshore power supply systems to reduce ship emissions (Gore, 2022; Elnajjar et al., 2021). However, the implementation of cold ironing across the region remains limited due to high capital investment requirements, the need for compatible grid infrastructure, and the absence of unified regional technical standards. In many cases, the cost of retrofitting existing berths and vessels for onshore power supply outweighs short-term environmental benefits, discouraging rapid adoption. Addressing these constraints will require joint funding mechanisms and harmonised technical guidelines across Gulf states to achieve wider scalability. However, scalability remains a challenge, with high infrastructure costs slowing adoption in several ports.

Technological advancements like AI-driven logistics have gained momentum in key trade hubs, particularly at Sohar Port (Oman) and Jebel Ali Port (UAE), where smart yard management systems enhance container handling efficiency (Rashid et al., 2020). Similarly, blockchain technology has been integrated at Port of Fujairah (UAE) and Sohar Port (Oman) to improve trade transparency and supply chain security (Liu et al., 2022).

Policy-driven initiatives have played a significant role in guiding sustainability adoption. Ports such as Sohar, Jeddah, and Dammam have adopted ISO 14001, strengthening their environmental management practices, while ISO 9001 and OHSAS 18001 certifications have supported operational quality and worker safety (Chen et al., 2019; Mustafa et al., 2021; Alzahrani et al., 2021). Saudi Arabia's Vision 2030 and the UAE Clean Energy Strategy 2050 have further accelerated investments in renewable energy, digitalisation, and smart infrastructure at ports like Khalifa, Jebel Ali, and King Abdulaziz (Elnajjar et al., 2021; Gore, 2022).

Despite these advancements, gaps in standardisation remain evident. Gulf ports often face delays in fully integrating sustainability frameworks, particularly in niche innovations like EV deployment and simulation technologies. Achieving full-scale adoption will require improved regional coordination, enhanced investment strategies, and infrastructure development as noted in the case polish study by Pacana and Ulewicz (2020) on making ISO 9001 more effective.

5.3. What opportunities and challenges do these drivers present in the context of Saudi Arabia and UAE sustainable ports initiatives?

The identified drivers present both promising opportunities and critical challenges for Saudi Arabian and UAE ports. On the opportunity side, ports that have invested in AI-driven logistics, renewable energy, and waste management systems have demonstrated notable improvements in operational efficiency and environmental performance (Rashid et al., 2020; Zhao et al., 2021). For example, Jebel Ali Port's digitisation efforts have improved trade monitoring, while Khalifa Port's solar and LED initiatives have significantly reduced energy consumption (Chen et al., 2019). Saudi ports such as King Abdulaziz and Jeddah are gradually leveraging similar solutions, particularly in renewable energy integration and environmental monitoring.

However, several challenges persist. Financial constraints pose a major barrier, particularly for the adoption of capital-intensive technologies like cold ironing and smart port infrastructure (Gore, 2022; Elnajjar et al., 2021). Additionally, regulatory inconsistencies across Gulf nations have created fragmented sustainability strategies, limiting cross-border coordination. Ports such as Dammam and Sohar have faced challenges in aligning with international environmental frameworks, slowing progress in adopting green initiatives (Saeed et al., 2021). Furthermore, while ports like Port Zayed and Jeddah have introduced circular waste management strategies, their scalability remains limited, partly due to insufficient regional incentives (Mustafa et al., 2021).

Addressing these challenges requires strengthening governance frameworks, promoting regional cooperation, and expanding financial incentives for ports transitioning towards sustainability. By combining policy reforms with greater investment in infrastructure modernisation, Saudi Arabia and the UAE can enhance their leadership in sustainable port practices.

6. Conclusion

This study examined the key drivers, technological advancements, and policy initiatives shaping sustainable port development in Arabian Gulf ports, with a focus on informing Saudi Arabian and UAE sustainability strategies. The findings demonstrate that landscape-level drivers such as IMO greenhouse gas regulations, supply chain digitisation, and renewable energy adoption exert the strongest influence across major Gulf ports. These drivers are closely linked to global trade and environmental trends, reflecting the growing need for regulatory compliance and improved operational efficiency. Regime-level drivers like ISO certifications and national strategies such as Vision 2030 and the UAE Clean Energy Strategy 2050 have successfully guided environmental and operational improvements in ports like Jebel Ali, Sohar, and Dammam. Meanwhile, niche-level innovations such as blockchain, EV deployment, and AI-driven logistics remain underutilised in most Gulf ports, despite their potential to enhance sustainability.

