Investigating the role of technological advancements in port operations and the development of smart, green and sustainable ports.

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Abstract

The advent of the Fourth Industrial Revolution has tremendously transformed the speed of adoption of technological advancements in all sectors and industries. Ports constitute one of the key industries undergoing this historic shift and transformation in their operations. Therefore, in order to keep pace with the rapidly changing operational landscape, the port industry is embracing and adopting at an accelerating pace the latest developments in technology with major impacts and benefits generated for both port operators and the hinterland.

Examination of the academic literature shows that the knowledge gap remains on how technological advancements in port operations affect the efficiency and performance of a port, and what benefits and impacts are generated for the hinterland. The researcher is not aware of any study that has holistically identified and analysed the relationship between technological advancements and generated benefits and impacts for port operators and the hinterland, as well as the different barriers and incentives for the development of smart, green and sustainable ports.

This research used a mixed-methods approach and included a literature review; a scoping study; a systematic review on the relationship between port efficiency and economic development; an investigation of the key characteristics of the world's leading container ports; a Website Content Analysis of the world's leading container ports; a case study of the UK port sector through in-depth semi-structured interviews with industry stakeholders; and a Participant Observation study of the transformational journey of a UK traditional port to become smart, green and sustainable. The analysis of the key characteristics of the world's leading ports and the Website Content Analysis focused specifically on container ports, while the UK Case study and the Participant Observation addressed all types of ports. The key technological trends pertinent to smart, green and sustainable ports are identified and smart scores are generated for a range of container ports around the world. This Dissertation contributes to fill the identified gap in the literature by providing: (i) insights and benchmarking of the world's major ports with regard to their smart, green and sustainability related practices and efforts; (ii) clear understanding of the different benefits and impacts generated from the application of technological advancements in port operations; (iii) detailed information on the factors behind the barriers for the maximisation of the potential gains generated for both port operators and the hinterland (iv) contribution to fill the identified gap in the literature by providing empirical evidence from the UK case study. A more comprehensive and precise understanding of the benefits and impacts generated from the application of technological advancements in port operations will guide policy makers and port operators make appropriate investment, design better policies, collaborate, address barriers (e.g.

skills gap, ownership structure, disincentives for investment, etc.) and identify drivers (e.g. the ports' client base is driving ports to focus more on new technologies, digitilisation and sustainability adoption, in line with trends in these areas along wider supply chain) as they plan towards the development of the smart, green and sustainable ports of the future, some of which too have potential to become clean energy hubs in their own right.

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Acronyms and Abbreviations

AAPA	**American Association of Port Authorities**
AGV	**Automated Guided Vehicle**
AI	**Artificial Intelligence**
AIS	**Automatic Identification System**
AMP	**Alternative Maritime Power**
AMS	**Automated Mooring System**
AR	**Augmented Reality**
ARMG	**Automated Rail Mounted Gantry**
ARTG	**Automated Rubber Tired Gantry**
ASC	**Automated Stacking Crane**
ALV	**Automated Lift Vehicle**
BCC	**Banker, Charnes and Cooper**
CA	**Content Analysis**
CASP	**Critical Appraisal Skills Program**
CCR	**Charnes, Cooper and Rhodes**
CCS	**Carbon Capture and Storage**
CGE	**Computable General Equilibrium**
CO2	**Carbon Dioxide**
CPPI	**Container Port Performance Index**
CS	**Corporate Sustainability**
DEA	**Data Envelopment Analysis**
DfT	**Department for Transport**
DMU	**Decision-Making Unit**

DTQC	**Digital Twin Quay Crane**
EMS	**Environmental Management System**
EPA	**Environmental Protection Agency**
E-RTG	**Electric Rubber Tired Gantry**
EV	**Electric Vehicle**
FA	**Factor Analysis**
FVG	**Friuli Venezia Giulia**
GDP	**Gross Domestic Product**
GDPR	**General Data Protection Regulation**
GHG	**Greenhouse Gas**
GNP	**Gross National Product**
GT	**Gross Tonnage**
GVA	**Gross Value Added**
HP	**Handover Point**
IAV	**Intelligent Autonomous Vehicle**
ICT	**Information and Communication Technology**
IHS	**Information Handling Services (publishing company)**
IMO	**International Maritime Organisation**
IoT	**Internet of Things**
ISO	**International Organisation for Standardisation**
IT	**Information Technology**
ITF	**International Transport Forum**
I-O	**Input-Output**
KPI	**Key Performance Indicator**
LAC	**Latin America and the Caribbean**

LED	**Low Emitting Diode**
LNG	**Liquefied Natural Gas**
Lo-Lo	**Lift-on Lift-off**
LPG	**Liquefied Petroleum Gas**
MARPOL	**Marine Pollution**
MPI	**Malmquist Productivity Index**
MVP	**Minimum Viable Product**
NOx	**Oxides of Nitrogen**
OPS	**Onshore Power Supply**
OREC	**Offshore Renewable Energy Catapult**
PCT	**Port Container Terminal**
PPI	**Port Performance Indicators**
QC	**Quay Crane**
RAF	**Royal Air Force**
RFID	**Radio Frequency Identification**
RMG	**Rail Mounted Gantry**
RO	**Research Objective**
ROI	**Return On Investment**
RQ	**Research Question**
RTG	**Rubber-tired Gantry**
SDG	**Sustainable Development Goal**
SFA	**Stochastic Frontier Analysis**
SLR	**Systematic Literature Review**
SOx	**Sulphur Oxides**
STS	**Ship-to-shore**

TA	**Thematic Analysis**
TEU	**Twenty-foot Equivalent Unit**
TFP	**Total Factor Productivity**
TP	**Technological Progress**
TTEC	**Total Technical Efficiency Changes**
UAE	**United Arab Emirates**
UNCTAD	**United Nations Conference on Trade and Development**
UK	**United Kingdom**
UN	**United Nations**
US	**United States**
VBS	**Vehicle Booking System**
VR	**Virtual Reality**
WPSP	**World Ports Sustainability Program**

“A smooth sea never made a skilled sailor”

Franklin D. Roosevelt (1882-1945)

Chapter 1. Introduction

1.1 Introduction

In the era of economic globalization and continuously changing shipping patterns, the vital role that ports play in modern transportation networks has been amplified (Chen, 2015). Since ports have always formed a vital link in the overall supply chain, they are regarded as pivotal elements in value-driven chain systems (Robinson, 2002; Tongzon and Heng, 2005; Chen, 2015). Therefore, the need for efficient practice in port operations constitutes an increasingly important challenge for both port operators and local governments (Gamassa and Yan, 2017).

The core objective of this research is to explore the determinants of port efficiency, the impact and the net benefits generated by the application of technological advancements in port operations on both port performance and the hinterland, and finally to describe in detail key ports concepts (smart port, green port, sustainable port). In this chapter the author outlines the overview of this thesis which is comprised of ten chapters.

1.2 Background to the Research

According to Goss (1990a), the economic function of a port is to provide benefits to the original producers of the exported goods and the ultimate consumers of the imported goods passing through it. Moreover, ports can be considered as major infrastructural assets that serve international trade and shipping, and their operation is a significant contributor for the achievement of a nation's competitive advantage (Tongzon and Heng, 2005; UNCTAD, 2018). Therefore, as international trade constitutes a significant engine for countries' economic development and productivity growth, port infrastructure and efficiency are among the most important elements for determining the level of a country's trade flows and economic prosperity (Feenstra and Ma, 2014; Sant' Anna and Kannebley Júnior, 2018).

Maritime transport carries more than four-fifths of global merchandise trade (by volume) and is considered the most reliable, energy efficient and economical mode of transportation (World Bank and IHS Markit, 2021). A continuously growing and significant portion of that volume, accounting for approximately 60 per cent of commercial value and 35 per cent of total volumes, is carried by containers (World Bank and IHS Markit, 2021). Containerisation has become the predominant driver of intermodal freight transport, as filling freight in containers decreases cargo handling and therefore losses and damages, while improving security and transport time (Gharehgozli et al., 2016; Agerschou et al., 1983). The surge of containerisation has also led to colossal changes in how and where goods are manufactured and processed (World Bank and IHS Markit, 2021). In particular, container ports face significant challenges and offer many opportunities and have thereby received a lot of attention from the academic community (Gharehgozli et al., 2016). Container ports are therefore pivotal nodes in global supply chains and of critical importance to the growth strategies of many emerging economies, as they can facilitate investment in distribution and production systems, creating employment, raising income levels and supporting the expansion of logistics and manufacturing (World Bank and IHS Markit, 2021). Based on these grounds, the focus of this thesis is primarily on container ports, and by choosing this focus the research is contributing to existing reviews on container port operations.

In recent decades the colossal changes in the maritime transport sector, particularly in the development of an efficient transport logistics chain, have affected the competitiveness and strategies adopted by ports (Cepolina and Ghiara 2013). Container shipping is characterised by a continuous search for economies of scale, as the deployment of larger container ships reap costs savings and contributes to a significant decrease in maritime transport costs (Merk, 2018). Today's port operating landscape is therefore portrayed by strategic shipping alliance formation, liner shipping consolidation, deployment of mega vessels, accelerated environmental sustainability trends, and a need to embrace and adopt digitalisation-driven innovations and technologies which require significant transformational potential (UNCTAD, 2021). Technological advancements will be critical for advancing environmental sustainability, as ports are facing excessive pressure to comply with the intense global sustainability agenda. Therefore, businesses and governments around the world aim to harness the synergies among technology, resilience, efficiency and environmental protection (UNCTAD, 2021). The way in which the impact of global key trends will be likely felt in ports is discussed below.

Over the last decade, the increase in containership size has accelerated, since both the average and the maximum size of container ships has doubled (Merk, 2018). Nowadays, the largest container ship can carry a capacity of over 24,000 TEU, with a length of 400 metres, a beam of 60 metres and a draught of 32.5 metres. In order to be ready to accommodate mega-ships, ports need to adapt port infrastructure, equipment, maritime access and hinterland transport connections accordingly (Merk, 2018). Therefore, globally, the port industry has invested huge amounts in order to cope with the technological demands created by containerisation and the deployment of mega-ships (Haralambides, 2019). Large impacts on the port system are related to the need for deeper berth depth and wider access channels, cranes with more outreach as larger ships are wider, faster and more efficient container handling, as the extremely high volume of containers must be handled in a relatively short time. Modern container terminals and cargo handling equipment have been built, and new organizational forms (mostly linked to privatisation), have been adopted during the past years, in an effort to maximise port efficiency and speed up operations (Haralambides, 2019). The critical issues behind this trend therefore concern the high investment that is required and the need of the development of an efficient system which would be able to process all the TEUs in the shortest possible time, while at the same time maintaining a high level of standards and safety. These developments took place due to the governments' and local authorities' understanding that ports now constitute the most significant link in the door-to-door supply chain, and therefore bottlenecks and inefficiencies in the port sector need to be minimised, as they can easily wither all benefits derived from economies of scale and regional economic development (Haralambides, 2019).

The deployment of bigger ships has also created industry consolidation and intense co-operation via alliances (Merk, 2018). Consolidation in container shipping is achieved through mergers and alliances that have been rising in recent years, due to the oversupplied shipping capacity dominated by mega container ships (Merk, 2018). The rise of global carrier alliances might raise competition concerns, as due to vertical integration of service capabilities, in particular terminal operations, the consolidation of the industry has contributed to the disappearance of smaller container ports and various independent terminal operators (Merk, 2018). Most ports depend on one or two alliances and the risk of losing calls from ships within the alliances provides these with huge leverage over ports to reduce their rates and invest in additional infrastructure (Merk, 2018).

Accordingly, ports are forced to grow to meet the current needs arising from the bigger ship call sizes, which require effective measures to be taken in order to ensure that space, labour, equipment, technology and port services are optimized (González and Trujillo, 2008; UNCTAD, 2018). However, not all ports are able to increase their physical capacity, as barriers - such as high port investment costs, port land availability, draft limitations, etc. - might exist (Merk, 2018). As such, the need for ports to substantially improve their efficiency and become more land productive is crucial (Merk, 2018).

Shippers and carriers have a large choice in the selection of their routings, and thus each and every node and link in the logistics chain has to implement strategies to attain the maximal efficiency in order to compete (Cepolina and Ghiara, 2013). For this reason, port management bodies in order to support trade oriented economic development, have been increasingly under pressure to enhance port efficiency by ensuring that port services are provided on an internationally competitive basis (Tongzon, 2001). Thus, since 2000, the measurement of port efficiency has become a pivotal and key research area in maritime economics (Haralambides, 2019).

In order to respond to the described port operational landscape and achieve maximised efficiency, the automation of container terminals and the use of advanced technologies have emerged as a solution and requirement. In accordance with the port operating landscape described, the advent of the so called “Fourth Industrial Revolution” has been unfolding (Schwab, 2016). Even though the three previous revolutions have created pivotal societal change and opportunity, today’s transformation is unique in terms of the tremendous speed with which new technologies and ideas are spreading around the world (Schwab, 2016). Every company across all industries is now forced to reassess their traditional ways of doing business in order to keep pace with rapidly changing technology and continuously increasing consumer expectations (Schwab, 2016).

In line with this trend, the port industry is also embracing and adopting, at an accelerating pace, technologies and latest developments in digitalization (UNCTAD, 2018). These developments are emerging from a combination of technologies, such as Internet of Things (IoT), automation, Big Data, robotics, blockchain, Information and Communication Technologies (ICT), which are becoming more and more common across communications, infrastructure and mechanical systems. The adoption of relevant technologies can increase operational efficiency, enhance port productivity, optimize traffic volumes, improve systems and automate processes, thus reducing significantly inefficiencies and errors (UNCTAD, 2018). Thus, in order to improve port operational efficiency and to cope with the current heightened requirements of shipping lines, cargo owners and freight forwarders, ports are investing in the latest technology to facilitate these needs. Most importantly, ports nowadays focus on the application of intelligent technology, which apart from efficiency gains, can induce sustainable development and contribute in the greening of the port and overall shipping industry (Chen, Huang et al., 2019). Finally, it is also important to highlight that the adoption of new technologies in ports significantly influences the national economy of the port’s region, as it can affect work and employment, accessibility, value added and production (Jun, Lee et al., 2018).

