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The role of Digitalization in enhancing green operational efficiency in Nordic Maritime Logistics

A case study of Finnish Ports

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Abstract

The maritime industry has become one of the world's most important modes of transportation, with over 90% of global trade by sea. It’s a hidden industry, yet it brings stability to the world’s economy, and much needs to be researched about it. Digital technologies have transformed the industry with data-driven approaches contributing to the International Maritime Organization (IMO) sustainable goals of net-zero carbon emissions and the Nordic policy framework for achieving green operational efficiency. Automation has streamlined operations in the Nordic region, and particularly in Finland. Communications have improved between smart ports, ships, and logistics, enabling real-time tracking of cargo and vessel movement. This research has identified key digital technologies and how they enable decarbonization/green operational efficiency in Finland, with a focus on the Port of Helsinki and the Port of Turku. A qualitative-dominant case study design was used, supported by quantitative operational and environmental measures from real-time tracking devices (Automatic Identification Systems) and annual port reports from the period 2020–2025. Qualitative documents have set the foundation of the study, with technical project documents, Nordic maritime policies, Finland’s Maritime Strategy, and port sustainability reports forming the backbone of digitalization in Finnish maritime logistics. Digitalization has contributed to reduced GHG emissions, with findings indicating a 66% reduction in carbon emissions in the Port of Turku (2020–2024) and a 9% reduction in the Port of Helsinki (2023–2025). Other contributions include Vessel turnaround times, berth movements, smart ticketing, and Automated Identification Systems, all in alignment with IMO 2050 targets. However, there remains a gap between technological adoption and policy outcomes, due to fragmented data systems, high procurement costs, and cybersecurity threats.

Keywords: Digitalization, IMO, maritime logistic, Finnish ports, Internet of Things, smart ports, green operational efficiency, emission reduction.

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Tiivistelmä

Merenkulku on noussut yhdeksi maailman tärkeimmistä kuljetusmuodoista ja yli 90 prosenttia kansainvälisestä kaupasta tapahtuu meritse. Digitaaliset teknologiat ovat muuttaneet alaa. Datalähtöiset lähestymistavat tukevat Kansainvälisen merenkulkujärjestön (IMO) kestävän kehityksen tavoitteita kuten hiilineutraaliutta. Pohjoismainen politiikkakehys auttaa vihreää siirtymää. Automaation avulla toimintoja on virtaviivaistettu Pohjoismaissa ja Suomessa. Viestintä on parantunut älykkäiden satamien, alusten ja logistiikan välillä, mahdollistaen rahtien ja alusten liikkeiden reaaliaikaisen seurannan. Tämä tutkimus tunnistaa keskeiset digitaaliset teknologiat ja miten ne mahdollistavat hiilidioksidipäästöjen vähentämisen/vihreän toimintatehokkuuden Suomessa. Tutkimus keskittyy Helsingin satamaan ja Turun satamaan. Tutkielmassa käytettiin laadullista tapaustutkimusasetelmaa, jota tukivat numeeriset operatiiviset ja ympäristölliset mittarit reaaliaikaisista seurantalaitteista (Automatic Identification Systems) ja vuosittaisista satamaraporteista ajanjaksolla 2020–2025. Kvalitatiiviset asiakirjat muodostavat tutkimuksen perustan. Näitä ovat tekniset projektiasiakirjat, pohjoismainen meripolitiikka dokumentaatio, Suomen meristrategia ja satamien kestävän kehityksen raportit. Ne ovat myös digitalisaation keskeistä taustamateriaalia suomalaisessa merenkulkulogistiikassa. Digitalisaatio on edistänyt kasvihuonekaasupäästöjen vähenemistä: tulokset osoittavat 66 prosentin vähenemisen hiilipäästöissä Turun satamassa (2020–2024) ja 9 prosentin vähenemisen Helsingin satamassa (2023–2025). Muita vaikutuksia ovat alusten kiertonopeudet, laituriliikkeet, älylipunmyynti ja automatisoidut tunnistusjärjestelmät. Tulokset ovat sopusoinnussa IMO 2050 -tavoitteiden kanssa. Teknologian käyttöönoton ja politiikan välillä on edelleen kuilu, johtuen hajanaisista tietojärjestelmistä ja hankintakustannuksista sekä kyberturvallisuusuhista.

Avainsanat: Digitalisaatio, IMO, merilogistiikka, suomalaiset satamat, esineiden internet, älysatamat, vihreä operatiivinen tehokkuus, päästöjen vähentäminen.

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1. Introduction

The maritime sector remains a major source of emissions and environmental impact. With sustainability and decarbonization becoming central to Nordic policy frameworks, the industry continues to face pressure to improve its environmental performance. Digitalization has become a key enabler of this transition, offering tools to optimize logistics, enhance efficiency, and reduce carbon footprints. The industry has proven to be the lifeblood of the global economy, contributing to over 80% of global activities through the movements of goods and materials (*Shipping Data*, 2025)**.** Recently, it has streamlined movements through digitalization and enhanced innovation of logistics technologies. For example, most countries have adopted the "autonomous ships and unmanned surface vehicles (USVs) equipped with Artificial Intelligence (AI)-driven algorithms, sensors, and remote-controlled systems which enable navigation with minimal human intervention and enhanced operational flexibility (Bourhriba, 2024). This evolution is beyond port operations and the maritime ecosystem. Nowadays, digitalization such as autonomous intelligence and Internet of Things (IoT) has interacted with the environment, improving the rate of emissions, economic expenditure, and livelihoods.

Finland is leading the Nordics in digital innovation and commitments to achieving sustainability within the industry. The country offers a unique context for examining how digitalization and innovations can advance sustainable maritime logistics. The Ports in Finland are integrated into the world's most advanced maritime clusters, with early adoption of autonomy, automation, and cloud-based solutions creating smarter and more efficient port systems. These advancements have also supported a transition towards greener, more efficient low-carbon operations by enabling data-driven resource optimizations (*Smart-Ports-and-Maritime-Logistics-from-Finland.*,2020).

Finland's digital innovations, such as automation, data analytics, and smart port systems, have transformed maritime logistics, aligning operational goals with sustainability targets. This study examines how digitalization contributes to improving operational efficiency and reducing carbon emissions in Finnish maritime logistics, in alignment with broader sustainability and decarbonization policies. Through this focus, the research aims to highlight the strategic role of digital transformation in achieving greener, more efficient maritime operations.

1.1 Background: The historical evolution and current imperative

The Industrial Revolution transformed the maritime industry with the introduction of steam-powered ships, which dramatically replaced sailing ships. Steam-powered ships made travel more reliable, enabling faster transport of people and goods, improving international commerce, expanding markets, and increasing competition. This revolution was so rewarding that ports developed large-scale operational centers that contributed to the transportation of goods and raw materials. After the evolution phase came the containerization era, which revolutionized shipping logistics, making supply chains more cost-effective and efficient. The innovations introduced by containerization have enabled globalization to accelerate, with seamless operations across rail and transportation logistics, supporting the ever-growing volume of global trade. From the evolution phase came the digitalization and green shipping phase, which transformed the industry as sustainable efforts and digital technologies were introduced, including blockchain, artificial intelligence, satellite communication, GPS navigation, and the Internet of Things. This 21st-century green shipping initiative has enhanced supply chain efficiency and visibility, with cleaner fuels and eco-friendly shipping designs helping address environmental concerns while meeting the needs of an eco-conscious world (Course, 2024).

Over the last 50 years, there has been a trend in the growth of shipping vessels, a phenomenon known as the "economies of scale." The evolution in large container shipping, such as the "Very Large Crude Carriers" and the "Ultra Large Container Vessels," has significantly reduced the cost of supply chains, transformed the economies of scale, and allowed for goods to be shipped at a lower cost. This trend has, however, paved the way for port expansions, which have come with social and environmental consequences (LIM, 2011).

The pattern of global trade has also changed in the last few decades, with a significant increase since the 1950s. The gross domestic product has since increased, with port development and vessel size all playing a role in this trend. According to Rodrigue et al, (2019) international trade has overtaken global GDP for the first time since 2007. There have been significant differences in trading patterns in the 19th, 20^{th,} and 21st centuries, showing how the maritime industry has developed technologically, economically, and politically compared to the 19th century, when only 10% of the GDP was represented. The growth of carriers, terminal operators, dockworker training, and cargo owners has contributed to the industry's evolution, impacting globalization. Shipping routes have also improved with the opening of new gateways such as the Panama Canal and the North Sea routes, which have made trading much faster, reducing transit times between hubs. Furthermore, safety and regulatory requirements have evolved, particularly with the adoption of international safety measures such as the International Ship and Port Facility Security Code, certification, and the Watchkeeping for Seafarers. These safety measures, in conjunction with digitalization, have improved the safety of port operations and shipping, with more devices able to detect any malicious activities, such as hackers and viruses. In addition, seafarers have become more regulated with policies ensuring they have access to improved living and working conditions (Maritime, 2024).

The maritime industry contributes to over 80% of global trade, serving as the backbone of the world economy and underscoring its significant importance in global supply chains. However, this sector has historically been a global contributor to greenhouse gas emissions, creating tensions between environmental sustainability and economic activity(George Cosmin et al., 2023). The international Maritime industry has played a role in fighting against climate change, taking urgent action to combat its impact. IMO has also developed strategies to reduce ship emissions, with various programs initiated as planning tools establish timelines to meet these targets (IMO, 2023). Achieving these targets has been challenging, given the historical trend towards a “business as usual” approach, which threatens the future of shipping. To help counteract this, the historical patterns of emissions due to technological and economic developments must be analysed. This requires more regulatory measures, including long-term comprehensive analysis of greenhouse gas emissions, and the adoption of digitalization as a strategic approach to navigate the tension between efficiency demands and environmental regulations (Wang et al.,2025).

1.2 Research contexts: Current state of digitalization in Finnish Ports

Digitalization continues to shape the maritime sector worldwide; there remain unprecedented opportunities to enhance environmental goals and meet operational efficiency. According to “Future Mobility Finland,” the country remains at the forefront of sustainable maritime solutions, with strong shipbuilding and low-emission port technologies. Finland’s maritime cluster integrates cutting-edge technologies in areas like sustainability, automation, and digitalization, making it a key player in the maritime industry (Valtonen, 2025).

Beyond technologies like AI and digital twins (which are pivotal in driving sustainability in digitalization), we can also look at Finland's approach to open data in port digitalization. The article on "Port digitalization with open Data" written by Inkinen et al. (2019) explains how digital technologies such as IoT, automation, and digital data remain publicly available and usable, as Finnish ports are hampered by fragmented data systems and organizational cultures. Artificial intelligence and digital twins depend on interoperable data and accessibility. The article indicates how Finnish ports still operate with non-machine-readable data. Digitalization improves efficiency and supports decarbonization, and through data transparency, these outcomes are met. For example, Automatic identification systems can optimize vessel routing and port congestion management, which helps in decarbonization, while open infrastructure data enables smarter logistics planning and berth capacity, which are all key components for green transitions (Inkinen et al., 2019).

The Nordic sustainability models emphasize multistakeholder cooperation, transparency, and inclusivity, which is crucial in ecosystem-based innovation and green digitalization for future ports, not just automated but also data-empowered. In addition, the senior principal consultant at DNV and project manager of the Nordic roadmap project quoted as saying "the International Maritime Organization (IMO) has set more ambitious decarbonization targets for international shipping with countries more committed to the acceleration of the processes." (Slotvik, 2023 Pg.1). This helps show the urgency towards meeting the IMO GHG emissions 2050 targets and how digitalization will play a pivotal role in the implementation. This study explores how digitalization can enhance operational efficiency while also reducing carbon emissions in Finnish Maritime logics. In closing, the future of green maritime logistics in Finland will be shaped not just by technologies, but also by how open and effectively data will be shared.