Despite valuable insights, this study faced notable limitations. The analysis relied on only 25 peer-reviewed studies, reflecting a limited body of research on sustainable port development specific to the Arabian Gulf region. The emerging nature of sustainability diversification strategies in Gulf ports has resulted in a knowledge gap, limiting comprehensive insights into newly evolving practices such as carbon credit schemes, circular waste management systems, and energy diversification models in this region. Future studies with broader coverage may uncover additional regional practices and offer deeper insights into the success factors of Gulf ports' sustainability efforts. As sustainability initiatives across Gulf ports continue to expand, future systematic reviews will have access to a broader and more diverse pool of empirical evidence. This will allow researchers to conduct deeper comparative analyses and identify emerging trends that further clarify the evolving trajectory of sustainable port development in the region.

To build on these findings, future research should explore the long-term impact of digitalisation strategies in Gulf ports, particularly the scalability of emerging innovations like blockchain logistics and AI-driven predictive analytics. Additionally, studies examining the role of public-private partnerships (PPPs) in financing large-scale sustainability projects will offer practical insights for policymakers. Further exploration of how climate adaptation strategies, such as flood control and renewable energy grids, can be customised for Gulf ports is recommended (Alghanmi et al., 2024). Finally, enhanced cross-border cooperation frameworks could accelerate sustainability adoption in Saudi Arabia and UAE, aligning their initiatives with global best practices (Lam & Notteboom, 2014; Gore, 2022). Strengthening such partnerships will be crucial for advancing port sustainability in this economically vital region.

Conflict of interest

The authors have no relevant financial or non-financial interests to disclose.

AI usage statement

Artificial Intelligence tools were used only for proofreading and correcting grammatical errors. All ideas, analysis, arguments, and overall content remain my own original work.

Data availability

The authors confirm that the data supporting the findings of this study are available within the article and/or its supplementary materials.

References

Acciaro, M., Ghiara, H., & Cusano, M. I. (2014) Energy management in seaports: A new role for port authorities. *Energy Policy*, 71, 4–12.

Adams, M., Quinonez, P., Pallis, A. A., & Wakeman, T. (2009) Environmental issues in port competitiveness. *Atlantic Research Report, Gateway Research Initiative Working Paper*, 7.

Al-Aboosi, F. Y., El-Halwagi, M. M., Moore, M., & Nielsen, R. B. (2021) Renewable ammonia as an alternative fuel for the shipping industry. *Current Opinion in Chemical Engineering*, 31, 100670.

Alghanmi, A. F., Aljahdali, B. M., Sulaimani, H. T., Turan, O., & Alshareef, M. H. (2024) An innovative deep-learning technique for fuel demand estimation in maritime transportation: a step toward sustainable development and environmental impact mitigation. *Water*, 16(22), 3325.

Alzahrani, A., Petri, I., Rezgui, Y., & Ghoroghi, A. (2021) Decarbonisation of seaports: A review and directions for future research. *Energy Strategy Reviews*, 38, 100727.

An, J., Lee, K., & Park, H. (2021) Effects of a vessel speed reduction program on air quality in port areas: Focusing on the big three ports in South Korea. *Journal of Marine Science and Engineering*, 9(4), 407.

Anser, M. K., Yousaf, Z., Nassani, A. A., Abro, M. M. Q., & Zaman, K. (2020) The role of carbon pricing in the relationship between air freight and environmental resource depletion: a case study of Saudi Arabia. *Clean Technologies and Environmental Policy*, 1–12.

Anwar, M., Henesey, L., & Casalicchio, E. (2019) Digitalization in container terminal logistics: A literature review. *27th annual conference of international association of maritime economists, Athens*, 1–25.