From all the above, it can be argued that a link exists among the three main elements discussed previously, namely port efficiency, economic development and technological advancements. Global key trends are creating increasing pressure on ports to adapt their role and function, as well as their infrastructure and handling equipment, to the present demanding operational environment and are thus pulled to maximise their efficiency. More specifically, in order to face all the challenges created from the global key trends and to respond to the growing demand, ports need to be efficient. Therefore, the required increased efficiency is achieved through the use of advanced technologies, such as automation and digitalisation. With the use of advanced technologies, ports can handle and store more cargo as operations have become faster and more efficient. Moreover, technological advancements can also affect the economic development of a region due to the affect they have on employment, accessibility, value added, environment and so forth.

1.3 Research Purpose and Design

The exploration of the available knowledge on the field of port efficiency and performance, technological advancements and local economic development reveals that the impact on port efficiency and local economic development from the application of technological advancements in port operations has not been yet sufficiently studied by the existing literature. Additionally, the researcher found that there is little research on the net benefits that can be generated from the application of new technologies in port operations. This research aims to bridge this gap and advance knowledge on the net benefits generated by the application of technological advancements in port operations.

Based on the literature review (Chapter 2) the core research objective (RO) is: **to investigate the relationship between technological advancements in ports, port performance, net benefits for the hinterland, benefits to stakeholders and the development of smart green and sustainable ports.** Table 1.1 summarises the overall research design of this thesis. The five research questions (RQs) that span this thesis were developed in Chapter 2, while the choice of methods / approach associated with each research question is described thoroughly in Chapter 3.

Research Objective	Research Questions	Method / Approach
RO. To investigate the relationship between technological advancements in port operations, port performance, net benefits for the hinterland, benefits to stakeholders and the development of smart, green and sustainable ports.	**RQ1.** Which are the latest technologies and smart, green and sustainability related practices adopted in ports?	Literature Review Scoping Study - Preliminary Interviews Website Content Analysis
	RQ2. What is the relationship between port efficiency and local economic development?	Systematic Literature Review
	RQ3. What are the key characteristics of the world's leading container ports and how can a representative port sample be identified for further analysis?	Sampling
	RQ4. What are the net benefits generated by technological advancements regarding both port performance and the local economy?	UK Case Study – 12 Interviews Participant Observation
	RQ5. How do different external factors affect the maximisation of the potential gains for port operators and the local economy?	Systematic Literature Review UK Case Study - 12 Interviews Participant Observation

Table 1.1: Overall research design

Figure 1.1: Graphical representation of research design

1.4 Contribution

The contribution of this research can be summarised as follows:

- Comprehensive review of the technological advancements presently adopted in port operations;
- Understanding of the relationship between port efficiency and economic development, as well as the factors affecting port efficiency;
- Understanding of the key characteristics of container ports and provision of a method of identification of a representative sample;
- Contribution to understanding the different net benefits that are generated from the application of technological advancements in port operations, as far as port performance and the hinterland are concerned;
- Provision of insights and benchmarking of the world's major ports with regard to their smart, green and sustainability related practices and efforts, according to their website disclosure and reported practices;

- Provision of detailed information on the factors behind the barriers for the maximisation of the potential gains generated for both port operators and local communities from the application of technological advancements in port operations;
- Contribution to fill the identified gap in the literature by providing empirical evidence from the UK case study.

1.5 Overview of the Thesis

This thesis comprises ten chapters. Chapter 1 introduces the core objective and describes the overview of this research. Chapter 2 explores the concepts of technological advancements, port efficiency and economic development, through a detailed literature review and identifies the knowledge gap this thesis aims to bridge. Chapter 3 details the research design and methodology selection. Chapter 4 reports on a Scoping study performed at the outset of the research to gain a deeper understanding of the current operational landscape, through the conduction of a series of preliminary interviews with key industry stakeholders.

Chapter 5, according to the knowledge gap identified in Chapter 2 and building upon the literature review, lays out a systematic review on the relationship between port efficiency and economic development.

The author in Chapter 6 presents how a sample of representative ports can be identified and explores the key characteristics of container ports. The understanding and exploration of a representative port sample helped and informed the Website Content Analysis and the UK Case study. Therefore, this Chapter helped the researcher understand more clearly the topic of port performance and the reasons behind how some ports are performing better than others, and in turn contributed to the selection of the port sample used for the Website Content Analysis reported in Chapter 7.

Chapter 7 explores through a Website Content Analysis, to what extent, if any, the world's major ports disclose information in their corporate websites focusing on their smart, green and sustainability related practices and efforts. In particular, the author developed a smart score and upon the results of this score the Chapter benchmarks the selected ports with regards to their smart status and derives results to classify them, according to their website disclosure and reported practices.

Chapter 8, taking the example of the UK, establishes the smart score of major UK ports and assesses the way in which they currently adapt to the technological advancements in the port sector. For this purpose, semi-structured in-depth interviews with 12 key industry stakeholders were held.

Chapter 9 reports on a year-long project at the Port of Tyne, which involved the development of the UK's first 2050 Maritime Innovation Hub in line with the UK's Maritime 2050 strategy, and establishes the smart score of the Port. The researcher used the Participant Observation technique for this step of analysis and participated in workshops held at the Innovation Hub, where key insights were obtained with regards to how ports develop solutions to adapt to the challenges facing the sector. In this Chapter, having performed a global study in Chapter 7 and a national study in Chapter 8 (UK), the author outlines a single port study (local), this being a progression from the general to the particular.

Finally, Chapter 10 outlines the conclusions and contribution of this research.

1.6 Conclusion

This chapter introduced the research topic and outlined both the approach adopted in the research and the structure of this thesis. Chapter 2 will now review the literature on the themes under investigation (technological advancements, port efficiency and performance, green, smart and sustainable port concepts, benefits for the hinterland) and address the research gap this thesis aims to bridge.

Chapter 2. Literature Review

2.1 Introduction

The purpose of this literature review is to explore and understand the concepts of port efficiency, economic development, technological advancements, as well as what a smart, green and sustainable port constitutes. It also explores the drivers of port efficiency, and more specifically, the effect on port efficiency of port ownership, port security and regulation level, inter-port and intra-port competition, cargo diversity, berth allocation, turnaround time, hinterland size, hinterland accessibility, cargo handling equipment and technological advancements is analysed based on the examined literature. The aspect of technological advancements' impact on port efficiency is emphasized, as it is currently one of the most important drivers of port efficiency, which however has not been sufficiently studied by the existing literature. In this context, one emerging topic concerns the analysis of the relationship that exists between technological advancements, port efficiency and local economic development.

To the best of the author's knowledge, the interaction among these three concepts has not been thoroughly studied in previous literature. Therefore, this literature review will firstly investigate the concepts of technological advancements, port efficiency and economic development. Secondly, the factors that affect port efficiency will be analysed.

The chapter is organised as follows: after this brief introduction, Section 2.2 examines technological advancements in ports, one of the main elements characterising the shipping market evolution; Section 2.3 analyses the concept of port efficiency, the main methods used to measure it and the main factors affecting it; Section 2.4 discusses the regional benefits and impacts created by the operation of ports, the measures used to assess the economic impact of ports, as well as the concept of sustainable port development. Finally, Section 2.5 concludes by presenting the findings of the literature review.

2.2 Technological Advancements in Ports

The root of the word 'technological' derives from the Greek word 'tekhnologia', which means 'systematic treatment' Oxford (Dictionary, 2019). According to the Cambridge (Dictionary, 2019) technology refers to the use of scientific knowledge or processes in business, manufacturing, industry, etc. and to the use of new equipment and machinery that has been developed using scientific knowledge or processes. A more detailed definition of technology is given by the Business (Dictionary, 2019) which refers to it as “the purposeful application of information in the design, production, and utilization of goods and services, and in the organization of human activities”.

As technology evolution is rapidly improving, human-machine interactions and human decision making are becoming more feasible (Pundir, Devpriya et al., 2019). In turn, this is aiding businesses to gain pace in their operations, handling complexities with ease, lesser costs, enhance speed and efficiency, prevent loss and build high levels of customer satisfaction (Pundir, Devpriya et al., 2019; Pundir, Jagannath et al., 2019). Hence, there has been general consensus that technical advancements are aiding businesses to achieve superior trade-offs between efficiency, sustainability and resilience (McKinnon, 2018).

In accordance with the advent of the Fourth Industrial Revolution in all sectors and industries, ports are also developing and applying state-of-the-art technologies in their operations (Jun, Lee et al., 2018). The rising tide of new trends in port strategies and the rapid technological change of the last decades, has put pressure on port authorities in modifying their role and strategy, to face the global competition (Cepolina and Ghiara, 2013). Therefore, the complexity of port operations and the excessive need to enhance port efficiency throughout the various crucial vessel- and cargo-handling phases in ports, has pushed the introduction of new technologies in port operation (Muñuzuri, Onieva et al., 2019). A review of ports globally shows that the port industry has moderately embraced technology, with operations of many ports having dramatically changed over the last few decades (UNCTAD, 2018).

2.2.1 Internet of Things (IoT) and Information and Communication Technology (ICT) infrastructures in Ports

Internet of Things (IoT) can be described as an intelligent infrastructure, connecting wired and wireless networks to objects in the surrounding area that exchanges information between them (Ferretti and Schiavone, 2016). IoT technology has evolved rapidly in recent years and has made a significant difference in transportation and logistics industries (Jun, Lee et al. 2018). Companies willing to improve their efficiency and productivity, benefit from the implementation of IoT technology as it generates higher revenues and is a critical driver of value creation (Ferretti and Schiavone, 2016). A recent study by Ferretti and Schiavone (2016) involved the detailed illustration of the way that IoT technologies redesign the business processes of seaports. Through a case study of Hamburg port, they concluded that the adoption of these technologies improves the performance of processes related to technology and information.

Furthermore, one of the various tools of port authorities' evolution and a core part of the smart port industry is established in Information and Communication Technology (ICT) infrastructures, which enhances the efficiency in managing the logistics flow within the supply chain (Cepolina and Ghiara, 2013; Botti, Monda et al., 2017). The increasing number of applications based on ICT can aid companies in the freight transportation industry to improve the performance of their processes (Marchet, Perego et al., 2009). These applications are aiming to integrate an increasing number of traditional services, i.e. warehousing and transportation, with the help of information-based services, such as tracking and tracing, mode and route planning, information transfer, booking, claims management, reporting and freight rate computation (Marchet, Perego et al., 2009). ICT can increase interoperability between onshore logistics systems and ports, improve collaboration and participation among the various stakeholders involved in the processes and improve the accessibility of various logistics-flow related data (Jun, Lee et al., 2018). Therefore, ICT is regarded to be one of the most strong networking and communication tools, that enables data sharing and information flows (Cepolina and Ghiara, 2013).

In order to demonstrate the strategic role of ICT in logistics and port systems' prosperity, Cepolina and Ghiara (2013) attempted to analyse the requirements and constraints that are involved in the full exploitation of the opportunities induced by ICT. For example, the documentation process, that plays a remarkably critical role for bottlenecks, can be significantly improved with ICT and in turn increase the overall logistics and port efficiency. The authors concluded that ICT induces added value both at an operative and at a system level.

Overall, IoT and ICT in ports make a significant difference in improving efficiency and performance of processes, while collaboration between the various stakeholders of the supply chain is increased, as data sharing is enabled and information flows efficiently. Meanwhile, automation is also increasingly used in container terminals as a means to improve their efficiency, productivity and competitiveness (UNCTAD, 2018).

2.2.2 Automation in Ports

In 1993, the ECT Delta Terminal situated in the port of Rotterdam was the first to introduce the concept of "automated terminals" (Martín-Soberón, Monfort et al., 2014). The terminal was equipped with Automated Guided Vehicles (AGVs) and Automated Stacking Cranes

(ASCs), handling the storage and interchange equipment without operators. Since then, the list of semi-automated and fully-automated terminals has not stopped increasing and it will continue growing given the huge investments being dedicated to the construction of new automated terminals and automation projects all over the world (Martín-Soberón, Monfort et al., 2014).

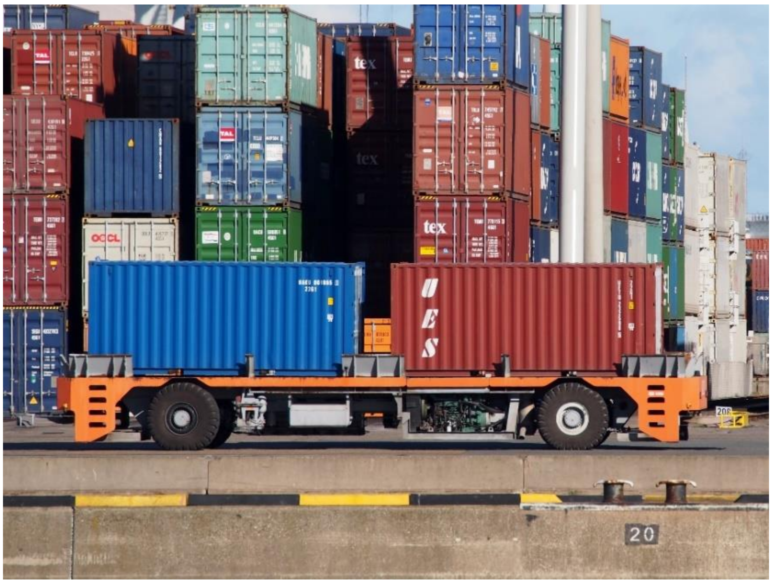

Figure 2.1: Automated Guided Vehicle (AGV) container mover at Port of Rotterdam

Source: Wikipedia Commons.