1.3 Problem Statement

A problem statement is defined as a "concise description of the issue or challenges that research aims to address" (Hassan, 2024 Pg.1). Finland is recognized as a digital frontrunner both globally and within the Nordic maritime sector. The country's ports have actively developed a suite of innovative technologies, such as smart port systems, automation, AI-driven solutions, data-sharing platforms, and digital twins, all of which help reduce carbon emissions. The International Maritime Organization and the Nordic sustainability regulations have committed to accelerating digitization; however, despite proactive adoption and regulatory pressure, the practical environmental impact of these innovations in Finnish ports has not been systematically evaluated. There remain gaps between technological advancements and the extent of achieving measurable outcomes towards decarbonization and green operational efficiency within Finnish Ports. This study will examine the gaps between technological adoption and environmental outcomes to assess the impact of digitization on Finland's sustainability in the maritime industry.

1.4 Research Objectives

Research objectives are commonly known to be “clear and concise, with statements of specific goals and aims of a research study defined.” (Alam, 2023 Pg.1). These objectives are to:

1. Explore digitalisation and sustainability projects in Finland, such as smart ports, real-time monitoring, and automation.
2. Analyse different types of technological innovations such as Internet of Things, Automated Identification Systems (AIS), and Artificial Intelligence-based scheduling to influence emission reductions and operational efficiency.
3. Discover barriers and enablers in applying digital technologies in the maritime industry.
4. Study the alignment of national and regional digital transformation policies like Finland’s Maritime Transport strategy, Nordic sustainability targets, and the International Maritime 2050 targets.
5. To strengthen this link between digital innovations and environmental sustainability through policymaking.

1.5 Research Questions

Technological impact (1): How do technologies in the Finnish Maritime industry (IoTs, AI, and autonomous vehicles) help impact qualitative and quantitative indicators for green operational efficiencies like energy consumption and carbon emissions?

This question will help draw the main objectives of this research study, outlining the key measurable outcomes of how digitization has helped reduce the rate of emissions, while also enabling operations in supply chains to run smoothly. It also identifies specific technologies that are key in indicators of green efficiency, with a methodology that sets up a qualitative dominant case study supported by quantitative port operating and environmental measures.

Policy alignment (2): To what extent has digitalisation in Finland's ports been in alignment with the national strategy (Finnish Maritime Strategy) and the regional Nordic targets (IMO 2050, Nordic Council) towards achieving its overall sustainability targets? Are stakeholders involved in bridging the gaps between policy goals and implementation?

The aim is to address governance alignments and the strategy behind examining the state of digitalization and sustainability initiatives in Finland. It not only focuses on technology within the industry, but it also investigates the necessity of document analysis and qualitative data in identifying barriers of fragmented systems.

Barriers and Enablers (3): What are the barriers and enablers of the maritime industry and what can be done to achieve its full potential of digitalization in carbon emission reduction? What strategies can be deployed in overcoming challenges in organizational, regulatory and technical setbacks?

This question specifically addresses systematic evaluation gaps with the practical impacts, focusing on real-world challenges.

1.6 Thesis structure

The introduction of the study establishes the foundation of the topic. This includes the background of maritime logistics and its role in environmental sustainability, with digitalization a key solution for green operational efficiencies. The introduction also mentions Finland as the core case study of the Nordic maritime logistics. The problem statement, objectives, and research questions are briefly introduced in this section.

Chapter two is the literature review. Various academic sources on digitalization in the industry, explore key technologies and their potential to contribute to operational efficiencies.

Chapter three presents the research methodology, which consists of a qualitative-dominant case study design, supported by quantitative performance data from port reports and the Automated Identification System (AIS tracker).
Chapter four is the key findings and analysis of the study. Finnish ports such as Port of Helsinki and Port of Turku will be analysed to establish the impact of digital technologies in achieving green operational efficiencies. Chapter five will be the discussion phase, which will interpret the key findings of chapter four, and Chapter six will provide the overall conclusion of the study.

2. Literature review

2.1 Digitization of the Maritime Industry

The Maritime Industry has evolved into data-centric technologies such as the Internet of Things, big data, and artificial intelligence. The International Maritime Organization and regional policies globally have led shipowners, port companies, and vessels to shift from an isolated to a more integrated ecosystem. According to Zhang et al.(2024) the maritime industry has, over the years, entered a critical stage of digitalization, and this has boosted the market and international trade. Furthermore, the rise of technology has paved the way for research and development, enabling companies to advance in terms of pursuing shipping intelligence while also practicing green shipping.

Digitalization and automation have transformed the maritime industry, with organizations meeting operational efficiency and effectiveness. According to Kosek et al. (2024) there is a new era of intelligent ports because of the impact of digitalization; this has not only improved operations, but it has brought sustainability and efficiency in the industry. This advancement has not only improved operations in ports, but it has also introduced competition, leading to decarbonization practices that have contributed towards net zero carbon emissions. Technological advancements demand a constant upgrade to integrated systems and tools. Organizations can benefit from integrated IT systems, expand their networks, automation, remote monitoring and control, data management, cyber security, and data standardization, all part of global trends (DNV, 2026).

A common global trend is the return of investment which is typically expressed with the rate of productivity and energy efficiency as compared to the usual cash flow. The rate of productivity in the industry has been influenced by the impact of digitalization, developing positive outcomes on green operational efficiency, and this has over the years, boosted the economy. Zhang et al. (2024) support this by mentioning how “higher levels of digitalization are associated with lower costs and energy consumption.” This shows that digitalization not only promotes environmental sustainability, but it also ensures that operational activities are done at a lower cost. Additionally, authors such as Raza et al. (2023) emphasize the importance of integrity, which helps reduce the cost. In their article on “digital transformation”, they explain how companies in the shipping industry are explicitly adopting data platforms to map digitalization and move from isolated tools to more integrated ecosystems.

The International Maritime Organization (IMO) has also looked to revolutionize digitalization in the shipping industry by 2027, with comprehensive strategies and plans set for the sector. These strategies aim to meet the standards of regulations, enhance efficiency, safety and meet sustainability across the maritime sector by leveraging advanced technologies (MaritimeHub, 2025).The plan has been to identify technologies and strategies to integrate ports and vessels while optimizing logistics and reducing greenhouse gas emissions. Another key regulation from the IMO addresses the threat of cybersecurity and the global digital divide. The IMO secretary-general, Arsenio Dominguez, has emphasized the importance and need for state-of-the-art technologies such as Artificial Intelligence algorithms and autonomous navigation, while also tackling the threat of cybersecurity (Chambers, 2025) .

The maritime industry has evolved to data-centric technologies such as the Internet of Things, big data, and artificial intelligence. The International Maritime Organizations (IMO) and regional policies globally have led to shipowners, port companies and vessels shift from an isolated to a more integrated ecosystem. Chen et al. (2024) mentions how the maritime industry has over the years entered a critical stage of modern technology and this has boosted the market in terms of international trade. Furthermore, the rise of technology has paved way for research and development, which has enabled companies to pursue in shipping intelligence while practicing green shipping.

A common global trend in the maritime industry is the focus on return of investment, which is typically expressed in terms of productivity and energy efficiency relative to cash flow. In terms of productivity, digitalization has had a positive outcome in green operational efficiency, boosting the industry's economy. According to Zhang et al. (2024) digitalization use is associated with energy consumption, which shows that it not only promotes environmental sustainability, but it ensures operational activities are done at lower costs. Additionally, Raza et al. (2023) mention the importance of integrity in achieving lower-cost operations. In their article on digital transformation, they explain how companies in the industry are explicitly adopting data platforms such as Internet of Things, automation and blockchain technologies in mapping out digitalization and moving from isolated tools to a more integrated ecosystem.

2.2 Key Technologies shaping the Maritime Industry

Digitalization has been a term used globally to describe technological advancement in the maritime industry. Port digitalization has brought efficiency in various nodes within the ports, particularly in handling cargo, containerization, navigation, and in autonomous vehicles, for example. The emergence of technologies has given opportunities to platforms like open data sources, resulting in data combination potential, bringing benefits to change, such as one technology impacting the next; for example, blockchain technology significantly makes navigation efficient. Through this, blockchain technology assists with paperwork, helping reduce processing time and ensuring fewer errors in the maritime industry. Open data is also an opportunity for tackling carbon emissions, contributing to environmental sustainability (Inkinen et al., 2021). All in all, ports may be considered as one unit, as they consist of a multitude of simultaneous data processing, and this makes the industry more effective in daily operations.

This chapter will investigate the trends of port digitalization and how they will potentially shape the industry in meeting the International Maritime Organization 2050 targets of net zero Carbon emissions and the Finnish maritime strategy goals of transitioning towards green clean technologies (IMO, 2023).

2.2.1 Cyber security

As geopolitical tensions rise globally, the need to stop cyberattacks has increased. Over the years, there have been common concerns about the existing structures of vessels in the industry, and according to Lv. (2020) tensions have continued in the operational environment, affecting government and maritime cybersecurity. Researchers such as Kayisoglu et al. (2025) have written articles “exploring cyber security threats and security models in cross-border paperless monitoring systems” and have helped explain the importance of cyber security in trading digitally across borders. Additionally, they mention that “adopting paperless systems in cross-border trade offers numerous benefits including increased efficiency, cost savings and faster processing times for companies and logistics providers” (Kayisoglu et al., 2025 pg.1) . The maritime industry is growing due to the seamless transfer of information and data systems, which enables the exchange of documents such as contracts, bills, and receipts, all of which require data protection through cybersecurity.

According to Bocayuva. (2021), the international supply chain has experienced critical cyber incidents, such as the Port of Antwerp in 2013. During this incident, drug traffickers hacked into a vessel using remote control of the port terminal system in Belgium. This incident triggered companies in the European Union to respond effectively to risks of security by ensuring port authorities and terminal operations adhere to policies and strategies to conduct formal risk analysis. Bocayuva. (2021) also mentions how these policies should follow shipping standards like the Ship and Port Security Code that was initiated by the International Convention for the Safety of Life at Sea, ensuring shipping companies can be safe and aware of risk management and cyber security. Identifying vulnerabilities of vessels of port networks through risk analysis such as the Port Facility Security Assessment (PFSA) will be useful in measuring different security levels within the system. In addition, the diagram below (Universe, 2025) significantly identifies more precautions that should be practiced within the maritime sector; these include detecting threats through alert systems, integrating multi-constellation navigation systems, and growing the integration of cybersecurity metrics into charter party clauses. Cybersecurity policymaking helps mitigate threats of cyberattacks. By establishing new frameworks and existing policies, decision-making structures will ensure companies are aware of any significant threats to their databases and information systems, enabling agile tactical, operational, and strategic responses.

Table 1. Cyber incidents affecting maritime navigation. Source:
https://www.shipuniverse.com/news/maritime-cybersecurity-gains-momentum-amid-rising-threats/

Recent Cyber Incidents Affecting Maritime Navigation			
Date & Region	**Incident Type**	**Details & Impact**	**Operational Consequences**
Mid-June 2025 – Gulf of Oman & Hormuz	GPS/AIS Jamming	Nearly 1,000 ships reported false coordinates; tankers recorded in rural Russia before reappearing near Iran.	Increased collision risk—Front Eagle collision confirmed; navigation disrupted.
June 2025 – Strait of Hormuz	Electronic Interference	Naval agencies flagged rising GPS/AIS disruption near Bandar Abbas and Hormuz area.	Commercial vessels escorted; some avoided the corridor amid high-risk advisory.
2024 – Global Maritime Network	Legacy System Attacks	239 documented disruptive cyber-attacks affecting navigation, AI vessels, and port systems.	Shipping firms urged to update legacy OT/IT systems; awareness of navigation failures rose.
Oct 2024 – Baltic Sea Region	GPS Jamming / Spoofing	Finnish coast guard reported constant GNSS interference; tankers missed their bearings or spoofed locations.	Authorities issued warnings; vessel rerouting and safety protocols reinforced.
Mid-June 2025 – Black Sea & Taiwan Strait	Wider EW Tactics	Pattern of increasing use of EW tools like jamming and spoofing in hot zones, including Black Sea and East Asia.	Operators adding backup navigation, manual protocols, and enhanced crew training.

Incidents compiled from verified navigation tracking disruptions and EW advisories between 2024 and mid-2025. Reflects evolving maritime cyber risk across global waterways.