Badurina, P., Cukrov, M., & DundoviĆ, Č. (2017) Contribution to the implementation of “Green Port” concept in Croatian seaports. *Pomorstvo*, 31, 10–17.

Balić, K., Žgaljić, D., Ukić Boljat, H., & SliškoviĆ, M. (2022) The port system in addressing sustainability issues—a systematic review of research. *Journal of marine science and engineering*, 10, 1048.

World Bank, (2022) *Middle East Container Ports Are the Most Efficient in the World* [Online]. Available: https://www.worldbank.org/en/news/press-release/2022/05/25/middle-east-container-ports-are-the-most-efficient-in-the-world#:~:text=WASHINGTON%2C%20May%2025%2C%202022%20%E2%80%94,and%20S%26P%20Global%20Market%20Intelligence. [Accessed 12 February 2023].

Bjerkan, K. Y., & Seter, H. (2019) Reviewing tools and technologies for sustainable ports: Does research enable decision making in ports? *Transportation Research Part D: Transport and Environment*, 72, 243–260.

Brew-Sam, N. (2020) *App use and patient empowerment in diabetes self-management: Advancing theory-guided mHealth research*, Springer.

Chen, J., Huang, T., Xie, X., Lee, P. T.-W., & Hua, C. (2019) Constructing governance framework of a green and smart port. *Journal of Marine Science and Engineering*, 7, 83.

Chen, Z., & Pak, M. (2017) A Delphi analysis on green performance evaluation indices for ports in China. *Maritime Policy & Management*, 44, 537–550.

Clarke, R. (2006) *An automated terminal is a green terminal*. American Association of Port Authorities.

Costa, J. P., Lacalle, I., Llorente, M. A., Le Brun, O., Ptsikas, L., De Marco, G., Garnier, C., Simon, E., Gherghina, A., & Tsolakis, O. (2021) Advantage of a green and smart port of the future. *WIT Transactions on The Built Environment*, 204, 203–217.

De La Peña Zarzuelo, I., Soeane, M. J. F., & Bermúdez, B. L. (2020) Industry 4.0 in the port and maritime industry: A literature review. *Journal of Industrial Information Integration*, 20, 100173.

Elnajjar, H. M., Shehata, A. S., Elbatran, A. A., & Shehadeh, M. (2021) Experimental and techno-economic feasibility analysis of renewable energy technologies for Jabel Ali Port in UAE. *Energy Reports*, 7, 116–136.

Flynn, S. V. (2021) *Research design for the behavioral sciences: An applied approach*, Springer Publishing Company.

Geels, F. W. (2002) Technological transitions as evolutionary reconfiguration processes: a multi-level perspective and a case-study. *Research Policy*, 31(8–9), 1257–1274.

Ghenai, C., Bettayeb, M., Brdjanin, B., & Hamid, A. K. (2019) Hybrid solar PV/PEM fuel cell/diesel generator power system for cruise ship: A case study in Stockholm, Sweden. *Case Studies in Thermal Engineering*, 14, 100497.

Gholizadeh, A., Madani, S., & Saneinia, S. (2020) A geoeconomic and geopolitical review of Gwadar Port on belt and road initiative. *Maritime Business Review*, 5, 335–349.

Gore, A. (2022) Towards sustainable port management: Comparative evidence from Italy, UAE and India. *International Journal of technology management & sustainable development*, 21, 331–351.

Haidari, B., Bakhtiari, A. R., Yavari, V., Kazemi, A., & Shirneshan, G. (2013) Biomonitoring of Ni and V contamination using oysters (Saccostrea cucullata) at Lengeh Port, Persian Gulf, Iran. *CLEAN–Soil, Air, Water*, 41, 166–173.

Jawad, L. A., & Ibrahim, M. (2017) On some cases of fish anomalies in fishes from the Port of Jubail, Saudi Arabia, Arabian Gulf. *International Journal of Marine Science*, 7.

Khalid, A., & Al-Mamery, M. (2019) Competitiveness of Arabian gulf ports from shipping lines’ perspectives: Case of Sohar port in Oman. *Journal of Industrial Engineering and Management (JIEM)*, 12, 458–471.