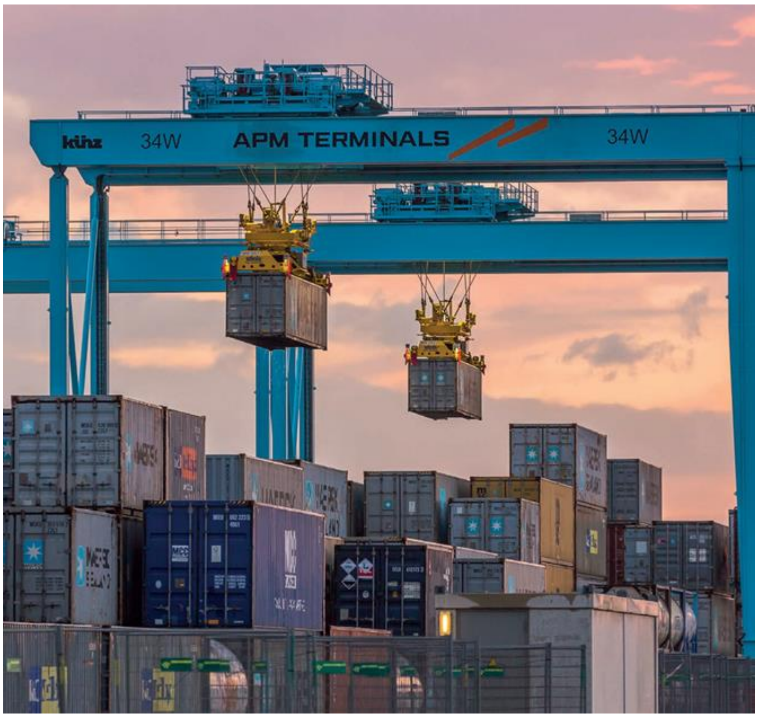

Figure 2.2: Automated Stacking Crane (ASC) at Port of Rotterdam

Source: Kuenz cranes.

The main objectives of a container terminal are to maximise the terminal throughput and to minimize the ship turnaround time (Zhang, Wan et al., 2002). Figure 2.3 describes the container flows in the terminal as illustrated by Zhang, Wan et al. (2002).

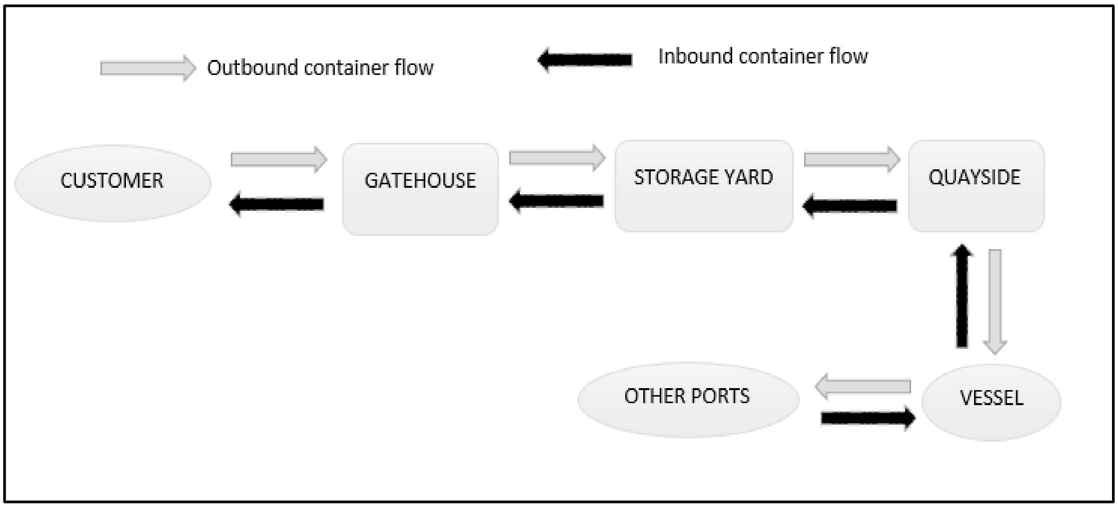

Figure 2.3: Container Terminal Flows

Source: Own elaboration from Zhang, Wan et al. (2002)

An automated container terminal consists of the berthing area located at the quayside, the travelling area of Automated Guided Vehicles (AGVs) and a storage yard (Yang, Zhong et al., 2018). More specifically, the berthing area is equipped with Quay Cranes (QCs) for loading and unloading containers, while the travelling area is used by AGVs to move the containers form the berthing area to the storage yard. AGVs are pivotal transportation vehicles equipped with automatic guiding devices that can move containers between the QC on the quayside and the ASC on the yard side. Figure 2.4 illustrates a typical layout of the operation in an automated container terminal.

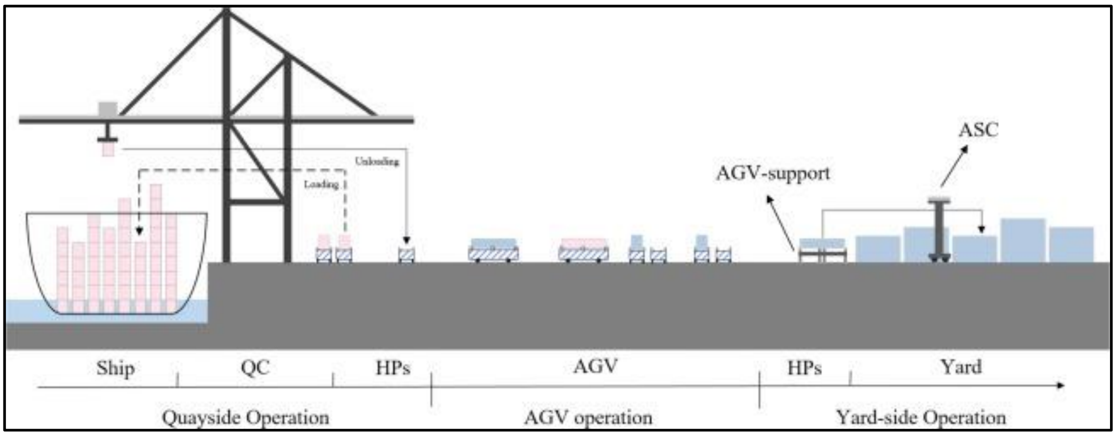

Figure 2.4: The operation in automated container terminals

Source: Wang and Zeng (2022)

As illustrated in Figure 2.4, in front of each block in the yard area there are handover points (HPs) where the container transfer between the AGV and ASC is conducted, while a few HPs also exist under the back-reach of each QC for the container transfer to/from AGV.

The efficiency of container terminals relies heavily on the effectiveness of resource allocation throughout the different handling stages (Zhang, Wan et al., 2002). The broad development of automation includes the automation of yards, gates and quay cranes (Martín-Soberón, Monfort et al., 2014). These automation techniques increase the productivity of container cranes, which in turn result in an increased port efficiency (Zrnić, Petković et al., 2005). As cranes become faster and larger, yard operations are becoming increasingly difficult, demanding a highly efficient yard system (Slutej and Kolonić, 2009). Storage yards situated in container terminals are used to store temporarily the inbound and outbound TEUs until they are either picked up by trucks or loaded onto vessels or trains (Zhang, Wan et al., 2002). According to Zhang, Wan et al. (2002), yard operation is the most complicated part of a terminal, because both inbound and outbound TEU flows are handled. Hence, automatic operation eliminates the limitation in storage capacity faced by many ports, as it offers an optimal stacking density and peak capacity capable for ensuring continuous manning of every single crane (Slutej and Kolonić, 2009). Due to the above reasons, container terminals have been increasingly adapting automated rail mounted gantry cranes (A-RMG) for their yard container handling operations (Slutej and Kolonić, 2009). Rail mounted gantry cranes are used to load, unload, move and stack containers in large container storage yards.

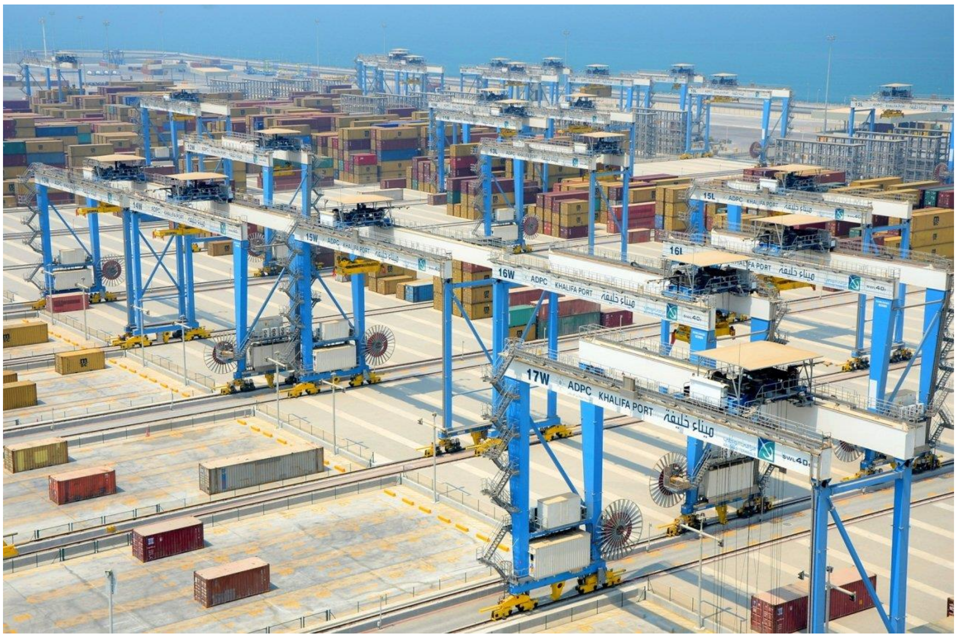

Figure 2.5: Automated Rail Mounted Gantry Crane (A-RMG)
Source: Konecranes.

At the same time, advances in ship-to-shore (STS) container cranes technology include the automation of their operation systems, as ports are seeking to keep up with the increasing global competition and improve their operational performance (Zrnić, Petković et al., 2005). They have therefore adopted automation technologies throughout their loading and unloading handling equipment. Figure 2.6 depicts an automated STS container crane.

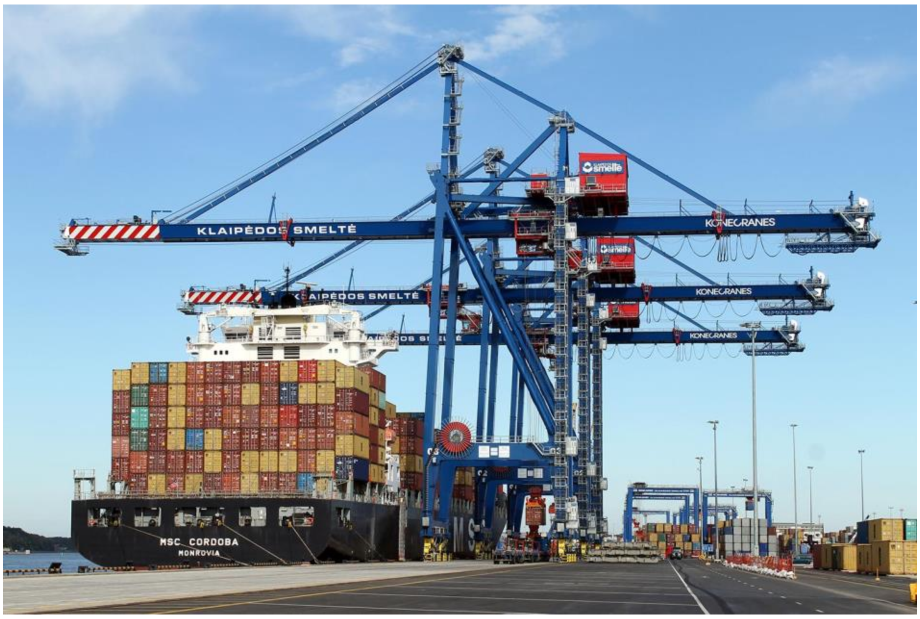

Figure 2.6: Ship-to-shore (STS) container crane
Source: Logistics Manager.

Recognizing the trend towards automation, Martín-Soberón, Monfort et al. (2014) introduced an automation philosophy that adapts the application of currently available technologies on the market to the specific needs of port container terminals. They highlighted that implementation of automation in Port Container Terminals (PCTs) needs a prior careful consideration of the individual needs of the PCT, related to the level of automation sought and its present level of development. The methodology they suggested consists of five stages:

1. Diagnosis;
2. Study of the available technologies on the market;
3. Design of viable solutions;
4. Selection of the most promising solution
5. Definition of the implementation project of the most promising solution.

The author concludes by presenting in detail the advantages, disadvantages, and challenges of container terminal automation. Some of the main advantages listed from the adoption of automation in ports are increased operational productivity, increased flexibility to handle and adapt to demand peaks, operation with high yard density offering more capacity with the same space, more efficient use of resources, operating with electric equipment thus minimizing emissions and noise and less variable operational economic costs. On the other hand, the list of disadvantages mainly includes the possibility of loss of job positions, the requirement of higher capital outlay, less flexibility for operational handling and the difficulty to react fast when exceptions occur.