Table 1 was added as an example as it depicts recent cyber incidents affecting maritime navigation between the period of 2024 and 2025. The one that stands out in the image is the Strait of Hormuz. According to (*The Strategic Importance of the Strait of Hormuz*, 2026) the maritime channel has a role in global oil distribution. This area is targeted because of the number of resources it possesses. Between the months of May and June, Hormuz and the Oman Gulf areas had nearly a thousand false reports from tankers, which escalated the risk of collision in the area near Iran. Other common incidents include the 2023 global maritime network that involved over two hundred documents disrupting navigation, automated vessels and port systems, and the October 2024 Baltic Sea region incident that affected the Finnish coastguard, which reported constant GPS interference.

Overall, cybersecurity threats in the digital maritime world present a critical paradox in that PS, automated intelligent systems, and connected systems all produce operational efficiency through navigation, which also introduces new exploitable vulnerabilities.

2.2.2 Artificial Intelligence and Big Data Analytics

Big data analysis is defined as “the science of fusing heterogeneous data from various sources, drawing relations and conclusions among them, making predictions to gain insight, and supporting decision-making.” (Semanjski, 2023 Pg.1) . In simple terms, data analysis is often used to describe data-driven decision-making, which involves converting raw data into a more structured and systematic form. In port operations, data is collected through machine learning and the Internet of Things (IoT), which is significant for ensuring reliable and efficient handling of large volumes of data. This chapter will focus on the importance of AI and how it's shaping the industry.

Artificial intelligence, along with key digital trends like the Internet of Things (IoT) and blockchain technology, has been crucial to port management and decision-making. This is because real-time data is used to improve ship operations such as cargo handling and containerization, while also minimizing the risk of frequent breakdowns. According to Sadiku et al. (2025), the Internet of Things and artificial intelligence are everyday devices we use, and these are part of commercial technologies that communicate with each other over the internet. They further elaborate by noting how the devices have produced various transformations, particularly in real-time monitoring, which has helped increase energy efficiency and improve ship management. This shows how digitalization in the maritime industry not only shows ability to process data from wireless sensors but also improves operational efficiency, safety, and sustainability, all contributing to the development of the global economy (Sadiku et al., 2025). In addition, other authors like Zhang et al. (2024) mention how the Internet of Things (IoT) sensor networks provide real-time data collection on how ships perform on their routes, which involves monitoring emissions, port operations, and making supply chains more efficient and adaptable. For example, the Port of Rotterdam in the Netherlands uses a dashboard to report sea-related data for container management and enabling interactions with external systems through cloud-based platforms. This helps justify the significant impact of these technologies particularly on achieving green operational efficiency. Moreover, these technologies have helped the industry evolve, contributing to environmental sustainability and the global economy (Muñuzuri et al., 2020).

In addition, applying these digital technologies will help shipowners predict routes through navigation, identify equipment failures, and optimize fuel consumption, which benefits schedule maintenance and achieves operational efficiency (Inkinen et al., 2021). Route navigation is key to ensuring seamless operations, and big data analytics play a big role in this. Intelligent shipping and big data have become major trends in the maritime industry due to their ability to leverage the Automated Identification System (AIS) and historical voyage data to create trajectories and reduce carbon emissions. Furthermore, Chen et al. (2024 Pg1) asserts that "the rise of automation technology has produced autonomous navigation of ships, pushing the overall shipping industry towards the emergence of green technologies." This helps explain the significance of machine learning and artificial intelligence in route optimization. According to the International Maritime Organization, policies and procedures must be followed to keep pace with technological development. For example, the "European Union regulation of 2020/256" helps in promoting autonomous navigation and route optimization.

Artificial intelligence not only helps identify malfunctions within the vessel, but it also reduces human-induced errors. To support this, Bavassano et al.(2020) mention how automation and human intervention have helped vessel operations, particularly by providing transparency, which has helped reduce human errors. In addition, artificial intelligence and big data analysis have enhanced security, and through the integration of different technologies, processing becomes efficient, helping companies be innovative, resilient, and productive. Additionally, Raza et al. (2023) explain how artificial intelligence, combined with cloud-based data, provides an innovative platform for capacity forecasting, improving operational efficiency and achieving customer satisfaction. He further highlights how artificial intelligence is used to helps achieve customer satisfaction by ensuring emails are read at a much faster rate, which helps supply chains run smoothly.

Overall, artificial intelligence and big data analytics are the core enablers of information transfer within the industry. The ability of containers to sense external (high tides, storms, collisions) through wireless sensors and machine learning is significant, as it enables shipowners to be more aware of their surroundings. Sensors are a big part of data analytics, and with machine learning, the Internet of Things, and artificial intelligence all contribute to real-time data analysis, it shows how fast the industry has progressed.

To conclude, big data analysis and artificial intelligence are very important technologies in the maritime industry. These technologies not only provide significant value in operational efficiency but also in enhancing situational awareness and supporting risk assessment in improving navigation safety.

2.2.3 Automation: Robotics, autonomous shipping in ports and Drones

The Maritime industry has evolved from traditional shipping methods to more sophisticated cargo-handling methods, and through the integration of key technologies such as robotics, automation, and drone operations, shipping has never been more advanced. It has been one of the biggest trends in modern history, with the industry aiming to achieve net-zero carbon emissions by 2050. While automation remains an integral part of environmental sustainability, the industry still benefits immensely from safety, operational costs, and the ability to replace unavailable crew members.

The global maritime industry is reaching new heights with automation at the core of economic development (USD 8,2 Billion market by 2050) (Agarwal, 2025), and this substantially justifies the impact of digitalization within the industry. Automation is a vital trend with laws and regulations guarded by the International Maritime Organization, such as the Marine Autonomous Surface Ships (MASS). The maritime industry is becoming more technologically aware while defining the extent of human involvement. According to Zhang et al. (2024) technology has brought precision in shipping activities, reducing the amount of mistakes while alleviating personnel shortages. This proves the value of automation in the industry, which has created time-saving measures. Furthermore, the Marine Autonomous Surface Ships regulations have introduced four levels that define autonomous vessels, which have evolved over the years. The first level of MASS is the decision support phase. This phase recognizes how crew members remain an integral part of onboard vessel operations, contributing to decision-making regarding safe navigation, route optimization, and all crucial in monitoring vessel performance (Agarwal, 2025).

The second level involves remote-controlled operations, with crew members also playing a part in onboard decision-making. Ships are often controlled remotely from shore-based remote-control centers (RCCs), which handle complex technical demands such as engine operations and navigation, while members on board deal with physically demanding situations, such as emergencies and the handling of goods. Ironically, this further explains the importance of a traditional approach to the maritime industry, particularly with human involvement, as they remain a key part of supply chain operations and economic development. The third-level regulation is more of a modern technical approach to cargo handling and shipping. This layer eliminates human intervention on board, but they remain a pivotal part in remote control through the shore-based Remote-Control centers. To some extent, this level yields greater operational efficiency than the other MASS levels, because it eliminates circumstances that lead to human-induced errors. To support this (Zhang et al., 2024) explain how crew involvement is required to monitor Artificial Intelligence-driven decision making to verify data and intervene when errors that cannot be identified by technologies occur. Autonomous vehicles also require technologies such as Internet of Things sensors, digital twins, and machine learning methods to be monitored by on-board technicians and engineers. In addition, international conventions such as IMO's SEEMP (Ship Energy Efficiency Management Plan) still require regulatory compliance and human intervention, particularly in verifying emission reports and quality logs. As autonomous technology continues to be adopted in the industry, crew members still have a say in maintaining regulatory compliance.

Finally, the fourth level of MASS autonomous regulation looks to eliminate human involvement from all shipping operations. A classic example of this situation is practiced in the port of Singapore, which will be discussed in the case study below.

Fully autonomous shipping enables real-time decision-making, underscoring the importance of IoT, digital trends, artificial intelligence, and algorithms. These regulations by IMO and MASS are the future of the maritime industry, and not just in this sector, but in all activities of the global economy, such as retail, agriculture, and mining, for example. Robotics and autonomous vehicles in the maritime industry will be programmed to avoid collisions, ensuring safe navigation and route optimizations while responding to emergencies effectively. While the port of Singapore has adopted this practice, other countries are gradually transitioning to more digitalized shipping technologies, and the adoption of autonomous vehicles has gained momentum due to their ability to get a competitive advantage in the market. An example of this movement is Norway’s Yara Birkeland, which is pioneering zero-emission container ships designed to navigate short sea routes without human control, thereby significantly improving supply chains (Agarwal, 2025) .

To conclude, autonomous vehicles are slowly replacing humans in daily operations, due to the introduction of technologies such as 5G networks, which enable ultra-low- latency and remote-control operations. Articles written by Aslam et al.(2023) explain how the emergence of remotely controlled vessels brings several developments for ports, and this includes remote control centers and communications with vessels (Inkinen et al., 2021).

2.2.4 Digital applications in international ports

The industry has paved the way for digital improvements; countries such as Singapore are introducing technical innovations in port operations, with examples of automated vessel tracking using satellite imagery and navigation of remote-controlled systems. Singapore’s PSA International Tuas port has electrified automated cranes which are fully digitalized to track and handle the movement of goods, enabling effective operations at hubs. According to Marcus Williams, “the port has enabled 5G automated guarded vehicles which are supported by intelligent data-driven management systems, smart engineering and power management platforms.” (Williams, 2025 pg.1). These systems are remotely managed through the port's control centre, improving vessel management and ensuring reliability. Sensors on the port of Singapore are vital in daily operations as they are popular for the provision of real-time data on sites, such as vibrations, temperature, and quality of equipment, which help enable long-term durability of products.

Other examples of popular ports that have been technically advanced are the port of Rotterdam and Port of Antwerp, which have installed what is commonly known as “smart bollards” sensors used to measure and monitor berth utilization (Bourhriba, 2024). Another example of how technology has effectively improved port operations is the United Kingdom’s Port of Dover which introduced the digital twin technology, a transformative tool that provides ships with virtual replicas of vessels enabling them to test various operational scenarios and monitor real-time operations. According to Coursera Staff, “Digital twins are virtual representations of physical objects used for modelling and design purposes. These virtual models are used to digitally represent performance, identify inefficiencies, and design solutions to improve their physical counterparts" (Staff, 2026 pg1). This is useful because it aids operational management and prepares for worst-case scenarios arising from external environmental factors caused by climate change. The digital twin is a safe and advanced method for forecasting weather conditions, enabling the safe arrival of ships and ports.

As the industry is highly networked with various operational interfaces, there remain significant opportunities for digital transformation and adoption of data- intensive technologies such as AI and big data analytics, which potentially enhance sustainability, efficiency and safety. However, according to Mark Fruth and Frank Teuteburg, maritime operations remain underdeveloped, but this is changing annually as more businesses adopt digital models that integrate the International Maritime Organization's electronic data exchange between the shore and ships (Fruth & Teuteberg, 2017). The applications of smart containers, such as the example of Singapore's PSA International Tuas port, weather systems, and real-time navigation, have all improved vessel scheduling, and these innovations have proven to show digital connection within the maritime industry, which has slowly helped to lower emissions in the value chains (Williams, 2025). This has also been aligned with the Finnish smart ports and has helped in meeting up with the Nordic decarbonization policies.

2.3 Conceptual Framework structure

The Framework will represent a pathway of Digital technology inputs, which will then be processed through an operational mechanism to achieve green operational efficiency outcomes. Moderators such as systematic barriers and enablers will also be analysed in the influence of Maritime policy governance.

Table 2. Conceptual framework.