Lam, J. S. L., & Notteboom, T. (2014) The greening of ports: a comparison of port management tools used by leading ports in Asia and Europe. *Transport Reviews*, 34, 169–189.

Lawer, E. T., Herbeck, J., & Flitner, M. (2019) Selective adoption: How port authorities in Europe and West Africa Engage with the globalizing ‘Green Port’idea. *Sustainability*, 11, 5119.

Lim, s., Pettit, S., Abouarghoub, W., & Beresford, A. (2019). Port sustainability and performance: A systematic literature review. *Transportation Research Part D: Transport and Environment*, 72, 47–64.

Liu, G., Chang, D., & Wen, F. (2022) Research on the Beibu Gulf Port Container Terminal Operation System Construction Performance Evaluation Based on the AISM-ANP. *Journal of Marine Science and Engineering*, 10, 1574.

Mahmud, K. K., Chowdhury, M. M. H., & Shaheen, M. M. A. (2023) Green port management practices for sustainable port operations: a multi method study of Asian ports. *Maritime Policy & Management*, 1–36.

Miller, K., & Hyodo, T. (2022) Assessment of port efficiency within Latin America. *Journal of Shipping and Trade*, 7, 1–27.

Mustafa, F. S., Khan, R. U., & Mustafa, T. (2021) Technical efficiency comparison of container ports in Asian and Middle East region using DEA. *The Asian Journal of Shipping and Logistics*, 37, 12–19.

O’dea, R. E., Lagisz, M., Jennions, M. D., Koricheva, J., Noble, D. W., Parker, T. H., Gurevitch, J., Page, M. J., Stewart, G., & Moher, D.. (2021) Preferred reporting items for systematic reviews and meta-analyses in ecology and evolutionary biology: a PRISMA extension. *Biological Reviews*, 96, 1695–1722.

Pacana, A., & Ulewicz, R. (2020). Analysis of causes and effects of implementation of the quality management system compliant with ISO 9001. *Polish Journal of Management Studies*, 21, 283–296.

Page, M. J., Mckenzie, J. E., Bossuyt, P. M., Boutron, I., Hoffmann, T., Mulrow, C. D., Shamseer, L., & Moher, D. (2020) Mapping of reporting guidance for systematic reviews and meta-analyses generated a comprehensive item bank for future reporting guidelines. *Journal of clinical epidemiology*, 118, 60–68.

Page, M. J., & Moher, D. (2017) Evaluations of the uptake and impact of the Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) Statement and extensions: a scoping review. *Systematic reviews*, 6, 1–14.

Pak, J. - Y., Yeo, G. - T., & Coo, B. - M. (2009) A study on selecting green indexes of a seaport. *Journal of Navigation and Port Research*, 33, 653–657.

Papathanasiou, T. (2023) Geopolitics, climate change, and energy in the Wider Middle East (Master’s thesis, Πανεπιστήμιο Πειραιώς).

Rashid, M. M. U., Granelli, F., Hossain, M. A., Alam, M. S., Al-Ismail, F. S., Karmaker, A. K., & Rahaman, M. M. (2020) Development of home energy management scheme for a smart grid community. *Energies*, 13, 4288.

Saeed, N., Cullinane, K., Gekara, V., & Chhetri, P. (2021) Reconfiguring maritime networks due to the Belt and Road Initiative: impact on bilateral trade flows. *Maritime Economics & Logistics*, 23, 381–400.

Schwandt, T. A. (2000) Three epistemological stances for qualitative inquiry: Interpretivism, hermeneutics, and social constructionism. *Handbook of qualitative research*. Sage Publishing.

Shadi, A., Hong-Oanh, N., & Shu-Ling, C. P. (2018) Critical factors in organisational effectiveness: The case of Saudi Arabian seaports. *Journal of Sustainable Development of Transport and Logistics*, 3, 49–65.

Szaruga, E., Kłos-Adamkiewicz, Z., Gozdek, A., & Załoga, E.. (2021) Linkages between energy delivery and economic growth from the point of view of sustainable development and seaports. *Energies*, 14, 4255.