2.2.3 Green Port Concept

One of the colossal challenges that humanity faces nowadays is climate change and global warming, and thus all people and industries must endeavour to reduce emissions and save energy (Lam and Notteboom, 2014; Chen et al., 2019). At the same time, maritime transport is a large and growing source of greenhouse gas (GHG) emissions, as it accounts for around 3% of total global GHG emissions and generates about 15% of some of the world's main air pollutants annually (Englert et al., 2021). Although most of the emissions attributed to maritime transport occur at sea, the most discernible part occurs in port-cities and port areas, since the health impact there is the most directly noticeable one (Merk, 2014). Ports are therefore facing a high pressure from the public in terms of committing to perform their social responsibility and demonstrate a top level of environmental performance in order to ensure community support (Lam and Notteboom, 2014).

One of the major impacts generated by ports' operation is air pollution, specifically GHG emission which in turn leads to global warming, as GHG traps heat (Lam and Notteboom, 2014). It is estimated that within 400 km of the coastal area are emitted approximately 70% of the world's shipping emissions, of which 60-90% is generated from auxiliary engines during the berthing period (Endresen, 2003; Corbett et al., 2007). During the port handling process occur also other kinds of pollution, such as noise and dust pollution. According to an ITF study (Merk, 2014) the greatest part of emissions in ports is generated from shipping activity; in developed countries between 70% to 100% of emissions in ports can be attributed to shipping; up to one fifth is represented by trucks and locomotives; while emissions occurring from equipment rarely exceed 15%. There are also health effects generated by port operations impacting the local community and residents adjacent to ports, including lung cancer, asthma, cardiovascular disease, premature mortality and other respiratory diseases (Bailey, 2004).

Due to the above reasons, the past years have seen a growing attention on the environmental impact of port development and operations (Acciaro et al., 2014b; Lam and Notteboom, 2014; Puig et al, 2017; Chen et al., 2019; Arof et al., 2021). The growth of transportation to and from the port has also generated pollution and traffic congestion, which is increasingly becoming a concern for the people adjacent to ports (Jung, 2011). Ports are therefore facing very high pressure from the public with regard to their social responsibility (Lam and Notteboom, 2014). It is indisputable that ports must demonstrate an even greater level of environmental performance in order to ensure the port-city's community support (Lam and Notteboom, 2014). The environmental performance of a port also plays an important role in attracting investors and trading partners, as a port with a high level of community support and a robust environmental record is likely to be favoured over ports showing a low environmental responsibility (Lee and Lam, 2012). Ports and their stakeholders can also use their commitment to green improvements to take advantage of commercial benefits by way of positive branding and corporate savings (Arof et al, 2021).

Based on these grounds, the International Maritime Organization (IMO) has set out a vision to decarbonise the shipping sector, and has adopted an initial strategy to reduce at least 50% the GHG emissions from the global shipping sector by 2050, compared to 2008, while simultaneously pursuing efforts towards entirely phasing them out (Joung et al., 2020). While the focus is on ship design and operation, ports also have a pivotal role to play in facilitating the reduction of shipping emissions and the decarbonisation of maritime transport (Merk, 2018a). Therefore, the reduction of environmental pollution by port operation and the application of innovative environmentally-friendly technologies in ports is no longer an option, but a necessity (Acciaro, Ghiara et al., 2014; Jun, Lee et al., 2018).

The development of modern ports should adapt to the trend of environmental protection, as green and intelligent designs are the two major goals for the future development of ports (Chen, Huang et al., 2019). Given the above, a new term has emerged during the past years, the "*green port concept*", which proactively harmonizes climate change mitigation and adaptation into its plans and operations. This concept refers to several measures aimed to achieve sustainability at ports, considering that apart from meeting all environmental standards in its day-to-day operations, a port also needs to have a long-term plan for improving its environmental performance (Arduino et al., 2011). Responding to the environmental challenges, many developed economies have taken independent actions to implement legislation and green port policies in their countries (Arof et al, 2021).

The adoption of innovative technologies such as renewable energy installations in port areas and onshore power supply or the use of alternative fuels has seen a great upsurge in the port sector in recent decades (Acciaro, Ghiara et al., 2014). During the last decade, particular attention has been therefore given to air pollution caused by shipping and thus various technologies are used in order to reduce the CO_2 emissions from port operations (Ortega Piris, Díaz-Ruiz-Navamuel et al., 2018).

It is well-known that the ships' electrical demand when at berth is usually satisfied through the auxiliary engines which consequently generate air pollutants (SOx, NOx, CO_2 and particle discharge), acoustic noise and vibrations (Arduino et al, 2011; Borkowski et al., 2012; Coppola et al., 2016).These air pollutants cause negative environmental and health impact on the surrounding communities (Arduino et al, 2011). One of the efficient ways to reduce the negative environmental impact of ships while berthed, that is also generating many social and environmental benefits, is the power supply from an onshore power source (Arduino et al. 2011; Borkowski et al., 2012). Ship-to-shore power supply or cold ironing is thus a paradigm that has been recognised as a way to satisfy the emissions reduction targets and has been adopted in some ports as a measure that belongs to the green port concept (Arduino, 2011; Coppola et al. 2016). Cold ironing is the process of turning the ship's main auxiliary diesel engines off while berthed and plugging into a shoreside electrical supply point installation in the port (Arduino, 2011; Borkowski, 2012). This process results in the emission elimination while the ship is berthed along with a decrease of vibrations and noise (Borkowski et al., 2012). Bouman et al. (2017) estimated the potential CO_2 reduction from the use of onshore electricity, through the systematic review of relevant studies, and their results showed that it is possible to reduce air emissions considerably with a range of 3-10%. Cold ironing is also known as Onshore Power Supply (OPS), Alternative Maritime Power (AMP) supply, Shore Connection, shore-side electricity (Arduino et al., 2011; Acciaro et al., 2014b).

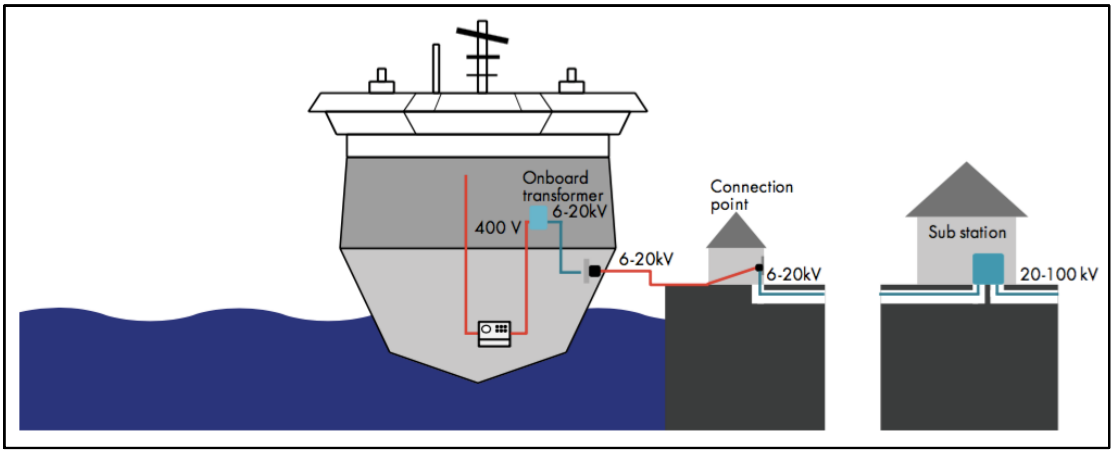

Figure 2.7: Onshore Power Supply (OPS)

Source: Port Technology International.

Moreover, renewable energy installations (such as solar, geothermal, waves and wind power) and alternative fuels (such as LNG, LPG, hydrogen and biofuels) constitute additional pivotal measures with high emission mitigation potential (Bouman, 2017; Acciaro et al., 2014b). Renewable energy plays a significant role within ports, as they are usually located in areas exceptionally suitable for power generation from wind, waves and geothermal energy (Acciaro et al., 2014b). Ports often also have wide flat surfaces, such as warehouses and storage areas, ideal for the installation of solar panels (Acciaro et al., 2014b). Moreover, the development of offshore renewable energy installations and wind farms also plays an important role in the minimisation of CO_2 generation in ports (Acciaro et al., 2014b). Another opportunity for green port measures, lies in the development of biofuels and ports might also benefit from such a development in terms of providing bunkering services, which is already happening for alternative fuels such as LNG and LPG, as ports are developing new LNG bunkering infrastructure (Acciaro et al., 2014b). Finally, ports might also become significant players in carbon capture and storage (CCS), as they already plan to acquire an important role in waste disposal and material recycling (Acciaro et al., 2014b).

Another element that ports have to pay great attention, due to the serious problem of the correlated air pollutants emissions that are produced, is the mooring of ships in ports (Coppola et al., 2016). Ortega Piris, Díaz-Ruiz-Navamuel et al. (2018) were the first to measure the actual reduction in the CO2 emissions of merchant vessels in ports, as a result of the substitution of traditional mooring systems with the new automatic systems. Automated Mooring Systems (AMS) allow vessels to be moored without the use of ropes and are being implemented in various ports around the world. In a case study of the port of

Santander (Spain), Ortega Piris, Díaz-Ruiz-Navamuel et al. (2018) applied two “bottom-up” methodologies to the traffic in the port for the year 2014. Their results indicated that the implementation of automated mooring systems leads to a reduction of 76.78% in CO2 emissions in the port compared to the traditional mooring systems when calculated using the EPA method (methodology described in the document “Analysis of Commercial Marine Vessels Emissions and Fuel Consumption Data” by the United States Environmental Protection Agency, Air and Radiation), and to a 76.63% reduction when calculated using the ENTEC method (methodology described in a document by ENTEC UK Limited; environmental and engineering consultancy in the UK). This is due to the reductions obtained in the operating times of the vessel engines during the manoeuvres, since according to the study the main and auxiliary engines consume only a quarter of the fuel with the automatic system compared to the traditional operation. Therefore, since the implementation of AMS leads to significant environmental benefits by extensively reducing CO_2 emissions in commercial ports, port authorities should promote its implementation in their long-term planning decisions.

Figure 2.8: Automated Mooring System (AMS)

Source: NauticExpo.

The electrification of several aspects of port operation is another attractive solution to address the emissions problem at ports (Jaspreet et al., 2011). Port electrification and reduction in GHG emissions can be achieved through several measures, in addition to onshore power source, as discussed above. Some of the measures that are adopted by ports around the world for reducing their carbon footprint include the replacement or retrofitting of diesel cargo handling equipment such as cranes and forklifts with electric equipment (Jaspreet et al., 2011). Yang and Chang (2013) compared the performance of rubber-tired gantries (RTGs) with electric rubber tired gantries (E-RTGs) from the perspective of CO2 reduction, energy savings and reduction of operating costs. The gantry cranes that are used in container terminals and yards include rail mounted gantries (RMGs) and rubber-tired gantries (RTGs). The former employs electric power while the latter are powered by diesel fuel, therefore having clear differences in CO_2 reduction and energy savings. Diesel RTGs, despite their drawbacks of high pollution, high noise and high energy consumption are still employed by most container yards for container handling. Motivated by the need to reduce exhaust pollution caused by cargo handling equipment in container yards and terminals they analysed the impact of E-RTG use on the green policies of international hub ports. The authors discovered that E-RTG cranes give a significant performance improvement when compared with diesel RTGs, while simultaneously achieving 86.6% energy savings and a 67.79% reduction in CO_2 emissions. Moreover, they highlighted that apart from being environmentally friendly, E-RTGs are expected to have a payback period of only 2.2 years and can also alleviate the impact of diesel oil price hikes. Finally, they pointed out that governments should formulate regulations and provide incentives to terminal operators to encourage them to upgrade their handling equipment or alternatively implement E–RTG conversion projects.

Figure 2.9: Automated Rubber Tired Gantry (ARTG) System

Source: Konecranes.

Another measure to reduce carbon emissions generated through port operation, is the use of the new type of automated guided vehicles (AGVs) called Intelligent Autonomous Vehicle (IAV), which represents a new intelligent green technology extensively used in ports (Kavakeb et al., 2015). The most common used automated vehicles in port operation are the automated guided vehicles (AGVs) (Kavakeb et al., 2015). IAVs have a better manoeuvrability and also the special ability to pick up and drop off containers by themselves (Kavakeb et al., 2015). Kavakeb, Nguyen et al. (2015) used a discrete-event simulation model and a cost model to analyse the impact of using this green vehicle technology on the performance and the total cost of a European port. Their results indicate that this green vehicle technology, apart from being friendly to the environment, it can have similar efficacy to regular trucks due to its better manoeuvrability. Additionally, it can significantly improve port performance thanks to its ability to pick up/drop off containers in terms of the number of crane moves per hour and finally that the total present value for IAVs is significantly lower than that of trucks (even though the IAVs capital compared to that of trucks is much higher).

There are also some other port management tools and energy management strategies for encouraging and enforcing green port development (Acciaro et al., 2014b; Lam and Notteboom, 2014). These include pricing policies and monitoring and measuring emissions. Around the world port authorities are adopting a greening approach towards port management, in an attempt of boosting their environmental and economic competitiveness, as well as to ensure their operating license as regulation linked to their environmental performance is more rigorous (Lam and Notteboom, 2014). Pricing strategies are used to enhance a port's competitive position and as environmental incentive tool in ports (Lam and Notteboom, 2014). By slowing ships can reduce their airborne emissions of pollutants, and thus some ports are granting ships that slow down a discount as an incentive for enhancing environmental performance in combination to having economic benefits.