Digital technology implementation	Green operational efficiency	Moderating factors and policy alignment

Input (digital technologies)	Processes (Operational mechanism)	Output (Green operational efficiency	Moderators (Barriers and Enablers)	Governance (Policy alignment)

Internet of Things	Real-time data sharing	Co2 Emissions	Data fragmentation	IMO 2050
Digital twins	Predictive analytics	Energy consumption	Cybersecurity	Nordic strategy
Open data platforms	Just-in-time arrivals	Optimized resource use	Organisational culture	Finnish Maritime Strategy
Fin traffic vessel program	Berth optimisation	Energy consumption	Public-private partnerships	Finnish Maritime Strategy

The conceptual framework in the diagram above illustrates the Maritime industry and its high level of interconnectedness. The maritime supply chain involves several actors, including logistics providers such as forwarders, port operators, shipping companies, senders and receivers, all mapped out within a framework showing financial services and regulatory stakeholders. Furthermore, the diagram visualizes how digital transformation in the maritime industry is centred on intelligent technologies, stakeholder coordination, and data sharing in continuous support of resource optimization, reduction in idle times and adaptation to green operational efficiency idle to Finnish ports and the Nordic sustainability goals (Fruth & Teuteberg, 2017).

Awake AI is one example of a Finnish company applying this kind of Framework as it continues to serve as a real-world embodiment of an integrated digital supply chain. The company directly engages several key stakeholders such as ship operators, port authorities, and cargo owners through digitized technologies such as real-time data analytics and smart port technologies. These various stakeholders each have their own roles within the supply chain. For example, the port operators are responsible for maximizing and supporting cyber-physical port systems; the terminal operators enhance port call efficiency through resource coordination, which helps present the diagrams' emphasis on data-driven operations; ship operators enable just-in-time arrivals through big data analysis; and finally, the cargo owners deliver full supply chain transparency.

Awake AI an example of how the theoretical framework is digitally networked in maritime ecosystems, with stakeholders pivotal in reducing inefficiencies while also directly contributing to green operational efficiencies in Finnish maritime digitalization (*Smart-Ports-and-Maritime-Logistics-from-Finland.* 2020 pg.24).

2.4 SWOT analysis: Digitalization for green operational efficiency (literature review)

A SWOT analysis of a literature review helps identify the strengths, weaknesses, opportunities, and threats of a subject application and defines the scope of the study (Kosti & Kundu, 2020). The SWOT analysis below looks at digitalization and how it drives operational efficiency in the industry. It highlights strengths in regulatory alignment and operational efficiency; weaknesses in high costs and data fragmentation; opportunities in key technologies such as blockchain and 5G networks. However, these opportunities also bring cybersecurity and environmental threats (Figure 1).

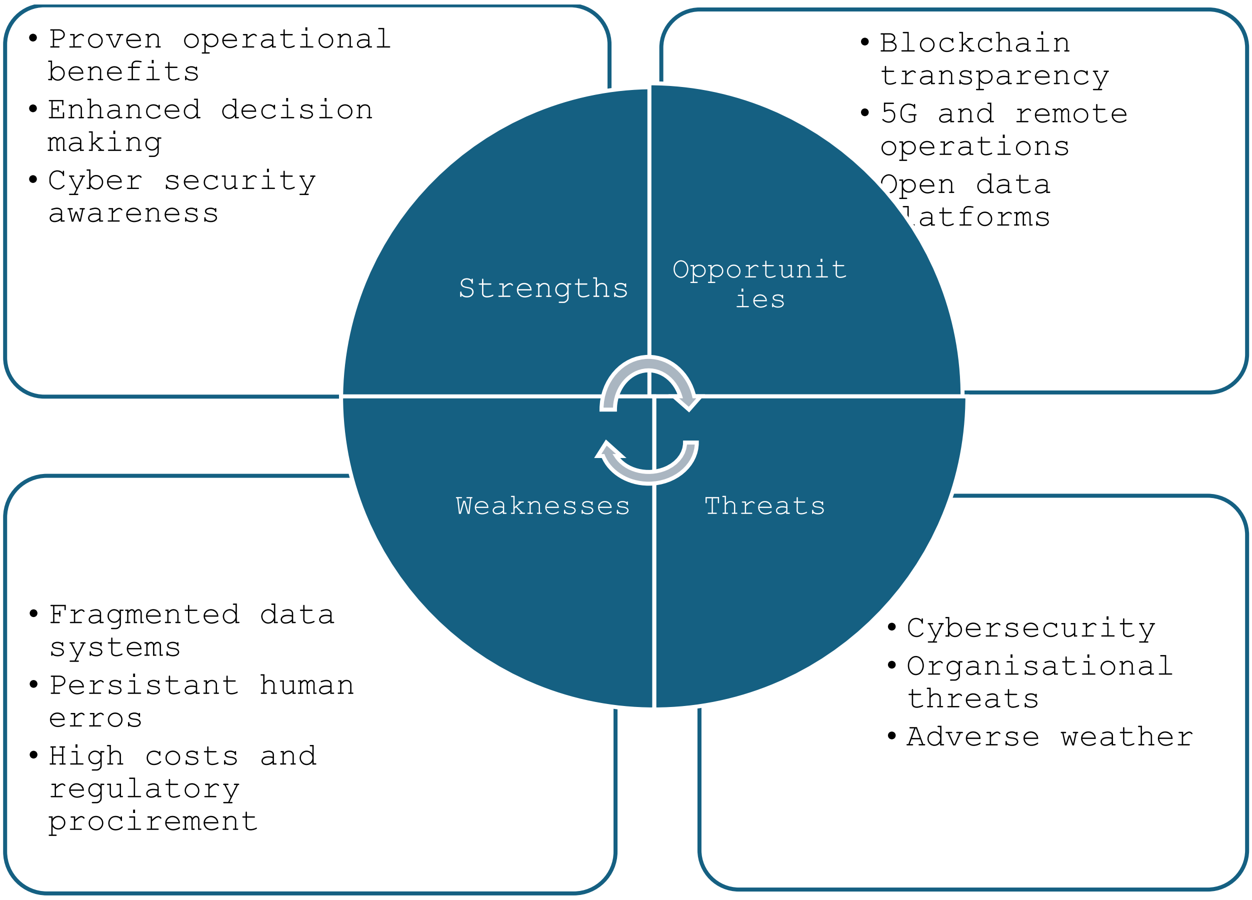

Figure 1. SWOT analysis of the literature review

2.4.1 Strengths

Proven operational benefits

The literature review constantly proves how digitalization such as artificial intelligence, Internet of Things and blockchain technology, etc, has reduced operational costs which improves cargo handling and productivity rate Zhang et al. (2024) and Raza et al. (2023).

Enhanced decision making

One of the major strengths of integrating key technologies in the maritime industry is its ability to enhance quick and reliable decision-making. Real-time data the Internet of Things and Artificial intelligence has made information transfer ever so reliable and productive, enhancing route optimization, contributing to operational efficiency (Sadiku et al., 2025).

Cybersecurity awareness

The literature review has also proved the significance of information transfer across the oceans. Organizations, companies and shareholders are looking to diversity from the physical transfer of information to a more digitalised methos, the necessity to adapt and to the fast market has become the norm. However, we have identified technology as the hub for cyber-attacks, and with articles written by Bocayuva. (2021) and Lv. (2020) the growing concern of cyber-attacks has led to policies and formal risk frameworks to be developed.

2.4.2 Weaknesses

Fragmented data systems

Data fragmentation, also known as "information silos," has led to the software and equipment from multiple vendors being congested. Too much information flow in the system can cause data duplication which can further lead to lack of transparency and operational performance (Brunila et al., 2021).

Persistent human error

Despite the introduction of automated vessels and port operation centres, humans prone to error. The International Maritime Organization encourages staff training technological awareness and compliance with regulations such as the SEEMP. However, humans could still panic when dealing with artificial intelligence or emergency response in unprecedented situations (Agarwal, 2025).

High costs and regulatory procurement

Procurement of advanced technology can be seen as a weakness. According to Inkinen et al.(2021) procuring technologies such as IoT and large-scale networked machinery requires a lot of security updates and maintenance. Their security demands are not just expensive; they can also become operationally complex.

2.4.3 Opportunities

Blockchain for Transparency

In the weakness section, the issue of information transparency was addressed due to multiple vendors and congested systems. Now, with blockchain technology, a significant opportunity arises in addressing the challenge of data transparency. The papers written by Li & Sun,

(2025) explain how decentralized systems produced by blockchain technology could establish a platform to enable multiple stakeholder communication while addressing the issue of data security breaches. This is one of the biggest opportunities in this industry.

5G and Remote Operations

Remote operations and 5G networks enhance seamless information and data flow. The literature review identifies opportunities associated with the MASS levels, particularly levels 3 and 4, which explain how ultra-low-latency and 5G networks have enabled autonomous vehicles to depend less on human control while also reducing the rate of carbon emissions. The opportunity for technological advancement in maritime logistics is ever-growing.

Open data platforms

Open data platforms such as Automated Intelligent Systems (used in the methodology section of this research), port infrastructure, and machine-readable data are useful for navigation and route optimization. The data is free and available the public. This opportunity is unique as it not only allows the industry to flourish, but also to tackle the issues of berth occupancy (time between arrivals and departures at ports) and congestion management.

2.4.4 Threats

Cybersecurity has been at the forefront of the most common threats experienced in the industry. Digital shipping and ports continue to face threats from cyberattacks. For example, recent case studies documented attacks at the Port of Antwerp in 2013, Gulf of Hamaz GPS spoofing in 2025, and an interruption in the Baltic Sea. These cyberattacks showed the vulnerabilities in navigation and port systems (Bocayuva, 2021). This has also led to geopolitical tensions with regional conflicts triggered by the results of cyber threats. Other threats include organizational threats, with internal cultures looking to maintain a competitive advantage through trade wars and adaptations to unstable global conditions, further limiting their ability to integrate the system. The industry has also faced threats from the external environment, particularly due to adverse weather, which disrupts navigation and global supply chains.

3. Research Methodology

3.1 Research approach

Research approach refers to the process or plan that provides a framework for researchers to conduct their study. It clearly indicates the research approach, including methodologies and strategies applied in collecting data, analysing, and interpreting the results. The approach helps align the study with its objectives, while producing valuable and reliable results (Hassan, 2024). This study will adopt a qualitative-dominant case study supported by quantitative port operational and environmental measures. The qualitative analysis section will analyse systematic documents of Finland, Nordic Maritime policies, port sustainability reports (Port of Helsinki and Port of Turku), industry publications, and technical project documents. The quantitative data specifically investigates port operations data such as port annual reports, including the energy consumption rates, emission rates, and information from Automated Identification Systems (AIS) accessed from Marine Traffic tracking data.

The research does not consist of primary data such as interviews and site visits due to access constraints. The data is collected from secondary sources, including public documents which are common in the Maritime industry (Fruth & Teuteberg, 2017). The secondary data collected will answer questions relating to digitalisation within the industry, including its influences on green operational efficiencies (a qualitative approach), and quantitative data to measure the outcomes achieved.

3.2 Research Design: Case Study of Finnish Ports

A research design is a framework or blueprint that guides how data is collected, measured, and analysed. It provides a platform that refers to the strategies set for research and the process of achieving them. The structure used should be clear and precise in approaching the research question while also ensuring the goals are reliable and valid (Hassan, 2026).

The methodology will focus on a small sample size that represents Finland's maritime digitalization and green operational efficiency. The Automated Identification System (AIS) will be used to monitor marine live-tracking data on vessel operations in the Ports of Helsinki and the Port of Turku. This will be important as it will show berth usage from January 2023 to December 2025, based on turnaround times (arrival and departure timestamps). Furthermore, the qualitative data collected consist of information from annual sustainability reports of the Port of Turku and the Port of Helsinki, all of which show emission rates and energy consumption.

3.3 Data Analysis

Data analysis is the process of collecting, analysing, describing, and interpreting data. It is an important part of research as it allows you to apply data-driven decision-making. Data analysis is also a "technique used to gain insights from datasets, which can be used for operational research and future decision making (Eldridge, 2026).

The analysis will be conducted using qualitative document analysis and quantitative description analysis. The qualitative approach examines various documents, such as port reports, national strategies, and technical project descriptions, all with thematic content analysis and a deductive coding framework. A thematic content analysis is a tool used to facilitate data collection, allowing users to collect datasets from computational techniques. Chapters 2 and 4 will identify the digital technologies implemented, green operational efficiency, moderating factors, and policy alignment (Eldridge, 2026) . The data will be analysed by identifying inputs, processes (operational mechanics), outputs, moderators, and governance through policy alignment.