Taneja, P., Van Rhede Van Der Kloot, G., & Van Koningsveld, M. (2021) Sustainability performance of port infrastructure—a case study of a quay wall. *Sustainability*, 13, 11932.

Wu, J., Yan, H., & Liu, J. (2009) Groups in DEA based cross-evaluation: An application to Asian container ports. *Maritime Policy & Management*, 36, 545–558.

Xu, L., Shi, J., Chen, J., & Li, L. (2021) Estimating the effect of COVID-19 epidemic on shipping trade: An empirical analysis using panel data. *Marine Policy*, 133, 104768.

Zhao, C., Li, R., Wang, Y., Yu, H., & Gong, Y. (2021) Study on the propagation of sustainable development concept among Gulf ports based on complex network. *Maritime Policy & Management*, 48, 478–496.

Zhu, L., Qin, C., & Peng, C. (2018) Analysis on energy saving and emission reduction of clean energy technology in ports. *IOP Conference Series: Earth and Environmental Science*, IOP Publishing, 052060.

Zis, T., North, R. J., Angeloudis, P., Ochieng, W. Y., & Harrison Bell, M. G. (2014) Evaluation of cold ironing and speed reduction policies to reduce ship emissions near and at ports. *Maritime Economics & Logistics*, 16, 371–398.

Karagkouni, K., & Boile, M. (2024) Classification of green practices implemented in ports: The application of green technologies, tools, and strategies. *Journal of Marine Science and Engineering*, 12(4), 571.

Al-Alawi, A.I., Al-Faresi, R.K.E. & Abdel-Razek, R.H. (2016) Evaluating the effectiveness of biometric technologies in controlling the border ports of the state of Kuwait. In Proceedings of the 25th International Business Information Management Association Conference-Innovation Vision 2020: From Regional Development Sustainability to Global Economic Growth, IBIMA 2015 (pp. 1335–1352).

Alves, C. G. M. D. F., & Meza, L. A. (2023) A review of network DEA models based on slacks-based measure: Evolution of literature, applications, and further research direction. *International Transactions in Operational Research*.

Villabruna, V. E., Hluszko, C., Rossi, D., Barros, M. V., Lam, J. S. L., & Lermen, F. H. (2024). Barriers and strategies for green investments in environmental, social and governance: a seaport companies' study. *Management of Environmental Quality: An International Journal*, 35(6), 1193–1212.

Appendix A: Reviewed Papers

DE LA PEÑA ZARZUELO, I., SOEANE, M. J. F. & BERMÚDEZ, B. L. 2020. Industry 4.0 in the port and maritime industry: A literature review. *Journal of Industrial Information Integration,* 20, 100173.

RASHID, M. M. U., GRANELLI, F., HOSSAIN, M. A., ALAM, M. S., AL-ISMAIL, F. S., KARMAKER, A. K. & RAHAMAN, M. M. 2020. Development of home energy management scheme for a smart grid community. *Energies,* 13, 4288.

SZARUGA, E., KŁOS-ADAMKIEWICZ, Z., GOZDEK, A. & ZAŁOGA, E. 2021. Linkages between energy delivery and economic growth from the point of view of sustainable development and seaports. *Energies,* 14, 4255.

Miller K, Hyodo T. Assessment of port efficiency within Latin America. Journal of Shipping and Trade. 2022;7:1-27.

GORE, A. 2022. Towards sustainable port management: Comparative evidence from Italy, UAE and India. *International Journal of technology management & sustainable development,* 21, 331–351.

ELNAJJAR, H. M., SHEHATA, A. S., ELBATRAN, A. A. & SHEHADEH, M. 2021. Experimental and techno-economic feasibility analysis of renewable energy technologies for Jabel Ali Port in UAE. *Energy Reports,* 7, 116–136.

ALZAHRANI, A., PETRI, I., REZGUI, Y. & GHOROGHI, A. 2021. Decarbonisation of seaports: A review and directions for future research. *Energy Strategy Reviews,* 38, 100727.

ZHAO, C., LI, R., WANG, Y., YU, H. & GONG, Y. 2021. Study on the propagation of sustainable development concept among Gulf ports based on complex network. *Maritime Policy & Management,* 48, 478–496.