Ports are also increasingly adopting an environmental management system (EMS) which is a formal system to proactively manage the environmental footprint of a port and the environmental programmes of the port related to pollution prevention, control and protection (Florida et al., 2001). In essence it is a documented process of the port's day-to-day operations which also describes the strategic planning for the management of environmental impact processes and their continuous enhancement (Lam and Notteboom, 2014). Monitoring is one of the pivotal aspects in EMS, and the most common environmental monitoring indicators are air quality, water quality, noise, energy consumption, while also soil quality, sediment quality, marine ecosystems, terrestrial habitats, water consumption, waste management and carbon footprint are also monitored by ports (Puig et al., 2015).

Overall, the mutual integrated development of a technologically advanced and green port contributes to improving port productivity and competitiveness, while simultaneously accommodating issues of environmental protection and sustainability (Chen et al., 2019). It is evident that all ports need to accelerate their decarbonisation strategies and implement measures to reduce their carbon emissions. Commercially, ports will also need to demonstrate their green credentials, as more and more customers request their whole supply chain to be green, this making ports a significant node that needs to be decarbonised.

2.2.4 Smart Port Concept

The concept of ports adopting technology-based solutions, such as IoT, robotics, big data management and analysis, as well as new approaches to port operations and planning, in order to gain maximised efficiency, is referred to be switching to "smart ports" (Molavi, Lim et al., 2019). Thus, the relatively new *"smart port concept"* has emerged during the last years. Recognizing the major role that ports play in national economies, highly developed countries have been eagerly investing capital for the development of smart port technologies in traditional port areas (Jun, Lee et al., 2018). Smart ports have been also called intelligent ports, autonomous ports or robotic ports in several studies, and therefore the definition of the smart port concept is blurred (Jun, Lee et al., 2018). Table 2.1 includes the various definitions given by researchers to the Smart Port concept.

REFERENCE	DEFINITIONS
A framework for building a smart port and smart port index (Anahita Molavi, Gino J. Lim & Bruce Race, 2020)	The concept of smart port involves a variety of advanced digital technologies consisting of monitoring, control, automation, and intelligent equipment and applications working together, to optimize the port operations and revitalize the existing infrastructure for a cleaner and strengthened port.
Smart Port as a Key to the Future Development of Modern Ports (A. Karaś, 2020)	The idea of Smart Ports is not only management of technological processes, but also digitalization, increasing the efficiency of operations in ports, integration of ports with cities and acquiring energy from alternative sources. Smart Port - the new model of management is a series of innovative tools used on technological and organizational level.
Constructing Governance Framework of a Green and smart port (Jihong Chen, Tiancun Huang, Xiaoke Xie, Paul Tae-Woo Lee and Chengying Hua, 2019)	Smart ports are designed to operate and manage modern ports with full use of intelligent technologies and means. The construction and sustainable development of a smart port should be based on the principles of cooperative cooperation, technological innovation, environmental protection, energy conservation, and the full use of information technology to realize intelligent and green port operation.
A conceptual model for a cyber-social-technological-cognitive smart medium-size port (Claudia A. Durán, Felisa M. Córdova, Fredi Palominos, 2019)	Smart ports are highly automated and use technology 4.0 to efficiently manage and improve logistics processes, in addition to making intelligent decisions with a large amount of data in real time to identify existing opportunities and risks.
Smart port: design and perspectives (Kaoutar Douaioui, Mouhsene Fri, Charif Maboruki, El Alami Semma, 2018)	The concept of the smart port is based on the automation of terminal operations and on the interconnection of all actors in the port chain through the automated transfer of mobile data in real time.
Internet of Things for Smart Ports: Technologies and Challenges (Yongsheng Yang, Meisu Zhong, Haiqing Yao, Fang Yu, Xiuwen Fu, Octavian Postolache, 2018)	A smart port may be defined as a fully automated port where all devices are connected via the so-called IoT Smart Port. A network of smart sensors and actuators, wireless devices, and data centers make up the key infrastructure of the smart port, which allows the port authorities to provide essential services in a faster and more efficient manner.
Impact of the smart port industry on the Korean national economy using input-output analysis (Wang Ki Juna, Min-Kyu Leeb, Jae Young Choia, 2018)	The smart port is generally related to the improvement of port productivity and efficiency by adopting an automated system using a high level of technology such as the IoT, Information and Communication Technology (ICT), Big Data and environmentally-friendly technology.
Towards Smart Port: An Application of AIS Data (Aboozar Rajabi, Ali Khodadad Saryazdi, Abderrahmen Belfkih, Claude Duvallet, 2018)	A smart port is a port which reinforced properly with technologies and terms such as sensors, cloud computing, fog computing, Internet of Things (IoT), robots, Radio-frequency Identification (RFID) and big data management and analysis. A smart port has the ability to cope with the challenges of previous generations of the ports more efficiently. Generally, it helps the port authorities and terminal operators to adapt well and rapidly to the changing conditions of the port.

Table 2.1: Smart Port definitions

Although there are some differences in smart port definitions given by researchers, the smart port concept is generally related to the improvement of port efficiency and productivity by adopting a convergence of new technologies such as advanced port technology, automation, Big Data, Internet of Things (IoT), Information and Communication Technology (ICT) infrastructures, eco-friendly technology, robotics, Artificial Intelligence (AI) and unmanned vehicles and equipment (Buiza-Camacho-camacho, Del Mar Cerbán-Jiménez et al. 2016; Ferretti and Schiavone 2016; Botti, Monda et al. 2017; Jun, Lee et al. 2018; UNCTAD 2018; Yang, Zhong et al. 2018).The major drivers for the adoption of smart ports are the efficiency and productivity gains (Yang, Zhong et al. 2018).

According to Botti, Monda et al. (2017), ICT technology takes the main role of the smart port industry by increasing the efficiency of the supply chain. The authors highlighted that ICT solutions can enhance interoperability among onshore and port logistic systems, increase efficiency in managing logistics flow within port areas and improve the accessibility of various data related to logistics flow. Furthermore, the authors added that ICT technology can improve participation and collaboration among various actors of the port supply chain. In particular, ICT contributes significantly to the trend towards "smart port", as ports can take advantage of ICT applications for improving information sharing and knowledge analysis to increase energy and operations efficiency, as well as environmental sustainability (Molavi, Lim et al., 2019).

Additionally, Buiza-Camacho-camacho, Del Mar Cerbán-Jiménez et al. (2016) analysed the smart port concept from three areas: operational, energy and environmental. The authors assessed 23 factors that define the level of 'smartness' of a Mediterranean container port. More specifically, the study focused on determining which factors would be the most significant for a container port to be close to the smart port concept and it was based on the sector's experts' opinions. The technological level, followed by the automation level, determined the smart port configuration, and next intermodality was also considered as a key factor. However, according to the authors, the environment and energy areas must endeavour to accelerate their carbon neutral footprint with regard to the operational area. Similarly, and focusing on the same three areas, Buiza, Cepolina et al. (2016), described the situation regarding the smart concept in 2015 in Mediterranean container ports. Their results indicate 23 criteria and 68 Key Performance Indicators (KPIs) to guide the assessment of a port in terms of the smart port concept. Among their results, the more significant is that port authorities do not generally have a clear, updated overview of key performance indicators leading to a significant lack of published data. The authors suggest that improvements must be made in terms of data availability. According to Molavi, Lim et al. (2019), a fourth activity domain, additional to the three stated above (namely: operational, energy, environment), is safety and security, which incorporates safety and managements systems and integrated monitoring and optimisation systems.

The operation of a smart port seeks to enhance port productivity, but can also provide solutions for energy and environmental issues (Molavi, Lim et al., 2019). Therefore, air pollution, soil pollution and water pollution mitigation, as well as waste recycling and the application of new renewable energy technologies in ports are key aspects of smart ports with a sustainable goal (Jun, Lee et al., 2018). Topics related to energy and environment, such as reducing energy consumption, implementing renewable energy and improving operations to be environmentally friendly are among the initiatives of the smart port concept (Molavi, Lim et al. 2019). Thus, a green port and a smart port are not independent of each other and have a close relationship, as under the premise of green ports, smart ports apply new technologies to reduce environmental pollution and achieve the aim of sustainable development of green ports (Chen, Huang et al., 2019). The environmental aspect of smart ports is focused on the reduction of environmental pollution (soil, air, noise and water pollution) by port operation.

A smart port's characteristics according to the literature can be summarised as follows: it is a technologically advanced port that also provides solutions to environmental issues generated from its operation, seeking to gain maximised efficiency, productivity, as well as faster and more secure provision of services, through the adoption of a convergence of new technologies including automated equipment, eco-friendly technology, Big Data, Internet of Things (IoT), Information and Communication Technology (ICT) infrastructures, robotics, Artificial Intelligence (AI) and unmanned vehicles and equipment.

In conclusion, although the port industry is regarded as resistant to change and conservative, major steps are taken for ports to be transformed into being 'smart'. All the technologies, systems and solutions that have emerged during the past few years and have been described above, are shifting this perception and are leading the port sector into a smarter, more efficient, interconnected and digital future. The need to progress and accelerate their transition into being 'smart' will be paramount for ports, as the ever changing demands of global trade are putting pressure into the port sector to adapt to the requirements that the so called Industry 4.0 has created.

2.2.5 Technological Advancements and Employment

Nowadays, the global economy is on the edge of a new industrial revolution and new technologies are expected to dramatically metamorphose the labour market in the next two decades (Fuei, 2017). The impact of the increasing adoption of smart technologies in ports has significantly affected the workforce skills required and the traditional organisation of work in the port sector (Gekara and Thanh Nguyen, 2018). Thus, the changing nature of employment in ports and port-related sectors has raised many questions regarding the interpretation of economic benefits that are received by port-cities (Hall, 2009).

The existence of concerns that technological innovations in the industry might cause dramatic unemployment has been expressed in a report by World Economic Forum (2016). This report underlines that it is critical for businesses to take an active role towards supporting their current workforce, though re-training, re-skilling and up-skilling. Advances in artificial intelligence, robotic technologies and data analytics place under threat a broad range of tasks that were formerly considered to be non-automatable (Fuei, 2017). Therefore, the types of occupations that will be required in the future are expected to radically change due to digitalization (Fuei, 2017).

Gekara and Thanh Nguyen (2018), based on a qualitative study, discussed the ways in which technological changes have affected the nature of work and the type of skills required nowadays at container terminals. They provide evidence that the impact of the adaption of new technologies in the port industry is not simply linked to job displacement. On the contrary, they point out a rather complex transformation which includes reconfiguration, displacement and the emergence of new jobs. In terms of work skills, these changes have implicated a great requirement for computer skills, while the study concludes with the fact that future workers will differ significantly in terms of the work type they will do, their qualifications, their training and the skills they will be required to have.

There is evidence however, that a large amount of jobs will be lost due to computerisation and digitalisation. Fuei (2017) investigated the susceptibility of jobs to automation and computerisation in Singapore. The key objective of their study was to understand the impact of emerging technology on employment and jobs in Singapore. The author found that around 25 per cent of Singaporean employment is at high risk of computerization in the next ten to fifteen years. Even though this number might seem quite high, if compared to estimates produced by other countries, it places Singapore as having one of the lowest share of jobs at high computerisation risk. According to the author, retraining and education are the two key policy solutions that companies should adopt in order to prevent the disruptive impact of new technologies on employment.

However, history has shown that technology ultimately creates more jobs than it destroys, as automation accelerates one aspect of the job, thus increasing the demand for human workforce to perform other tasks that have not been automated (Fuei, 2017). Bessen (2016) reached this conclusion, after investigating the main relationships between occupations and technology, to find that against common belief, occupations that use computers in reality grow faster, rather than slower. Consequently, the author rejects the hypothesis that computers generate a significant overall job loss, albeit acknowledging that computerization does shift employment and creates the requirement of new skills.

As stated above in Section 2.2.4, the operation of a smart port seeks to improve port productivity, but also induces economic impact, in terms of production, value added and employment effects in the surrounding port region (Jun, Lee et al., 2018). Jun, Lee et al. (2018) adopted a hybrid methodology, using a series of Delphi surveys and input-output analysis, to estimate the economic impact of smart port technology on the Korean national economy and compared its economic impact with that of the traditional port industry. The authors noticed that the smart port industry is characterized by the forward linkage effect, which signifies that it is used as an intermediary process in other industries. Their results indicated that a shift towards smart ports can influence positively the national economy. In their study they showed that the economic impact of investment in the smart port industry increases production by 5.7%-12.3%, the value added by 16.8%-36.5% and the employment by 130%-205.9%. Therefore, according to the authors, the smart port industry has a significant positive effect on national economic development compared to the traditional port industry.

In conclusion, the impact of the adoption of new technologies in the port sector has been controversial. Although some studies support that a significant number of jobs will be lost, others suggest that more jobs are being created, and underline the fact that the new skillset required will generate a shift in the nature of jobs rather than job loss. Automation and digitalisation are a paradigm-shifting movement, changing the traditional processes and skills required in the industry, but that are also creating a significant positive effect on economic development compared to the traditional port industry, as technology may replace some jobs, but will also create a base for prosperity and opportunities for new, safer and highly payed jobs.

2.3 Port Efficiency

The rising tide of containerisation and the colossal use of containerised cargo not only has induced technological changes in the maritime industry but also caused port transformations (Pérez, Trujillo et al., 2016). To adapt to this new era, port reform processes were planned with the main goals being the promotion of competition and efficiency together with the modernization of ports. The literature on ports has acknowledged the significance of seaport's efficiency for a smooth and efficient operating transportation system (Odeck and Bråthen, 2012).