Quantitative data will focus on annual reports from the Port of Helsinki and the Port of Turku for the period 2020–2025, as well as Automated Identification Systems tracking for statistical analysis. The port's annual reports will present the emission rate in tonnes and electricity consumption per megawatt-hour. The AIS marine traffic data will show turnaround times to justify berth efficiency (arrival to departure), use mean, median, and range, indicate journey durations, speeds, and scheduling times, all of which are pivotal in achieving operational efficiency.

The qualitative and quantitative data analysis techniques all consist of a triangulated relationship. For example, the emission reductions collected from the ports of Helsinki and Turku were all supported by the Automated Identification System, which shows the turnaround times. Another example is the statement on “smart port development,” which appears in the policy documents and technical reports from the University of Turku projects.

3.4 Data collection methods

3.4.1 Quantitative data analysis

Quantitative data collection will investigate trends, identify research gaps, and produce measurable outcomes within the maritime industry. Information will be drawn from various sources, including port performance reports (e.g., vessel turnaround times), environmental reports, inventory data (rates of carbon emissions, energy consumption, and the share of renewable energy), budget allocations for digitalization projects, and technological investment data. It will also include document analysis of annual sustainability reports and port publications in cities such as Helsinki and Turku.

3.4.2 Qualitative data analysis

Qualitative data collection will complement quantitative findings by helping to understand the barriers and motivations behind them. Document analysis will be key in this section, with various sources vital in the collection of information. Sources such as Finland's national Maritime strategy, maritime transport system, annual sustainability reports, and international regulatory standards like the IMO will be important in establishing the basis for identifying these findings.

3.5 Ethical considerations and limitations

The research followed formal procedures and guidelines in using publicly available data. No confidential information was accessed; therefore, no formal committee approval was required.

4. Findings

4.1 The policy framework for smart ports and social institutions

Smart ports in the Finnish Maritime strategy

The Finnish Maritime Strategy has a strong foundation in emphasizing efficiency, competitiveness, and sustainability in the maritime industry. The Maritime Strategy for Finland 2014–2022 is central to the vision of smart port development, a multistakeholder collaboration platform, integrated systems, and data-driven performance, which closely align with the core components of smart port frameworks (*Smart-Ports-and-Maritime-Logistics-from-Finland.* 2020.).

Smart port systems in Finland are characterized by digital integration, environmental performance, data exchanges amongst stakeholders, and intelligent systems to optimize logistics. This strategy is a highlight of the importance of intelligent logistics chains, which, according to Kumar. (2026) describes it as AI-driven automation that has helped businesses operate smoothly, revolutionizing production and helping transform global logistics and supply chains. This underscores the importance of documentation in traffic data and helps represent seamless flow across maritime logistics chains. In addition, Finland's smart port operations consist of various components, such as data interoperability, which allows for centralized electronic systems that enhance transparency; port community systems (PCS) for advocating national service points based on traffic data; and intelligent infrastructure that supports vessel traffic management for optimizing port operations.

The Finnish maritime strategy also includes a maturity model for smart port development, categorized into phases. The first common phase is the digital foundation that digitizes basic processes through platforms such as Portnet, followed by the intelligent optimization phase that includes real-time data analytics for predicting disruptions and optimizing resource use, and the final phase of the maturity model is the integration and collaboration that involves linking systems across various stakeholders, such as logistics operators and port authorities, for example. This model is a good indicator that Finnish ports are well-fragmented and continue to demonstrate that digitalization is key in enhancing green operational efficiency. However, smart ports in Finland still rely on public-private partnerships to develop port innovations, government involvement, as well as international cooperation with neighbouring countries such as Sweden and Estonia, which are pivotal in environmental monitoring, for example. Sustainability and resilience are also critical in smart port development for Finland's environmental goals, with green technologies (liquid natural gas) and energy-efficient operations all integral in enabling economic and ecological efficiency (*Smart-Ports-and-Maritime-Logistics-from-Finland.2020*).

To conclude, Finland's Maritime strategy document shows a clear roadmap for smart development in Finnish ports. It emphasizes the importance of collaborative governance, shared data platforms, and integrated digital systems, which align with global smart port frameworks. These elements are pivotal in positioning the country's ports as intelligent hubs capable of adapting to future challenges and opportunities.

4.1.2 Digitalization in Technical and Social Institutions in Smart Port Cities

The port of Turku has recently looked to modernize its operations digitally with the help of the city of Turku. Through the smart port city project, operations and functions have become more efficient as digital technologies are increasingly integrated. The smart port city project funded by the University of Turku has been vital in creating a synergy among the city and the harbour, and the people of Turku, with all parties benefiting from shared infrastructure and data.

Digitalization has been key in developing the port of Turku, with projects aiming to enhance data efficiency, environmental sustainability, security, measures, and social inclusion. The Port's smart city project has set targets for data sharing, helping stakeholders contribute towards improving the services for citizens. This shows that industry not only looks at technological advancements, but also focuses on social inclusion, which is key for future generations. In addition, the city has aimed to foster social engagement through creating collaborative design tools that allow people to be active co-creators of a smart and sustainable city, "leveraging their roles as contributors, such as advertisers, content producers and service developers (Wahlström et al., 2025).

4.1.3 Smart Port-city's digital technology, environmental sustainability, and quality of life

The Port of Turku has benefited from urban development, with shared infrastructure like data and digital technology greatly aiding maritime logistics. For example, integrating various services from the maritime cluster creates opportunities to streamline operations, which helps reduce negative impacts on life while also enhancing residents' quality of life (Wahlström et al., 2025).

Smart port cities offer several benefits, including shared data, environmental sustainability, mobility and access, enhanced safety and security, and economic and social integration. With shared data and connectivity, the port ecosystem becomes seamless, improving traffic system planning, contributing to supply chain management and energy consumption. This is crucial for meeting the IMO 2050 targets and Finland's environmental sustainability goals. The smart port-city integration also enables environmentally friendly initiatives, such as onshore power generation or the use of electrified equipment, which help create a low-carbon urban area around the port.

Smart port cities have paved the way for smart mobility solutions, which have also been integrated into the maritime industry. For example, there has been progress towards building autonomous vehicles, applying drone operations for marine navigation the use of public transport, which has helped improve citizens' accessibility and proved convenient for dockworkers. Furthermore, with digitalization susceptible to security risks, smart port-city integration has paved the way to mitigate these risks with ecosystems advancement in surveillance, cybersecurity and emergency response all contributing towards residents' well-being life (Wahlström et al., 2025) .

4.1.4 Social inclusion in smart port Cities

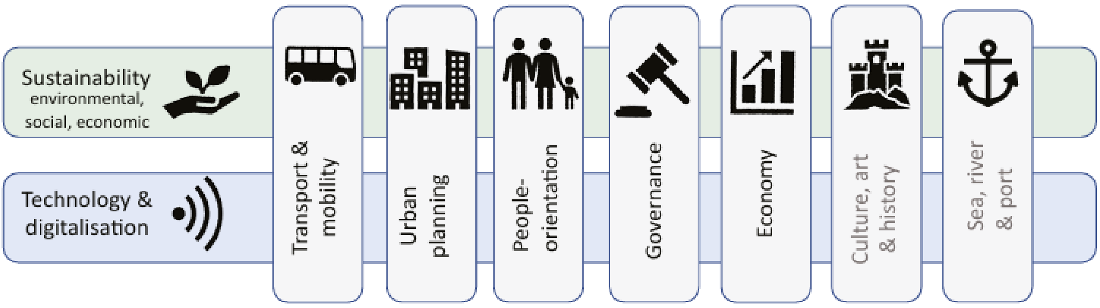

Figure 2. Social inclusion in smart port cities. Source: Research Briefings 1/2025 Digital integration generates synergies driving the development of a smart port-city

Smart port cities are not only technical, but also socially inclusive. The voices of the people impacted by port development are as important as the economic activities too. Technology and digitalisation are sustainable modern initiatives in the maritime industry as it provides access to information, which is all designed to help not only the port management but the community.

The image above represents social inclusion in smart port cities and the maritime industry. This is a critical dimension of port development, such as the Port of Turku. Local community, workers, and citizens are part of the long-term sustainability of smart ports. The multi-layered smart port city frameworks above are a true reflection of how digital technologies such as AI, IoT, and autonomous vehicles drive green operational efficiency. In addition, the Port of Turku smart project shows digital integration helps improve the quality of life for residents, which helps create value between the port and city. This helps ensure citizens are free from pollutants and health hazards caused by carbon emissions. Therefore, people-centred approaches in maritime digital strategies is not just ethical, but it also provides practical implications for low-carbon smart ports in Finland and beyond (Wahlström et al., 2025).

4.2 Policies and regulations for Maritime energy transition

4.2.1 International regulations and standards

The International Maritime Organization has been responsible for establishing regulatory standards for the shipping industry, helping to bring balance to the global economy. The IMO also consists of two other conventions, that have played a vital role in maintaining environmental sustainability, MARPOL (International Convention for the Prevention of

Pollution from Ships) and SOLAS (International Convention for the Safety of Life at Sea). MARPOL aims to protect the marine environment from ship-borne pollution, ballast waste, and carbon emissions, whereas SOLAS addresses the operational aspects of ships, including the movement of goods and cargo handling, the design, construction, working environment, and protective security measures(*Smart-Ports-and-Maritime-Logistics-from-Finland. 2020*). With these key regulations, digitalization in the shipping industry can be adopted while ensuring standards are met.

The International Maritime Organization, as of 2023, has adopted a strategy to reduce greenhouse gas emissions from ships, including reaching net-zero GHG by 2050. In this effort, IMO has set targets to assess companies' compliance in the shipping industry to ensure environmental sustainability standards are met. For example, the main metrics include the EEDI (Energy Efficient Design Index) which aims at reducing carbon emissions of different vessel types per capacity mile taken; the SEEMP (Ship Energy Efficiency Management Plan) used to manage ship and fleet efficiency over time through the Energy Efficiency Operations Indicator (EEOI), EEXI (Energy Efficiency Existing Ship Index) for measuring technical decisions required for carbon capacity through slow steaming and retrofitting clean technologies, and lastly the carbon intensity indicator that applies to all vessels above 5000 gross tonnage trading internationally. The international regulations and policies remain clear and IMO still argues that, although there has been much attention paid to the reduction of pollution, there are still some policy limitations on alternative technologies, such as digitalisation and the impact it can have on the environment (*Smart-Ports-and-Maritime-Logistics-from-Finland.2020*).

4.2.2 European Union regulations

The European Union has initiated an EU Emission Trading System that requires European communities with vessels of up to 5000 GT to comply with the trade and cap system. These regulations aim to reduce greenhouse gas emissions while allowing certain emissions subject the total amount of GHGs to be emitted. The European Union has also applied an Energy Taxation Directive (ETD) that provides a structure on the tax rates based on the performance of the vessels, including their impact on the environment and from an energy consumption perspective. These measures are being implemented to limit the use of fossil fuels, with the lowest rates given to companies that continue with sustainable practices, such as implementing key digital technologies while also adopting renewable energy sources. In addition, the European Union policies and regulations through the Fuel EU Maritime initiative program “look to address market barriers for sustainable alternative fuels,” which is crucial for companies in monitoring their operational efficiencies (Commission, 2025). In addition, the regulations of the Fuel EU Maritime have received certain criticism from shipowners as companies should achieve 75% cut in carbon intensity between 2020 and 2030. This regulation promotes biofuels rather than developing digital operational efficiency that endorses sustainability in the maritime industry.