BJERKAN, K. Y. & SETER, H. 2019. Reviewing tools and technologies for sustainable ports: Does research enable decision making in ports? *Transportation Research Part D: Transport and Environment,* 72, 243–260.

LIU, G., CHANG, D. & WEN, F. 2022. Research on the Beibu Gulf Port Container Terminal Operation System Construction Performance Evaluation Based on the AISM-ANP. *Journal of Marine Science and Engineering,* 10, 1574.

SHADI, A., HONG-OANH, N. & SHU-LING, C. P. 2018. Critical factors in organisational effectiveness: The case of Saudi Arabian seaports. *Journal of Sustainable Development of Transport and Logistics,* 3, 49–65.

GHENAI, C., BETTAYEB, M., BRDJANIN, B. & HAMID, A. K. 2019. Hybrid solar PV/PEM fuel Cell/Diesel Generator power system for cruise ship: A case study in Stockholm, Sweden. *Case Studies in Thermal Engineering,* 14, 100497.

SAEED, N., CULLINANE, K., GEKARA, V. & CHHETRI, P. 2021. Reconfiguring maritime networks due to the Belt and Road Initiative: impact on bilateral trade flows. *Maritime Economics & Logistics,* 23, 381–400.

CHEN, J., HUANG, T., XIE, X., LEE, P. T.-W. & HUA, C. 2019. Constructing governance framework of a green and smart port. *Journal of Marine Science and Engineering,* 7, 83.

JAWAD, L. A. & IBRAHIM, M. 2017. On some cases of fish anomalies in fishes from the Port of Jubail, Saudi Arabia, Arabian Gulf. *International Journal of Marine Science,* 7.

HAIDARI, B., BAKHTIARI, A. R., YAVARI, V., KAZEMI, A. & SHIRNESHAN, G. 2013. Biomonitoring of Ni and V contamination using oysters (Saccostrea cucullata) at Lengeh Port, Persian Gulf, Iran. *CLEAN–Soil, Air, Water,* 41, 166–173.

GHOLIZADEH, A., MADANI, S. & SANEINIA, S. 2020. A geoeconomic and geopolitical review of Gwadar Port on belt and road initiative. *Maritime Business Review,* 5, 335–349.

ANSER, M. K., YOUSAF, Z., NASSANI, A. A., ABRO, M. M. Q. & ZAMAN, K. 2020. The role of carbon pricing in the relationship between air freight and environmental resource depletion: a case study of Saudi Arabia. *Clean Technologies and Environmental Policy*, 1–12.

BALIĆ, K., ŽGALJIĆ, D., UKIĆ BOLJAT, H. & SLIŠKOVIĆ, M. 2022. The port system in addressing sustainability issues—a systematic review of research. *Journal of marine science and engineering,* 10, 1048.

WU, J., YAN, H. & LIU, J. 2009. Groups in DEA based cross-evaluation: An application to Asian container ports. *Maritime Policy & Management,* 36, 545–558.

ALVES, C. G. M. D. F. & MEZA, L. A. 2023. A review of network DEA models based on slacks-based measure: Evolution of literature, applications, and further research direction. International Transactions in Operational Research.

KHALID, A. & AL-MAMERY, M. 2019. Competitiveness of Arabian gulf ports from shipping lines' perspectives: Case of Sohar port in Oman. *Journal of Industrial Engineering and Management (JIEM),* 12, 458–471.

AL-ALAWI, A. I., AL-FARESI, R. K. E. & ABDEL-RAZEK, R. H. 2016. Evaluating the Effectiveness of Biometric Technologies in Controlling the Border Ports of the State of Kuwait. Journal of E-Government Studies and Best Practices, 2016, a1–20.

MUSTAFA, F. S., KHAN, R. U. & MUSTAFA, T. 2021. Technical efficiency comparison of container ports in Asian and Middle East region using DEA. *The Asian Journal of Shipping and Logistics,* 37, 12–19.

XU, L., SHI, J., CHEN, J. & LI, L. 2021. Estimating the effect of COVID-19 epidemic on shipping trade: An empirical analysis using panel data. *Marine Policy,* 133, 104768.