Efficiency can be defined in various ways, each satisfying a different purpose (Serebrisky, Sarriera et al., 2016). Thus, the concept of efficiency can be distinguished between economic, allocative and technical efficiency (Coto-Millan, Banos-Pino et al., 2000). According to Coto-Millan, Banos-Pino et al. (2000), the focus of economic efficiency is the degree to which costs are being minimized which is calculated by calculating the deviation from the efficiency frontier defined. Allocative efficiency can be defined as the deviation of the observed factor ratios from the optimal ratio, given the prices of the factors. Finally, technical efficiency measures how good the physical inputs adapt to producing one unit of output. Table 2.2 includes the definitions of the three types of efficiency.

EFFICIENCY TYPE	DEFINITION
Economic Efficiency	Is achieved when resources are used in such way that production is maximised at the lowest cost
Allocative Efficiency	Is achieved when production is at the level desired by society and the marginal benefit of the last unit produced equals its marginal cost
Technical Efficiency	Is achieved when a firm produces the maximum output with the lowest quantity of outputs required (prerequisite for economic efficiency)

Table 2.2: Efficiency Types

Source: Own elaboration from Serebrisky, Sarriera et al. (2016).

Monitoring and comparing ports in terms of their efficiency level has become a fundamental part of many countries' microeconomic reform regimes (Tongzon, 2001). Greater port efficiency is likely to induce lower export prices which consecutively help the increase in the nation's products competitiveness in international markets (Cullinane, 2002).

A port can become more attractive if port operators invest in its infrastructure, but another pivotal factor in port selection and competitiveness is port efficiency (Pérez, Trujillo et al. 2016). A port is efficient when it is able to produce a maximum output for given inputs, or uses minimal inputs to produce a given level of output (Notteboom, Coeck et al., 2000).

2.3.1 Methodological Approaches

Methodologically, the different techniques used to measure overall efficiency of ports can be divided according to at least two criteria (Notteboom, Coeck et al., 2000). The methods can be primarily distinguished between stochastic and deterministic, as the former takes into account the stochastic/random nature of data, while the latter does not. Secondly, we can differentiate the methods according to their parametric or non-parametric approach. On one hand, the parametric approach assumes *"that the boundary of the production possibility set can be represented by a particular functional form with constant parameters".* On the other hand the non-parametric approach "*concentrates on the regularity assumptions of the production possibility set itself and does not postulate a particular functional boundary*" (Notteboom, Coeck et al., 2000).

Since ports constitute a complex business with various different sources of inputs and outputs, the use of multiple inputs and outputs in the analysis is regarded essential for port efficiency studies (Valentine and Gray, 2001). Therefore, the input and output variables must be carefully chosen. Container throughput is usually used as the output variable, as it is the basic source of comparison among container ports (Valentine and Gray, 2001; Tongzon and Heng, 2005). Land, labour and capital on the other hand, represent the fundamental elements of modern enterprises, hence making sense to analyse these components when comparing companies (Valentine and Gray, 2001). When it comes to ports, land is the area that the port owns, labour relates to the number of employees employed by the port, and capital refers to the net assets of the port (Valentine and Gray, 2001). However, Notteboom, Coeck et al. (2000) highlight that the most relevant variables that affect directly the efficiency of a container terminal are the terminal quay length, the terminal surface and the number of quay cranes.

Scholars have attempted to answer the question of whether ports are as efficient and productive as they should be, by using frontier approaches to technical efficiency measurement. Ports are compared against among each other as measured by the distance to a given frontier (Odeck and Bråthen, 2012). The frontier is either composed of the best performers or is defined by an assumed functional form. The rationale behind the measurement of port efficiency, is that poorly performing ports can learn from comparable best performers in order to increase their efficiency and therefore improve transport systems and supply chains, which can in turn contribute to GDP growth (Odeck and Bråthen, 2012).

Frontiers can be classified in two types: parametric and non-parametric. All the common parametric methods, such as SFA, assume that in some way the data follow a normal distribution and that the spread of the data (variance) is uniform either between groups or across the range being studied. On the other hand, non-parametric methods, such as DEA, do not require the data to follow a particular distribution and do not assume a particular production function. They work by using the rank order of observations rather than the measurements themselves.

2.3.1.1 Data Envelopment Analysis (DEA)

Port efficiency has been broadly studied using standard Data Envelopment Analysis models and its variations (Wanke, 2013). Data Envelopment Analysis is a non-parametric technique, based on linear programming, used in econometrics and operations research for ranking and multi-variate frontier estimation, and can be applied for calculating apparent efficiency levels among a group of organizations (Panayides, Maxoulis et al., 2009). The DEA technique is concerned with assessing the efficiency of an individual unit, which is defined as Unit of Assessment (Thanassoulis, 2001) or the Decision Making Unit (DMU) (Charnes, Cooper et al., 1978). This unit organisational entity is responsible for controlling the process of production and for making decisions at various levels, including long-term strategies, short-term tactics and daily operations (Cullinane and Wang, 2006; Panayides, Maxoulis et al., 2009). In the port industry, DEA is used to assess and compare port performance, through the calculation of the relative performance of the DMU under investigation to the group's observed best practice (Notteboom, Coeck et al., 2000; Panayides, Maxoulis et al., 2009).

Data Envelopment Analysis is therefore used for assessing the efficiency of a decision-making unit (DMU) with numerous inputs and/or numerous outputs (Cullinane and Wang, 2006). DEA measures port efficiency as the ability for a terminal or port to match the optimal number of inputs to a given level of output (Figueiredo De Oliveira and Cariou, 2015). DEA relies on the estimation of an efficiency frontier, which is equal to the best performance according to the data provided by the examined sample (Serebrisky, Sarriera et al., 2016). The efficiency is therefore measured by benchmarking its actual output against the frontier that "envelops" all the ports included in the study (Nguyen, Nguyen et al., 2016).

DEA was first developed by Charnes, Cooper et al. (1978) as a means to measure service units, based on Farrell (1957) initial idea to link production frontiers and the estimation of technical efficiency (Valentine and Gray, 2001). There are four basic models: CCR (Charnes, Cooper et al., 1978), BCC (Banker, Charnes et al., 1984), as well as the Additive model and the multiplicative model. The basic differences among the models derive from a few factors such as taking or not into consideration the existence of economies of scale, the way in which inefficient DMUs are projected on the efficiency frontier and the frontier's geometric form (Martinez-Budria, Diaz-Armas et al., 1999). The DEA-CCR model considers constant returns to scale in order for all observed production combinations to be scaled up or down proportionally (Cullinane, Ji et al., 2005). On the other hand, the DEA-BCC model takes into account variable returns to scale and is represented graphically through a piecewise linear convex frontier (Cullinane, Ji et al., 2005).

The type of data used in DEA is either cross-sectional or panel data. DEA analysis of cross-sectional data involves a comparison of one firm with all other firms during the same period, providing s snapshot of producers and their efficiency, while on the other hand panel data enables a firm to be compared with another firm, but gives the chance to be compared taking into account not only a time snapshot but a time period (Cullinane, Ji et al., 2005).

The significant increase in the use of DEA during the last decade is mainly associated with the methodological and computational benefits of the technique, which appear to be suitable for the measurement of efficiency in the complex port environment (Panayides, Maxoulis et al., 2009). This technique evaluates port efficiency as the capability for a port or terminal to match the optimal number of inputs to a given level of output (Figueiredo De Oliveira and Cariou, 2015).The main advantage of DEA is that it can manage multiple inputs and outputs (Valentine and Gray, 2001).

Apart from the advantages of using DEA, there are also some limitations and problems that researchers face when adopting this technique for the measurement of port efficiency (Panayides, Maxoulis et al., 2009). For this reason there is a significant diversity among the studies, related to the selection of different inputs and outputs in the models, the difference in sample size and the variation in the profile of the samples selected, and also the adoption of different approaches (Panayides, Maxoulis et al., 2009).

A large amount of literature deals with the measurement of port efficiency and productivity of ports. Roll and Hayuth (1993) were the first researchers to attempt using DEA for the measurement of port efficiency. That study, although theoretical - as it did not use real data

- should be considered as a quantum leap as it is the first effort to apply DEA to measure port efficiency. Their suggested CCR model included 20 ports (DMUs), while the chosen inputs related to cargo uniformity, labour and capital and the outputs related to throughput and service. The authors concluded that DEA is a most suitable tool in measuring port efficiency levels.

Martinez-Budria, Diaz-Armas et al. (1999) introduced two new pivotal elements in the application of the DEA technique as a means to measure port efficiency. They applied DEA to measure the relative efficiency of 26 Spanish ports during the period 1993-1997. The first original element that they introduced was the adoption of time series data (1993 throughout 1997), while the second was the separation of the ports under study into 3 different groups, due to the complexity linked with their size and output composition. More specifically, the major differences of the 26 ports were recognized by the authors and therefore they separated them according to their complexity level. In this way a comparison among the ports in each group was permitted, whilst the use of time series data permitted the examination of the historic evolution of each port's performance. The study revealed that ports of high complexity showed higher comparative efficiency levels with a positive evolution over time, the ports of medium complexity showed a smaller growth in their efficiency levels and finally the ports of low complexity appeared to have a negative trend in their efficiency levels during the five years studied.

In his attempt to measure and compare port efficiency at an international level, Tongzon (2001) applied DEA to provide a measurement of efficiency for twelve international container ports and four Australian ports. For this assessment he used cross-sectional data for the year 1996 and considered cargo throughput and ship-working rate as the outputs for the model. The port inputs were divided into 3 categories, namely land, labour and capital. Moreover, in this study the delay time was also considered as input, since it is an indicator of how effectively the working time is being used. The author used constant (CCR-DEA model) and variable returns to scale (Additive model) assumptions and provided two different results for each port according to each model. The results indicated that four out of the sixteen ports (Melbourne, Rotterdam, Yokohama, Osaka) were identified as the most inefficient ports in the sample, while ten of the sixteen ports were found to be inefficient. The author concludes by suggesting that larger sample size and port clusters would bring more accurate results.

Similarly, using DEA analysis, Barros and Athanassiou (2004) studied the efficiency levels of 4 Portuguese and 2 Greek ports and tried to seek best practices in order to achieve improved performance. Their results suggested that scale economies should be their main target for adjustments, and secondly, that privatisation of these ports would allow them to improve their productivity and increase the competition.

Wu and Goh (2010), compared the efficiency of port operations in emerging markets with those in more advanced markets. Their sample comprised of 21 container ports, each of them being the largest in its country for the year 2005. By applying DEA frontier analysis, they concluded that none of the ports located in advanced markets could act as a role model for the field. The reason behind this conclusion was that three of the ports situated in emerging markets (namely Shanghai in China, Chittagong in Bangladesh, and Santos in Brazil) had efficiency levels in 2005 that surpassed those in the developed G7 nations.

In his two-stage network-DEA approach Wanke (2013) measured the efficiency of 27 Brazilian ports for the year 2011. This two-stage process, namely physical infrastructure efficiency and shipment consolidation efficiency, was adopted to optimize both stages in the same time. During the first stage assets are used to achieve a specific shipment frequency per year, while in the second stage these movements permit containerized and solid bulk cargoes to be handled. From the outcome of his study it can be highlighted that private administration in ports plays a positive role when it comes to physical infrastructure efficiency levels, whilst the operation of both types of cargoes and the hinterland size have a positive effect of shipment consolidation efficiency levels.

2.3.1.2 Stochastic Frontier Analysis (SFA)

Aigner, Lovell et al. (1977) and Meeusen and van Den Broeck (1977) simultaneously introduced the Stochastic Frontier Analysis (SFA) technique, as an alternative approach to DEA. SFA assumes the existence of a parametric function between production inputs and outputs (Cullinane, Wang et al., 2006). The primary advantage of this technique is that it allows for technical inefficiency and acknowledges that random shocks generated outside the control of producers can affect the output (Cullinane, Wang et al., 2006). Accordingly, the main idea behind this technique is that the error term is composed of two parts; a one-sided component capturing the effects of inefficiency relative to the stochastic frontier, along with a symmetric component permitting random variation of the frontier across firms, capturing the effects of other statistical 'noise', of the measurement error and random shocks.

In the context of SFA studies, many researchers have looked at port efficiency levels by applying Stochastic Frontier approaches for their analysis. Notteboom, Coeck et al. (2000)

for example, presented an approach for measuring container terminal efficiency based on Bayesian Stochastic Frontier modelling. By testing a sample of 36 European and 4 Asian container ports for the year 1994, they compared the level of (in)efficiency of different container terminals. The authors found that north European container terminals achieved a slightly higher efficiency score compared to southern terminals. Their results also indicated that terminals located in feeder ports are on average less efficient than those located in hub ports.

Coto-Millan, Banos-Pino et al. (2000) used a stochastic frontier cost function to estimate the economic efficiency of 27 Spanish ports through panel data, covering the period from 1985 to 1989. Their results indicate that larger ports are more economically inefficient compared to relatively smaller ports, detecting the presence of large-scale economies along with a lack of technical progress for the period studied.

Estache, González et al. (2002) through their SFA study for 11 Mexican ports in the period 1996-1999 (after the 1993 Mexican Port reform), concluded that reforms in the management of port infrastructure that promote its autonomous management (decentralization), generated large short-term improvements in the average performance of the sector. These improvements can be generated through privatization of services, but not necessarily through privatization of infrastructure.

Cullinane, Song et al. (2002) analysed the efficiency of 15 container ports in Asia, using also a stochastic frontier model, using cross-sectional and panel data, based on the period from 1989 to 1998. From their results it is concluded that the size of a port or terminal is closely correlated with the levels of its efficiency. Therefore, large throughput operations appear to have higher performance than their smaller counterparts.