4.2.3 IMO Global strategy for maritime digitalization

The International Maritime Organization has set out strategies to leverage emerging technologies to create a fully interconnected, harmonized and automated global sector (MaritimeHub, 2025). Shipping companies have adopted, helping them develop an organizational culture of technology advancement and development within the sector. Key technologies such as Internet of Things, Big data analysis, blockchain technologies, digital twins for example, are all safeguarded by the policies and initiatives designed by IMO to enhance operational efficiency, safety and, sustainability in the shipping industry. The IMO assembly, which is the highest governing body has set strategies that look to foster a harmonized interconnected and autonomous sector, Furthermore, these strategies allow for the identification of emerging technologies that support the industry in alignment with IMO’s various committees.

The Secretary-General of the International Maritime Organization MaritimeHub.(2025) mentions how the industry is moving towards a robust future filled with cutting-edge technologies that enhance its transformative potential. However, it also brings significant challenges, including security threats, cybersecurity risks, and the global digital divide. To combat cybersecurity risks, the 49th session of the IMO Facilitation Committee (FAL) in London outlined a plan to develop cybersecurity measures to safeguard maritime operations from attacks on the internet or corresponding networks.

To conclude, maritime digitalization remains a game-changing effort, with improved logistics and optimized routes that have reduced carbon emissions. This highlights how the maritime sector is not just going through a technological upgrade, but the strategic transformation is an opportunity for operational efficiency, global trade, and environmental sustainability.

4.2.4 Regulations for Sulphur Emission

Numerous international agreements and policies have contributed to the setting of environmental goals. The Finnish port in the Nordic region has been following regulations on sulphur emissions, with the Sulphur Emission Control Area (SECA) responsible for mitigating carbon emissions. These policies have helped with route and environmental optimisation, both crucial in meeting the International Maritime Organisation's (IMO,s) 2050 net zero targets (Inkinen et al., 2021).

The United Nations has initiated MARPOL (International Convention concerning prevention of pollution on the marine environment by ships), a key treaty established by the IMO. In 2012, the Nordic countries and particularly Finland were part of the sulphur emission regulations adopted by MARPOL and Annex VI, which set targets of reducing sulphur fuel consumption from 3,50% into 0,50% by 2020 (Fagerholt et al., 2015). This further explains the significance of adopting digitalisation in the maritime sector, as it brings opportunities to improve ship performance through real-time monitoring and optimisation of fuel efficiency while meeting the targets of MARPOL. Data-driven approaches in mitigating and cutting down the trade cap of sulphur not only help in operations but also empower workflows and improve communications, which contribute to ensuring a seamless flow for overall efficiency (admin tom, 2024).

The policies defined by MARPOL demand compliance from port companies as required by the European Commission Areas (ECA), and through the adoption of digitalization, energy-saving methods such as liquid natural gas, scrubbers, and fuel switching could be monitored. Digitalized approaches in sulphur emission prevention will assist in supporting renewable energy integrations, enhancing energy efficiency across various sectors of the industry. By switching to cleaner technologies, companies can reduce emissions, allowing them to be more flexible in adopting the IMO 2050 targets of net-zero carbon emissions, while also diversifying from traditional energy sources like coal (Crane, 2024).

4.3 Port of Helsinki analysis and report

The port of Helsinki is the busiest in Finland. It is also Finland's leading general port in terms of trade in goods and services, foreign trade, and digital applications in operational activities. Smart solutions have rapidly developed in Helsinki maritime activities, with passengers following smart port ticket gates and smart solutions in the transfer of goods, all contributing to sustaining the environment. The Helsinki port manager has emphasized that digital port projects have immensely improved the industry in working towards the IMO targets of net-zero carbon emissions. (Aunola, 2022).

In the Port of Helsinki E magazine company report, there is evidence of digital applications through drone operations, which have contributed not just to surveillance but also to navigation. The port can benefit from a range of imagery, which helps forecast the port's digital future, monitor containers thermally using visual images and thermal cameras, which help in containerisation of products, including moving and handling of goods (Liimatainen, 2026). The port is advancing by the day, and through the annual report, we can identify trends and how the impact of digitalization methods, such as drones, is contributing towards operational efficiency in Finland's Maritime industry.

The Port of Helsinki has developed its smart ticket system, with passengers passing through technical gates, boosting efficiency and saving time in terms of berth movements. The gate system has always been practiced at the West Harbour; different port terminals, such as the "Olympic terminal" and the "Katajanokka", are also progressing towards these initiatives. In addition to the Smart port ticket systems, the port has also introduced a technique that applies artificial intelligence through automatic identification. Automatic identification has been key to the flow of goods and services at the port, helping operations become time efficient. For example, the automatic identification system permits the measurement of permits to be measured automatically, and trucks are weighed effectively, which not just boosts the port operation, but it ensures the whole maritime cluster is running smoothly, contributing to the economy of Finland (Aunola, 2022). Collaboration and coordination within the maritime cluster have been made easier with the aid of artificial intelligence, big data analysis, drones, internet of Things, in that traffic congestion is prevented, for example. The Port of Helsinki eMagazine also reports on how smart traffic is being utilised to prevent traffic congestion, hence reducing the rate of carbon emissions in and around port areas. The smart traffic technology significantly identifies emerging traffic congestion and alerts the phasing of the traffic lights through real-time information from images from fixed cameras and drones, analysed by artificial intelligence. This is evidence of how digitalisation not only supports energy transition but helps resilience and efficiency, all contributing to the critical nodes of global trade.

To conclude, the managing director at the international association of Ports and Harbors (IAPH) mentions how “ Ports are more than just gateways for goods, they are the engine for economic growth, innovation and sustainability” applying key technologies such as drones, artificial intelligence and big data such as smart ticket systems and smart traffic congestions, ports can “ navigate uncertainty, seize opportunity and ensure global trade thrives in an era of change (Verhoeven, 2026 pg.1).

4.3.1 Emissions from Port areas

The Port of Helsinki produces carbon emissions from various sources such as ship and machinery emissions, vehicles, and emissions from port operations. According to the Port of Helsinki report “The emissions from the port include the emissions from vessels in water areas managed by the Port of Helsinki.” This includes the calculations of vessel arrivals and departures, including the time spent at the dock.(“Port of Helsinki, Annual Report 2025,” 2025 Pg. 26)

The total emissions from the Port of Helsinki amount to:

- 69,000 tonnes of CO2e, which is an improvement from 70,600 tonnes in 2024, a decrease of 2,2%.
- Emissions from ship traffic amounted to 6100 which was an increase of 4,9% since 2023.
- Vehicle traffic emissions amounted to 6200 CO2e, a 0,1% decrease in emissions since 2023.
- Machinery emissions operated in the port area amounted to 6900, a 5,7% decrease in emissions since 2023.

These results show progress towards net carbon emissions, and they represent the impact of digital technologies in achieving green operational efficiencies.

4.3.2 Emissions from the port of Helsinki operations

The Port of Helsinki operations indicate progress towards achieving the IMO's net-zero carbon emissions targets. The figures in the Port of Helsinki 2025 annual report show a clean transition to net-zero emissions at the port, with the share increasing from 71% in 2023 to 73% in 2024 and reaching 100% in 2025. This reflects the impact of key technologies such as artificial intelligence, blockchain, and the Internet of Things, for example. Simultaneously, it shows the effects of the environmental transition from fossil fuels, with onshore power rising from 6,444MWh in 2023 to 8,327MWh in 2024 before decreasing to 6,990 MWh in 2025. Despite the digital revolutions transforming the industry, demand for onshore power remains directly linked to ship activities. Key technologies have always been essential for shore-to-ship electricity because of their role in smart energy management systems, load balancing, real-time monitoring and automated billing platforms ("Port of Helsinki, Annual Report," 2025, Pg. 27).

4.3.3 Carbon emissions per ship

The Port of Helsinki 2025 annual report presents the emission rates of ships in tonnes, and CO2e emissions per ship net tonnes/CO2e(t)/1000NT. The figures indicate a decrease in total ship CO2 emissions and intensity after 2023–2024. Emissions at the port have reduced slightly from 57300 tonnes in 2023 to 56000 in both 2024 and 2025, indicating stabilization. The emissions per unit of transport from the Port of Helsinki improved from 0,56 CO2e(t) to 0,53 CO2e(t) and then to 0,51 CO2e(t) per 1000 net tonnes over the 3 years. This indicates that overall emissions in the port remain stable, likely due to the impact of digitalization and key technologies over the years, showing operational and technical efficiency("Port of Helsinki, Annual Report," 2025,pg .28).

4.4 Port of Turku (Analysis and Report)

4.4.1 Current ongoing projects and how they shape the maritime industry

The Port of Turku has advanced technologically, with the maritime sector becoming one of the most digitized cities in Finland. Many ongoing projects have contributed towards aligning with the international Maritime strategy of meeting net-zero carbon emissions by 2050. The Port of Turku has adopted key technologies which include Internet of Things/ big data analysis, artificial intelligence, 5G networking, and the green corridor sustainability initiative, all applied in various ongoing projects. These projects include examples such as ARPA, NaDaMe and 54M, for example, all providing key evidence of feasibility barriers and potential impacts of digital technologies and how they can be operational within the industry (*Smart-Ports-and-Maritime-Logistics-from-Finland.2020*).

4.4.2 Autonomous and intelligent system (AIS)

The University of Turku is currently undertaking projects aimed at creating intelligent hubs for autonomous operations to utilize digitalization within the shipping industry. These projects are useful for sustainable digitalization as they provide a platform for key technologies such as artificial intelligence and digital twins to be implemented in the real world. The University of Turku's applied sciences also serve as the hub for Autonomous Intelligent Systems (AIS) for the Port of Turku. Through this, robotics and machine learning are all explored within the maritime industry, with various components such as the test vessel eM/S Salama, the remote operation centre, 5G test network Turku and data platforms all integrated into one maritime cluster (Jokela, 2024).

These technologies reveal how complex implementing digitalization into the industry can get. For example, the University, in collaboration with the port, developed an unmanned surface vessel known as the eM/S Salama, which has been used as a test bed for automation and remote control, contributing towards the blue growth sector in Turku. The unmanned surface vessel is a unique sustainable project that’s also being implemented in Ferry operations and cargo handling at the Port of Turku. The eM/S Salama is a vital project because it provides green operational efficiencies through its sophisticated multi-model sensing systems algorithm that deploys thermal cameras, useful in detecting objects and providing situational awareness of the vessel's environment (Jokela, 2024).

4.4.4 Remote Operating Centres and 5G networks in Turku

The Port of Turku has immensely benefited from the Remote Operations Centre (ROC), particularly in vessel navigation, thereby helping reduce carbon emissions. A Remote-control centre requires complex algorithms and tools to maintain operational efficiency. The unmanned surface vessels (USVs) will help the port of Turku not only increase safety and efficiency but also improve its data communication links. According to the (Jokela, 2024) "The sensor data of the USV transferred to the Remote Operations Centre can also be utilized directly in a digital twin of the vessel," which will be vital for the industry in meeting its ongoing IMO 2050 targets.

The wireless communication links of the Port of Turku and the Turku University of Applied Sciences consist of networks that operate with SIM cards for 4G and 5G. For instance, the Port of Turku is currently using a 4G/5G private network (Rapidly deployable network) for its data testing of digital twins, artificial intelligence, and research and development use.

4.4.5 Sustainable shipbuilding ecosystem, Port of Turku

The University of Turku's Applied Sciences, in collaboration with Meyers Turkus's NecOleap locomotive project program, has developed project initiatives that have helped promote shipyards' objectives. The shipyards in the Port of Turku have a research budget of 6 million euros, and it aims to focus on reducing its carbon footprint through digitalization and strengthening its competitiveness both in the Finnish Maritime Cluster (Aramo-Immonen, 2024). The project is an example of how key digital technologies, such as blockchain, are being used to analyse the sustainability of material management and shipbuilding networks in the maritime cluster. For example, through the 54M model project implemented by the University of Turku and Port of Turku, companies are benefiting by identifying sustainable material activities and marketing positions, which is not only an economic boost but also an opportunity for operational efficiency and information flow. Furthermore, the project has improved the Port of Turku's environmental and cost efficiencies, as well as the performance of various companies within the supply chain. According to (Aramo-Immonen, 2024), the project has not only developed tailor-made digital solutions, but it has been a useful tool in optimization and monitoring, which has helped improve environmental performance.

4.4.6 Port of Turku Traffic and Management System

The Port of Turku has developed similar models to the Port of Helsinki for passenger and traffic management systems. The Smart port system has undergone a digital leap as a major passenger system, and the Port of Turku has experienced a similar advancement. A digital company called "Weasel Software OY" has helped the Port of Turku with continuous management of passenger and vehicle traffic in the terminal environment, ensuring smooth operations during peak hours. This is significant as berth movement is observed effectively. According to Eric Soderholm, managing director of the Port of Turku, the objectives of the Turku project is to ensure a smooth and comfortable experience for customers, contributing to turnaround and real-time operations (Laurila, 2026). The Weasel Software OY in the Port of Turku is a modern digital impact that creates opportunities for improvement across the industry and eliminates barriers such as operational bottlenecks and resource constraints.

4.4.7 Port of Turku Rate of emissions

The Port of Turku annual report of 2024 shows CO2 emissions per tonne from 2020-2024. The report indicates that 2020 produced the highest emissions in the air at 15,651 CO2 tonnes compared to 2024, which dropped significantly to 5,249 CO2 tonnes, an overwhelming reduction of 10,402 CO2 tonnes, approximately 66%. The biggest drop in that period was from 2020 to 2021, with 5252 tonnes recorded as having decreased. This marked the introduction of key technologies in ports, with various factors such as digital awareness contributing to environmental sustainability. It aligns with the Finnish Maritime strategy policies as the industry continues to make use of digital technologies, which have helped with port optimization, cargo handling, smart energy systems, and just-in-time arrivals; for example, all contributing to green operational efficiencies (*Port-of-Turku-Annual-Report*.2024. Pg.24)

4.4.8 The impact of digitalization on electricity consumption

The electricity consumption in the Port of Turku report shows a steady decline from the period of 2020 to 2024. In 2020, the port produced a total of 7488 MWh and in 2024 they produced a low of 5,829 MWh, a difference of 1659Mwh. This indicates improved utilization of digital technologies, which has proven operational efficiency within the Port of Turku, encouraging sustainability within the maritime industry.

4.5 Automated Identification System (AIS) for port and vessel movements

The Marine traffic website and Finland's Traficom port timetable will be used to identify trends and compare berth movement and berth occupation in Finland and the Nordic region.

The public data collection platform aims to achieve measurable outcomes. Through an Automated Identification System (AIS), we can identify the significance of Digitalization in the Maritime industry. In addition, the platform allows for route optimization, including efficiencies and deviations (position latitude/longitude over time), turnaround times for berth movements, speed patterns that demonstrate the importance of fuel efficiency and automation, and traffic density for network effects (Vessel types and IMO/ MMSI unique identifiers). These key technology indicators the impact of digitalization in achieving green operational efficiency.(traffic, 2026)

The Marine live tracking website is a public platform that helps collect quantitative data and sampling methods, which will be used to record specific vessels, departure times, arrival times, and average speeds from the Finnish ports.

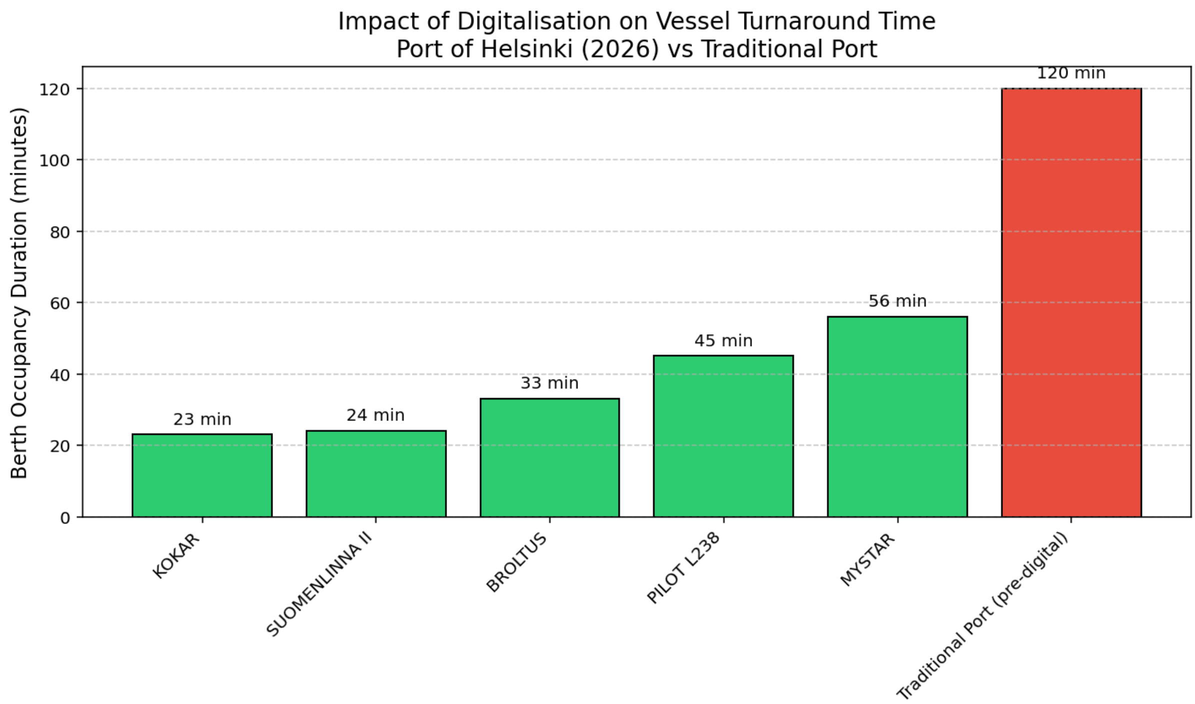

Figure 3. Impact of digitalization on vessel turnaround times. Source: Port of HELSINKI (FI HEL) | Live Arrivals, Departures & Details

Looking at the data provided above, the Marine live tracker and the vessel turnaround graph present arrivals and departures of vessels at the Port of Helsinki. This information shows how digitalization provides operational efficiency. For example, vessels such as Suomenlinna have a 24-minute occupancy, and Broltus has a 33-minute occupancy, due to factors including improved digital technologies, automation, and fewer paper-based operations.

In comparison, Finland's traficoms ports timetable presents traditional ways of operational activities, with vessels taking days between arrivals and departures. The occupancy takes up to 3 days in comparison to the 2026 Marine live tracker which has a turnaround time of up to 1 hour at most. The prolonged berth occupancy due to traditional methods in 2023 shows how manual documentation, slow communication, lack of real-time tracking, and non–optimized berths caused delays that routinely extended vessel turnaround times of up to several hours/days.(*Traficom: Satamien Aikataulut*,2026.)

4.6 Live tracking of Viking Grace example

Table 3: Viking Grace location. Source: [Global Ship Tracking Intelligence | AIS Marine Traffic]

Parameter	Value
Vessel name	Viking Grace
IMO number	9606900
MMSI	230629000
Departure port	Stockholm, Sweden
Destination port	Turku, Finland
Region	Baltic Sea
Recorded time	08 Apr 2026, 20:43 UTC
Speed	21.1 knots
Route characteristics	Baltic sea navigation

The table above illustrates how the public marine live tracker platform demonstrates maritime digitalization in action. It is a representation of the Automated Information System presented on the marine live tracker; in this example, the Viking Grace vessel's route navigation is from Stockholm (Sweden) to Turku (Finland). The IMO (International Maritime Organization) number is 9606900, and the MMSI (Maritime Mobile Service Identity) is 23062900 (a unique identification number for all vessels). On 08 April 2026 at 2043 UTC, the Viking Grace vessel was recorded travelling at 21.1knots. This information is important for monitoring vessels, tracking trip times, using speed readings to indicate operational status, and for just-in-time arrivals. Through the Marine Traffic app, ship routes are also shown as zig-zag movements, a useful way to monitor external factors such as weather and traffic congestion. The platform is also crucial for operational awareness and achieving operational efficiency, underscoring the importance of digitalization within the industry, which have improved operational efficiency.

4.7 Barriers and Enablers: Identifying problems in implementation and identification

Port digitalization has become the norm in modern-day maritime logistics, with ports worldwide regularly upgrading their systems in pursuit of a competitive advantage.

Digitization, to an extent has become a paradox of reality vs maturity, with small ports paradigms looking to adopt digital maturity in situations where experience and training are required to understand the maritime technological ecosystem. This is one of the most common challenges in today's world as decisions in the initial phases of digitalization, such as technology procurements, data governance, and architecture design, can be costly and complex to execute. According to an article written by Brunila et al. (2021) on “hindrances in port digitalization,” ports must execute regular reviews and updates to make decisions on the types of technologies that must be. This directly links to the topic on “the role of digitalization in enhancing green operational efficiency in Nordic maritime logistics,” and despite Finland being a global digital frontrunner, there remain gaps between the investments put in the procurement of technologies and the environmental outcomes. Finland Maritime Logistics has the capacity in digital tools and the know-how for productive and efficient supply chain operations; however, the fundamental conditions to execute these tools and deliver the intended outcome are often compromised.

Digital transformation in the maritime industry has significantly evolved shipment by introducing competition, increasing costs, and improving operational efficiency. In contrast to other industries such as banking, telecom, agriculture, and retail, the network-centric linear shipping industry slowly continues to adopt innovation and embrace digitalization (Raza et al., 2023). Successful port digitalization has been impeded by a lack of systematic identification, and to categorize challenges in daily operations, there needs to be a structure to implement measures to eliminate these barriers. According to the articles by Brunila et al. (2021), the authors categorized these challenges into five interconnected domains, namely resource-based, organisational, security, technicality, and strategy, with each category carrying investigations into green operational efficiency. In addition, Raza et al. (2023) mention how resource-based challenges, such as costly manual processes, customer interfaces, and particularly volatile fuel prices, must be adequately addressed, and this can be done through integrating renewable energy sources, such as liquid natural gas, installing solar panels, and generating energy from the wind. Furthermore, the Maersk logistics company, which carries out supply chains and offers integrated logistics solutions (Moller, n.d.) has proven that transport costs are not just from physical movements but also from documentation and management, which helps reveal how the digital environment does not allow for net-zero marginal cost, another challenge that the industry will need to address. This diagnosis from Maersk logistics company, as well as Finnish ports, such as Helsinki and Turku, has proven that green operational efficiencies can be identified and measured, with a series of academic articles documenting the essence of closing the gaps on digital adoption through addressing barriers such as insufficient technical skills, costs of procurements, and cybersecurity concerns, for example. However, Sanchez-Gonzalez et al. (2019) mention that shipping industries have become “reluctant in adopting new digital technologies and increasing innovations” compared to other sectors globally, and Finland has put itself in a position to argue against this. The country has been active in upgrading its smart port systems with a range of technical adoptions implemented, including AI-driven solutions and digital platforms. For example, the EU H2020 Corealsis project, defined as “Capacity with a positive environmental and societal footprint,” is a Finnish company that deals with autonomous port operations for smart logistics. This company has looked to close the barriers of digitalization through initiating projects that support emerging 5G networks for cargo handling and port operations. The company has developed cybersecurity projects and preparedness plans to identify, with this holistic approach significantly helping raise awareness across all maritime supply chains (*Smart-Ports-and-Maritime-Logistics-from-Finland.2020*).

Finland's digitalization projects face various barriers, particularly those mentioned in the previous paragraph, including technical, resource-based, organizational, security, and strategic barriers. Each of these categories has its own implementations that directly link to the investigations of green operational efficiencies in Finnish ports. For technical barriers, “information silos” have caused data fragmentation with equipment and software shared across multiple vendors, resulting in missed opportunities for optimization. This can cause information to be duplicated and later result in ports misplacing data, which could in turn affect supply chain management(Brunila et al., 2021). In addition, data fragmentation and duplication can lead companies to avoid transparency as they compete in the ecosystem. As Efimova et al. (2020) mentions how lack of information leads to operational bottlenecks and to mitigate this Tsiulin et al. (2020) add that blockchain technologies enable efficient use of decentralized and transparent database solutions. Blockchain technologies are also vital for communicating with multiple stakeholders, such as dockworkers, shipping owners, and maritime authorities, because they provide a platform to address issues like privacy breaches. Decentralization in blockchain technology will be important in preventing “data tampering,” which will allow for a smooth flow of economic and environmental activities in the maritime logistics industry (Li & Sun, 2025).