Pérez, Trujillo et al. (2016) through the estimation of a Stochastic Production Frontier, examined the evolution of the efficiency of main container terminals in Latin America and the Caribbean (LAC), as well as the determinants of terminal inefficiency. Their study investigated whether increases in efficiency obtained through port modernization and reforms in the LAC region, maintained over time. Their findings show an average level of 83% in technical efficiency in the period studied and a technological change of 5%, which indicate that port efficiency has evolved positively. Transhipment ports appeared to be less efficient than other port types and ports with three or four terminals were the most efficient ones.

Using the same geographical scope in their analysis, Serebrisky, Sarriera et al. (2016) explored the drivers of efficiency in the LAC region for the period between 1999 and 2009. They used a stochastic frontier model to develop a technical efficiency analysis of 63 container ports in the LAC. Their analysis showed an increase in the average technical efficiency of the examined ports from 52% to 64%. The findings also indicated that private sector participation is correlated with efficiency gains and that national income levels and public sector corruption were not significant drivers of port efficiency.

Finally, in a comparative analysis of the methodological merits of DEA and SFA, Cullinane, Wang et al. (2006) found a high degree of correlation between the efficiency estimates generated from each model, suggesting that DEA results are also robust to the DEA models applied or the distributional assumptions under SFA. Table 2.3 shows the main characteristics of DEA and SFA.

DEA	**SFA**
Non-parametric approach	Parametric approach
Deterministic approach	Stochastic approach
Does not consider random noise	Considers random noise
Does not allow statistical hypotheses to be contrasted	Allows statistical hypotheses to be contrasted
Does not impose assumptions on the distribution of the inefficiency term	Imposes assumptions on the distribution of the inefficiency term
Does not include error term	Includes a compound error term: divided in symmetrical and one-sided
Does not require specifying a functional form	Requires specifying a functional form
Sensitive to the number of variables, measurement errors and outliers	Can confuse inefficiency with poor specification of the model
Estimation method: mathematical programming	Estimation method: econometric

Table 2.3: Main characteristics of DEA and SFA

Source: Gonzalez and Trujillo (2009)

The major advantage of DEA, against parametric methods such as SFA, is that it does not impose any functional form on the frontier nor does it assume a particular distributional form for the efficiency errors terms; this major advantage is a weakness for parametric frontier models. Its only weakness compared to the parametric model is that it does not account for statistical noise in the data. DEA also offers a greater flexibility and less restrictions than SFA in regards with applicability, as there is no need to assume economic behaviours such as profit maximisation or cost minimisation (Nguyen et al., 2018). Moreover, compared with traditional approaches, DEA has the advantage that it can cater for multiple inputs to and outputs from the production process and does not require a priori an explicit determination of relationships between inputs and outputs (Tongzon, 2001).

Despite the apparent sophistication of the econometric and statistical approaches, these studies share many challenges and should be regarded with a note of caution, mainly concerned with differences in the reliability and definition of the input statistics, temporal consistency in the data available from ports and terminals, limitations in the transparency and trust between port authorities and terminal operators (World Bank and IHS Markit, 2021). Some of the main questions to address with regards to input reliability are whether the container handling space excludes or includes container depots adjacent or outside to the port area and whether it includes general cargo berths where overspill container are handled (World Bank and IHS Markit, 2021).

2.3.1.3 Malmquist Productivity Index (MPI)

The total factor productivity index has been suggested as an alternative measure to better understand port productivity (Cheon, Dowall et al., 2010). More specifically, according to Cheon, Dowall et al. (2010) the Malmquist Productivity Index (MPI) is an effective way of measuring the total factor productivity (TFP) change between two time periods and decompose the sources of efficiency changes. The assumption is that the temporal changes in efficiency can be attributed to total technical efficiency changes (TTEC), which is represented by the movement of a port along the production frontiers, and might occur within a short period; and secondly to the frontier-shift effect, which is represented by the shift of the productive efficiency frontier in a production function, and might occur due to a significant change such as technological progress (TP) (Estache, de la Fé et al., 2004; Cheon, Dowall et al., 2010). This approach allows the assessment of the relative importance the catching-up effects and the frontier-side effects generated from reforms aimed at increasing competition among ports (Estache, de la Fé et al., 2004).

Therefore, this methodological approach can link technological advancements to port efficiency, in order to explore whether a change in the average productivity of a port is due to technical gains or technical efficiency change (Schøyen and Odeck, 2017).

Estache, de la Fé et al. (2004) used the MPI to decompose and calculate changes in productivity for Mexico’s 11 main ports, for the period from 1996 throughout 1999. Their findings suggested that TFP in Mexican ports increased by an average of 4.1% per year in the period 1996-1999. The results also indicated that all ports, apart from one, maintained or improved their pure technical efficiency during the studied period.

More recently, Schøyen and Odeck (2017) measured productivity changes during the period 2009-2014, of the six largest Norwegian container ports against 14 Nordic and UK ports. Their approach was a DEA-based Malmquist productivity change index, which implemented a decomposition isolating the technical progress of the efficiency improvement. Their results showed a higher performance of the Norwegian ports compared to their international counterparts in terms of efficiency scores. However, when productivity growth over time was considered, the Norwegian ports appeared to have higher performance, but when a statistical test was applied this was proven false. Finally, the results suggested an approximate increase of 0.6% per year in total productivity for all ports in the sample, while this progress was attributed more by technological improvements and gains (investing in new technology and systems), rather than efficiency change.

2.3.1.4 Port Performance Measurement and Port Performance Indicators (PPI)

Port performance is usually associated with measures of partial productivity, which are commonly defined as ratios of output volume to input volume, and also with different measures of efficiency (Serebrisky, Sarriera et al., 2016). The productivity indicators are often related to time variables that aim to evaluate, for example, how fast the cargo is handled (Serebrisky, Sarriera et al., 2016). Among others, examples of these indicators include moves per crane-hour, moves per ship-hour, ship delay, dwell time and ship productivity. Through port indicators such as these, significant operational efficiency measures are provided.

The main ways to measure port productivity and efficiency can be categorized into three broad groups: physical indicators, factor productivity indicators, and economic and financial indicators (Bichou and Gray, 2004). Table 2.4 describes the types of Port Performance indicators:

Type of Indicator	Description
Physical indicators	• Time measures, mainly concerned with the ship e.g.: ship waiting time, ship turnaround time, berth occupancy rate, working time at berth, cargo dwell time
Factor productivity indicators	• Focus on the maritime side of the port e.g.: labour and capital required to load and unload goods from a ship
Economic/financial indicators	• Relate to the sea access e.g.: operating surplus or total income expenditure related to gross registered tonnes or net registered tonnes, change per TEU

Table 2.4: Description of Port Performance indicators

Source: Own elaboration from Bichou and Gray (2004)

As mentioned above, frontier models such as DEA and SFA have been widely used to assess port efficiency, both across different countries as well as within the same country. Such techniques have mainly focused on container ports, and usually fail to include aspects of logistics integration relevant to a modern port. Bichou and Gray (2004) proposed a logistics and supply chain management approach to measure port performance and suggested a framework of efficiency measurement that can reflect the logistics scope of port operations. They used the action research paradigm, which requires a close collaboration and relationship between the researchers and the practitioners. Action research is a suitable technique for theory building or development, but less suitable for hypothesis testing (Westbrook, 1995). The technique used was to present to experts and port managers a model of port performance for assessment and examination by them, leading to an improved model, and supported by a questionnaire of port managers that focused on performance indicators. The questionnaire was used to investigate techniques of port performance measurement. Even though most of the respondents confirmed the use of the combined indicators, they highlighted their dissatisfaction as far as the range of existing indicators is concerned.

2.3.2 Factors affecting Port Efficiency

2.3.2.1 Port Efficiency and Port Ownership Type

The goal of research studies on port efficiency varies and ranges from establishing a relation among efficiency type, port management type and port ownership type, to solely generating rankings of ports and evaluating the impact of port reform processes on port efficiency (Gonz, xe et al., 2009). Ports can be categorised according to their type of ownership or administration. The distribution of property rights to a range of parties over the services, infrastructure and superstructure of ports generates different patterns of port ownership (Cullinane, Ji et al., 2005). Goss (1990b) divided ports into three types according to the role played by the port authority, in probably the first discussion around this topic. Table 2.5 describes these three types of ownership:

Port Type	Description
“Comprehensive Port”	When the port authority performs all, or almost all, of the activities carried out within the port area.
“Landlord Port”	When the port authority is only responsible for planning the port and exercising overall control over the activities carried within it, while simultaneously delegating these extensively to private sector companies.
“Hybrid port”	When the responsibilities lie somewhere in between the description of the previous two types.

Table 2.5: Classification of ports according to the role played by the port authority

Source: Own elaboration from Goss (1990b)

A further development of this classification was carried out by Liu (1992), who divided ports into four categories. Table 2.6 illustrates these categories:

Port Type	Description
“Service Port”	When the port authority is responsible for the provision of all port services and facilities.
“Tool Port”	When the public port authority provides the infrastructure and superstructure, while the provision of services is licensed to private operators.
“Landlord port”	When the responsibilities of the port authorities are restricted to the provision of infrastructure, while investment in superstructure and port operation lies within the responsibility of licensed private companies.
“Private Port”	When the provision of all facilities and services is left to the private sector.

Table 2.6: Classification of ports

Source: Own elaboration form Liu (1992)

Another alternative for the analysis of port administration and ownership was proposed by Baird (1995) and Baird (1997) and refers to a port function matrix as illustrated in Table 2.7:

Port models	**Port functions**		
	Regulator	**Landowner**	**Operator**
PUBLIC	Public	Public	Public
PUBLIC/private	Public	Public	Private
PRIVATE/public	Public	Private	Private
PRIVATE	Private	Private	Private

Table 2.7: Port function matrix

Sources: Baird (1995), Baird (1997)

The conceptual framework proposed by these authors is based on the fact that a port must fulfil and provide the functions of regulator, landowner and operator, whether it is in public or private hands. Depending on which of these three functions is under the responsibility of public or private organisations (entities), the above function matrix makes it possible to determine the degree of the influence exerted by the private or public sectors within a given port.

Likewise, organisational structure also plays a significant role in the operation of a port (Valentine and Gray, 2001). From the five different types of organisational structure outlined by Mintzberg (1979), only three can fit into the modern port structure (Valentine and Gray, 2001). These are the simple structure, the machine bureaucracy and the divisional structure, with those not fitting being the adhocracy and professional bureaucracy. The adhocracy structure cannot be applied to ports due to its lack of austerity, while the professional bureaucracy is not applicable to a port because of the repetitive tasks and the routine existing within a port's daily service, which cannot be performed in an unsupervised manner, as they do in this type of structure (Valentine and Gray, 2001).

Table 2.8 describes the remaining three types of organizational structure that are suitable in the port industry.

Type of Organisational Structure	Description
Simple Structure	➔ Most flexible ➔ Allows separate divisions/departments to report straight to the top decision-maker ➔ Usually the first stage through which a company progresses in its evolution ➔ Due to its simplicity this structure is likely to be the most efficient
Machine Bureaucracy Structure	➔ Characterized by its many departments that report up a chain of command to a line manager before reporting to the top decision-maker. ➔ Decisions tend to be slower due to the long process that has to be followed before reaching the top ➔ This structure tends to be found in government owned enterprises and hence the inclusion of port bodies and corporatisation within this category
Divisional Structure	➔ It occurs when ports operate within large areas ➔ Each department must report to a regional office, which in turn reports to a select group of managers before reaching the top decision-maker ➔ This structure can be best seen in the municipal ports of the United Kingdom and Columbia’s port societies ➔ These structures tend to operate in joint public/private enterprises or when the port is owned by conglomerates

Table 2.8: Types of organizational structure in ports

Source: Own elaboration from Valentine and Gray (2001)

Prior to 1980s, worldwide port services were exclusively financed and operated by public sector entities (Coto-Millán, Fernández et al., 2016). During the last decades the ownership of ports has altered from being entirely in the hands of local or national governments to being in the hands of private entities, either partially or fully (Valentine and Gray, 2001). According to Coto-Millán, Fernández et al. (2016), this phenomenon was based on two different but complementary trends; firstly, the notion perceived by governments that the private sector could provide access to additional capital for service improvement and expansion, as well as being an attractive solution to the problems caused by infrastructure services; and secondly the increasing level of international competition that made the enhancement of the competitiveness in the sector mandatory. This global trend towards the institutional reform of the public sector has led many countries to adopt the policy of port privatization, as a means of improving their port efficiency and in turn their overall economic performance (Cullinane, 2002).

One of the pivotal objectives of port privatisation is claimed to be the enhancement of efficiency, as it is considered that the increase of the private sector in the operation and ownership of ports can aid port authorities to improve their operational efficiency (Cullinane, Ji et al., 2005; Tongzon and Heng, 2005).Efficiency should therefore be regarded as a fundamental measure in illustrating changes in the overall performance of a port following its privatization (Cullinane, Ji et al., 2005). Hence, the identification of the relationship between port efficiency and port ownership structure is crucial and has acquired a lot of interest from researchers over the past two decades (Valentine and Gray, 2001; Cullinane, Ji et al., 2005; Tongzon and Heng, 2005).

It is often suggested that privately operated container terminals would attain higher efficiency levels than those operated by semi-public or public companies (Notteboom, Coeck et al., 2000). Most studies examining the relationship between the private sector's participation and port efficiency find positive correlations, supporting the concept of principal-agent theory, which states that private ownership should be more efficient than public ownership (Coto-Millán, Fernández et al., 2016). However, other empirical studies that have also investigated the link between port ownership structure and port operation efficiency have provided evidence that there either is no clear-cut pattern, or that there is a negative correlation, between port efficiency and the type of ownership (Tongzon and Heng, 2005).