4.8 Document analysis: A Nordic comparison between Finland and Norway

Norway has gained a reputation for becoming a frontrunner in digital adoption, with most maritime software developers and technical leaders originating from Norway (*Maritime-Software 2024*.). Norway has nine smart ports under development to enable infrastructure development and support automation and operations to facilitate the green transition. For example, in Oslo, there are plans for the port to be the first to receive a 3D model above sea level. Stakeholders from the research project "AutoPort270" aim to develop the next generation of autonomous ports through a combination of Artificial intelligence, operations research, and cargo handling processes. Finland is leading in the digital maritime industry and is the frontrunner for smart ports, automation, autonomy, and cloud-based technologies. The national transport system plan 2021–2023, states that local authorities, as port owners, continue to promote port digitalization and automated shipping. In comparison Finland has transformed the world of digitalization with the introduction of innovative technologies within the maritime sector such as the "Fintraffic Vessel services". The FVS is a port activity app that represents the entire supply chain with an interface for port communication and collaboration within the ports, generating operational efficiency. The European Union has also created a vessel port notification system that allows countries like Finland to share key information across the European maritime single window(*Nordic Innovation*, 2024.). According to the Norwegian maritime authority "digital shipping has challenged commercial shipping and established between land and sea" but it's not only bought an opportunity for economic growth, it has "streamlined and provided a strategy for ships, crews and the environment, with the help of equipment and tools(Bua, 2026) . Artificial intelligence has dominated Norway's industry, and still hold significant potential in enhancing operational efficiency, safety and decision making. Port authorities and shipping owners have benefitted from key technological optimisation, route navigation fuel consumption and enhanced strategic decision. However, like the Finland Maritime Industry, the costs of processing the technologies are high, while data security and cyberthreats remain to be a significant barrier. In terms of GHG emissions, the Norwegian climate policy has "increased its greenhouse gas emission reduction target from 40% in 2030 to 55%, with a combination of 90–95% reduction by 2050 (Brun, 2024).

Finland's Port of Helsinki and Norway's Port of Oslo have similar targets in the digital maritime industry. The port of Oslo has an energy-led transition with over 85% of its reduction targets set by 2030. The country's maritime industry has particularly focused on cutting down its carbon emissions through shore power, battery electrification and biogases, with digital tools used to monitor port emissions. This has helped reduce GHG emissions in the port, which was responsible for 55,000 tonnes of CO2 emissions per year, accounting for 4% of the total emissions in the city of Oslo (Bua, 2026). However, Finland's maritime strategy is more data-driven, with autonomous vessels and real time data sharing optimising operational efficiency through improved emission rates and improved turnaround times. For example, the port of Turku has recorded a 66% CO2 reduction, and the port of Helsinki has a 9% reduction between 2020–2025, and unlike the port of Oslo, which relies on shore power, Finland's emission reduction is mainly due to data-centric digital integration. On the other hand, Finland's needs to improve on its onshore infrastructure at port level, as this will help achieve its sustainability goals.

Overall, the port of Oslo needs to address its gap of digital readiness through creating online platform such as Finland's Fin traffic vessel services and Portnet, and likewise Finland will need to cover the gap of implementation specify and updated governance. Integrating these technologies, require consistent and adoptive decision making, with a sustained political commitment, adequate regulation and public-private collaboration (Bourhriba, 2024).

5. Discussion

5.1 Interpretation and Findings

The embedded case studies of the Port of Helsinki and the Port of Turku illustrate how digitalization has enhanced green operational efficiency in Finland. The report reveals three different patterns, namely, the impact of digitalization in reducing greenhouse gas emissions, operational efficiencies shown from turnaround times, and policy alignment in its goal to achieve net-zero greenhouse gas emissions by 2050. Finland remains the digital frontrunner in the Nordic maritime sector, as ports continue to develop smart systems. There is progress towards meeting the IMO GHG net zero targets, as the documents indicate improved emission rates and the ways digital tools have supported operational and emissions management. However, the industry faces setbacks, predominantly in strategic organization, technical barriers, data fragmentation, transparency, and information silos. These challenges demonstrate that digitalization alone is not sufficient without coordinated systems.

5.2 Digitalization in emission reductions

The data discussed demonstrate the emission rate in the Ports of Turku and Helsinki, both showing significant progress towards achieving net-zero carbon emissions between the periods of 2020–2025. In contrast, the Port of Helsinki reported a modest 2,2% carbon emission reduction between 2023–2025. These results demonstrate a gap due to differing digital advancements within the ports and the timeframe in which they were recorded. To further elaborate, the Port of Turku introduced several digital initiatives within the period from 2020 to 2025, which include the eM/S Salama autonomous vessel projects and 5G private networks which contributed to remote operating centres. In contrast, the Port of Helsinki's modest emission reductions were mainly due to its busy schedules. This is different from the port of Turku, because of the high volume of ships and commercial activity in the area. For example, the emission per unit of transport was recorded as improving from 0,56 to 0,51 per 1000, a net reduction.

5.3 Operational efficiency improvement

The port turnaround times are a sign of significant improvement, demonstrating the importance of digitization in the industry. The Automated Identification System (AIS) and Viking Grace vessel show that turnaround times in 2026 ranged from 24 minutes to almost 2 hours, in contrast to the traffic data, which had a turnaround time of up to 3 days, delayed by fragmented communication and manual documentation. Digitalization has had a major impact on operations, with the study clearly showing how smart gate operations have contributed to the rapid and efficient mobilization of clients in the Port of Helsinki.

5.4 Addressing Research Questions

5.4.1 Research question one

How do advanced technologies in Finland's ports influence quantitative and qualitative indicators of green operational efficiency, such as carbon emissions and energy consumption?

Key technologies like Internet of Things, artificial intelligence, Automated Identification Systems, and blockchain technologies have proven how green efficiency and operational productivity have progressed in the industry. For example, we identify different mechanisms that have shown the impact of digitalisation. Route navigation and optimisation have been made easier, with the Viking Grace showing AIS data that has resulted in improved energy consumption, through indicators such as the duration of journeys in hours, speed, and distance travelled and zig-zag navigations that show that pathways of the journey. Furthermore, berth efficiency in ports through turnaround times have initiated seamless flow of daily port activities, contributing to operational efficiency which improves the economy of the industry. They have also been quantitative indicators that have shown improvements in emission rates and qualitative indicators demonstrating policy documents, and port reports that cite how digitalisation has influenced green operational efficiency in the maritime industry.

5.4.2 Research question 2

To what extent has digitalization in Finland's ports been in alignment with the national strategy and the regional Nordic targets towards achieving its overall sustainability targets?

From the findings, we can identify an alignment with the Finnish maritime strategy, with calls for improvements in data-driven port operations, intelligent logistics, supply chains, and international cooperation shown from the Fintraffic vessel services app and data sharing with Automated Identification Systems across borders (Sweden and Estonia). The information collected from the Nordic alignment through the maritime energy transition (DNV, 2026) and the European Union fuel maritime initiative is documented and serves to initiate the Finnish industry in the right direction. However, these documents still have gaps that need to be addressed in terms of policing and implementation. For example, the 2014–2022 Finnish maritime strategy was formulated, but it was not fully implemented to its desired targets. Another factor is how smart port operations vary across the country; for example, the Helsinki smart ports are advanced (because of how busy it gets) yet Turku ports specialise in autonomous vessels and research and development, which shows lack of coordination and consistency in policy making. Finally, stakeholders' involvement is fragmented, although they are public-private partnerships, more needs to be done in addressing the gaps in policy-making and digitalization.

5.4.3 Research question 3

What key barriers exist in the industry? What can be done to achieve its full potential for digitalisation, reducing carbon emissions, and what strategies have been deployed to overcome technical, organisational, and regulatory barriers?

The barriers found in the maritime industry are common, like other industries, retail, mining and agriculture for example. The biggest setback is resource-based barriers, and in particular, procurement and maintenance of key technologies like artificial intelligence and infrastructure. Another barrier in the digital world is the issue of cybersecurity. Cyber security threats remain common in the Baltic Sea, the Straight of Hamaz and other popular channels. These threats, including data fragmentation and information silos, require urgent attention and policymaking. However, the journey towards overcoming these barriers looks promising. For example, the University of Turku has developed testbeds and mechanisms aimed at addressing remote control centres through initiating 5G networks, while focusing on projects like the vehicle’s eM/S Salama. The industry has also benefited from the availability of public data through Portnet, Automated Identification System, and the Fintraffic vessel services, which have all contributed towards achieving the IMO GHG emission reduction and sustainable development goals.

6. Conclusion

6.1 Summary

To conclude, this study demonstrated the role of digitalisation in enhancing green operational efficiencies in Nordic Maritime Logistics, with a focus on Finland's ports as a case study. The findings have proven how the industry is moving towards an upward trajectory due to the impact of digitalisation. Key technologies like Internet of Things (IoTs), Artificial Intelligence, and blockchain technologies have contributed towards environmental outcomes, proving to be valuable in meeting the International Maritime Organisation's 2050 targets of greenhouse gas emissions. These technological impacts vary according to the port's magnitude; for example, the port of Turku had a 66% CO2 reduction from the periods of 2020–2024, while the port of Helsinki had a 9% reduction, all in alignment with policy documents. However, the industry still has fragmented data systems, high resource costs, and ongoing cybersecurity threats (Raza et al., 2023). The gap in reinforcing existing infrastructure and upgrading huge investments remains in Finland, the Nordic region, and the global maritime industry (Zhang et al., 2024). Overall, there is a long-term Finnish Maritime strategy that enforces the country's port digitalization is developed at a steady rate in alignment with the IMO GHG 2050 targets. This will initially depend on the coordination and attitudes amongst stakeholders, government, port owners, and the maritime cluster in sustaining the industry.

6.2 Contribution to knowledge

This research helps explain why Finland is regarded as a frontrunner in digital applications and green operational efficiencies in the maritime industry. The case studies of the Helsinki and Turku ports represent a small magnitude of what is an increasingly fast-developing industry in Finland. The research also addresses the urgency in covering the gap between technological investments and measurable environmental outcomes. In addition, the barrier and enabler section identifies data fragmentation, cybersecurity, procurement costs, and organizational setbacks as the main concerns; addressing these will help Finland's Ports develop immensely. Lastly, the study doesn't look at general digital tools, but it explicitly shows how these tools can help contribute to energy consumption, reduce carbon emissions, and achieve operational efficiencies.

6.3 Recommendations

Finland's maritime industry should adopt policies and strategies that produce clear environmental performance targets. More publications and research should be available online, not just to create global awareness around the unspoken industry, but also to provide a platform for staff development and training. The industry needs to address the issue of cybersecurity, and this could be done through constant security updates and policymaking (Raza et al., 2023). Furthermore, there needs to be a link in digital investments and the intended environmental outcomes, with constant evaluations of emission reports and energy consumption measures. Policymaking in the Finnish government should be regularly updated through binding digitalization targets and the establishment a national port digitalization board.

6.4 Further research

The topic paves the way for future research. Primary data would be pivotal in identifying barriers and enablers through stakeholder involvement, surveys, and interviews. Additionally, digitalization is growing rapidly in the industry, and research could benefit from identifying incidents such as GPS spoofing. There should be a cost-benefit analysis for future digital investments, key in analysing prospects of the industry (Brun, 2024).

6.5 AI Disclosure

Artificial intelligence tools were utilized in the preparation of this text to support literature exploration and enhance the identification of relevant sources and perspectives. AI was also applied to assist in organizing and refining analytical categories, as well as in interpreting and cross-checking thematic findings. Additionally, AI contributed to improving the clarity, structure, and overall readability of the written content.

7. References

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