One of the first studies to examine this relationship was conducted by Liu (1995) who used stochastic frontier production to compare the influence of public and private ownership on inter-port efficiency. The results of the study failed to identify ownership as a pivotal factor of production and their evidence did not establish a definitive relationship of efficiency in favour of one or other type of ownership. Similarly, Notteboom, Coeck et al. (2000) did not find any clear relation between ownership structure and efficiency level when they valued a variety of ownership and administrative systems in the examined port sectors.

In the same context of neutral effects, Valentine and Gray (2001) examined the relative efficiency of 31 differently owned container ports, to investigate whether there is a specific organizational structure and ownership type that leads to an increased port efficiency. The port sample was retrieved from the list of top 100 container ports published by Cargo Systems Journal, while the research data relates to the year 1998. In their study they compared ports owned by the public sector against privately owned ones, and some ports that combine both private and public features. To determine whether there exists or not a relationship among port performance, port ownership type and organizational structure, the authors used DEA Analysis (related to port efficiency) and cluster analysis (related to organisational structure). The study concluded that the simple organisational structure is the most efficient, whilst ownership type does not appear to significantly influence the efficiency of the port. Moreover, Coto-Millan, Banos-Pino et al. (2000) argued that the type of organisation has a significant effect on economic efficiency, since the results of their SFA analysis indicated that ports managed under a greater centralized regime were found to be more efficient than others. However, their findings indicated that greater autonomy in management results in greater economic inefficiency.

Contrary to these findings, various other empirical studies regard private sector participation as an effective policy to increase efficiency in ports. Cullinane, Song et al. (2002) through their SFA study in major container ports in Asia, provided evidence that some support exists for the notion that the reform of ownership from public to private can improve the economic efficiency of a port. They also argued that the level of deregulation is a significant variable which may also generate enhanced efficiency. Similarly, Cullinane and Song (2003) investigated the Korean container terminal sector, through a stochastic frontier model based on panel data for five Korean and UK terminal companies. Their results suggested that there is a positive relationship between the degree of private sector involvement in container terminals and their productive efficiency. It has conclusively been shown that an improvement in the productive efficiency has been induced following the implementation of privatization and deregulation policies within the examined sector.

Cheon, Dowall et al. (2010) implemented the Malmquist Productivity Index to evaluate the effect of port institutional reforms on port efficiency, for 98 major world ports in the period between 1991 and 2004. Their results illustrated that the restructuring of ownership contributed to total factor productivity gains, especially for larger ports, as it allowed the private specialized companies to concentrate on cargo handling services and terminal operation more efficiently. Likewise, Coto-Millán, Fernández et al. (2016) argued that port reforms in Spain during the last three decades, which promoted privatisation, port autonomy and intra-port competition, have had a positive impact on port technical efficiency. To investigate the link between port reforms and port efficiency, they used an SFA input-oriented model and a sample comprising of 26 Port Authorities during the period 1986-2012, Their study established a direct positive correlation between the reform and the improvement in efficiency, thus making it possible to conclude that port autonomy, privatisation and inter-port competition brought through the reforms in the Spanish port sector, were the most significant factors to enhance efficiency in the Spanish port system.

However, neither empirical studies nor economic theories can confirm that port privatization will necessarily lead to increased port performance. For instance, the study of Cullinane, Ji et al. (2005) presents a number of advantages and disadvantages of port privatization, providing an empirical examination of the relationship between relative efficiency in the container port industry and privatization. They used DEA to examine port efficiency of the world's top 30 container ports in 2001, to conclude by rejecting the initial hypothesis that greater involvement of the private sector in the container port sector inevitably leads to improved efficiency.

Tongzon and Heng (2005) were among the first to apply the stochastic frontier model that incorporated the inefficiency effect in the port industry. They presented an application of the stochastic frontier model, in order to demonstrate whether port privatization should be regarded as a fundamental strategy for ports to gain competitive advantage. Their study also examined the determinants of port competitiveness through principal component analysis and linear regression analysis. The key finding of their study was that the participation of the private sector in the port industry can increase to some extent port operational efficiency, leading to improved port competitiveness. Nevertheless, the relationship between port privatisation and port efficiency was not a linear one, as a full port privatisation did not appear to be an effective means of increasing port efficiency. This finding implies that port authorities should introduce private management, finance and operation instead of having public funds and administration, while simultaneously keeping the regulatory function. Finally, their results showed that a significant factor that determines port competitiveness is the adaptability to the demands of the customers, making it necessary for port operators and port authorities to understand the requirements of their customers and work towards meeting and exceeding their expectations.

In conclusion, although the existence of a direct correlation between the degree of private sector involvement and the enhancement of economic efficiency is not categorically proven, deregulation policies have been widely used in many countries and across many industries (Tongzon and Heng, 2005). Thus, privatisation is commonly perceived to be the most significant policy for enhancing the efficiency of the port sector (Cullinane, 2002).

2.3.2.2 Port Efficiency and Port Competition

Inter-port competition can be defined as the competition between or among different ports, while intra-port competition refers to competition within the same port when the port is not solely under the control of public port authorities, but many firms compete simultaneously for the same cargo (Cullinane, Ji et al., 2005). Due to the accelerated development of intermodal and container transportation, inter-port competition has made port managers to not only be concerned of whether their port has the required capacity or technology to serve its customers, but also whether they have the ability to compete for cargo based on the services and price offered (Cullinane, Ji et al., 2005).

The relationship between inter-port competition and port performance is another major issue that has created debates in the port industry. A study by Figueiredo De Oliveira and Cariou (2015) investigated whether inter-port competition impacts port efficiency score and if this potential relationship changes when it is evaluated at different levels. Their dataset included 200 container ports in 2007 and 2010 and the method they implemented to reach their objective was a truncated regression with a parametric bootstrapping model. The outcome indicated that competition impacts the efficiency score of ports and that an increase in competition results in a decrease of port efficiency. This impact was specifically noticeable when competition develops at the regional level, as port efficiency decreased with the increase of competition intensity. Moreover, the competition effect on port efficiency was not found to be significant when measured at a local or global level. Similarly, the findings of Pérez, Trujillo et al. (2016) also suggest that Latin America and the Caribbean (LAC) decision makers should take into serious consideration the promotion of inter-port competition and the strengthening of intra-port competition.

2.3.2.3 Other factors affecting Port Efficiency

Another policy variable that might affect the level of port efficiency is the port security level. The way that port security policy affects port efficiency is not a linear one, in contrast with other factors such as the number of berths, the yard area and the number of port workforce which have a positive and linear relationship with port efficiency (Yeo, Pak et al., 2013). In order to analyse the correlation between seaport security levels and container throughput, the study of Yeo, Pak et al. (2013) adopted the Systems Dynamics Method to simulate and estimate the impact of the increasing level of security in Korea on container volumes. This methodology is used to analyse the potential effects of a policy by modelling the structure of a system through the use of computer simulation (Forrester, 1997). Their results indicated that high security costs can burden a port and initiate a loss in the port's competitiveness, which can in turn result in significant market share loss. They highlighted that an excess in port security levels can reverse port attractiveness, and through their quantitative results the authors argued that significant economic benefits can be attained by Korean seaports if the seaport maintain a lower security level.

Port size is also considered to be a determinant factor in the degree of port efficiency (Gonz, xe et al., 2009). Martinez-Budria, Diaz-Armas et al. (1999), Cullinane, Song et al. (2002), Tongzon and Heng (2005), Cullinane, Wang et al. (2006) all show through their studies a significant and positive correlation between larger port/terminal size and increased efficiency levels. On the other hand, Liu et al. (1995) finds that the impact of port size on port efficiency is small, while Tongzon (2001) concludes that port size is not a determinant factor for port efficiency levels. Contrary to the above, Notteboom, Coeck et al. (2000) indicate that high levels of competition among small terminals lead to higher degrees of port efficiency, while Coto-Millan, Banos-Pino et al. (2000) also show that smaller port authorities have the highest indexes of port economic efficiency. Finally, Turner, Windle et al. (2004) stated that, among other determinant factors of port efficiency, the relationship between the rail industry and the ports (intermodality) is a critical determinant of port efficiency levels.

2.4. Ports and Economic Development

2.4.1 Transport Infrastructure Investment and Economic Impact

The transportation sector is a pivotal factor in terms of economic and regional development, and generates a significant influence on national integration to the world's economic market (Dwarakish and Salim, 2015). The terms economic growth and economic development, when linked to a specific development or investment, cover the long-term increase in economic activity, which can be associated to the specific investment, and which can act as an addition to the direct transport benefits (Banister and Berechman, 2001). Transport infrastructures and their relative efficiency constitute a pivotal factor in boosting economic development (Ferrari, Percoco et al., 2010). Therefore, investment in transport infrastructures is a significant element in the creation of a sustainable and efficient transport sector, as efficient intermodal flows are regarded as critical to the future success of transport policies (Woodburn, 2013).

One of the aspects that is improved through transport network investments is connectivity to international markets (Bottasso, Conti et al., 2018). In the context of transportation planning, connectivity represents the cost, ease and time of travelling between different transportation route systems or modal systems (Alstadt, Weisbrod et al., 2012). Transport connectivity has played an important role in the gradual expansion of trade flows, which involve both domestic and foreign trade (Li and Qi, 2016). China's government, for example, has proposed the so called "One Belt, One Road" initiative, which is a new economic paradigm focusing on cooperation and connectivity among Eurasian countries, and aims to redirect China's domestic overcapacity and capital for the development of regional infrastructure in order to improve trade relationships with Asian, central Asian and European countries (Kennedy and Parker, 2015).

The question of "whether investment dedicated to transport infrastructure promotes economic growth at local and regional levels" has received much attention from researchers. According to Li and Qi (2016), the significant investment in China's infrastructure equipment during the past few decades, has contributed enormously in its economic development and has been a critical driver of growth. Li and Qi (2016) examined through a regression analysis of panel data over the period 2002-2014, the relationship between transport connectivity and regional economic development in China. Their empirical results indicated a statistically significant and positive impact of transport connectivity on economic development in China. Banister and Berechman (2001) also attempted to answer this question, by defining and presenting a set of conditions which need to exist simultaneously in order for economic development from these investments to take place. They point out that economic development and growth are two terms that include the long-term increase attributed to the specific transport infrastructure investment, which can be shown to be a significant addition to the direct transport benefits (e.g.travel time reductions). Table 2.9 illustrates the necessary set of conditions that must exist in order for economic development to take place, outlined by Banister and Berechman (2001).

Presence of underlying positive externalities	Investment factors	Political factors
• agglomeration and labour market economies • availability of a good quality labour force • underlying dynamics in the local economy	• availability of funds for the investment • scale of the investment and its location • the network effects • the actual timing of investment	• broader policy environment within which transport decisions must be taken • sources of finance • level of investment (local,regional,national) • the supporting legal, organisational, institutional policies and processes • complementary policy actions (grants, tax breaks)

Table 2.9: Set of conditions for economic development from transport infrastructure investment

Source: Own elaboration from Banister and Berechman (2001)

A further investigation by Pradhan and Bagchi (2013) related to the effect of transportation infrastructure on economic growth in India over the period 1970-2010, found a bidirectional causality between road transportation and economic growth. The authors suggest that the expansion of transport infrastructure, both rail and road, along with gross capital formation, will lead to substantial growth of the Indian economy.

2.4.2 Ports and Net Benefits

Ports are considered to be one of the primary components of the transportation sector and have strategic importance for the development and growth of national economies, as they handle more than 80% of world merchandise trade by volume and more than two thirds of its value (UNCTAD, 2018). They constitute big and complex businesses, not only because of the valuable technology, land and labour inputs they combine, but also because of the fundamental role they play in distribution systems and global production (Hall, 2007).

Hence, ports are increasingly recognized as key elements in shaping the overall competitiveness of national economies (Mangan, Lalwani et al. 2008). More specifically, the economic contribution of port development to local communities includes elements such as value added, fiscal revenue and employment (Dooms, 2015). Therefore, if regarded as a supplier of jobs for example, ports do not only serve an economic, but also a social function (Dwarakish and Salim, 2015). Moreover, from a national perspective, ports also play an important role because they generate duties and taxes and they generally constitute growth poles for national industries as they improve their competitiveness (Benacchio and Musso, 2001).

Within the port impact studies, Bottasso, Conti et al. (2014) argue that ports might have non-negligible effects on local GDP, while they underline the fact that spillover effects can be associated with port activities, inducing indirect impact on regions outside the place where the port is located. However, there are also some costs suffered by local economies, in terms of land consumption, traffic congestion, coast waste and environmental problems (Benacchio and Musso, 2001). The increased port activity that has been induced by containerization, reflects many external costs in port cities and plays a key role in the regional economy (Hall, 2009; Chang, Shin et al., 2014).

The significance of port infrastructure on regional economic development has been studied extensively by many researchers. Coto-Millán, Pino et al. (2010) represented one of the first attempts to estimate the economic impact that an investment in a project for the expansion of the port of Santander would have on employment and economic growth in Cantabria. They detected a stable relationship between employment, regional output, human capital, the supply of private capital and the port infrastructure. The authors highlighted the importance of investment in infrastructures for the development of a region, as the lack of ports and other transport infrastructures slows down the operation of an economic system and has a negative on the living standard of citizens and on employment.

Increasing attention has been also devoted to the effects of rail network enhancement to achieve a shift of containers from road to rail. Woodburn (2013) investigated this matter to determine the rail freight efficiency effects of a loading gauge increase on the corridor from Southampton port to the West Midlands in April 2011, which allowed 9’11’’ high containers to be transported on standard wagons. Their methodology included a “before” and “after” survey, with the former taking place in 2007 and the latter in 2012. Their results indicated that there has been a considerable improvement in the rail freight efficiency, as both on-train capacity and train loads have substantially improved.

Recently, Bottasso, Conti et al. (2018), also investigated the impact of port infrastructure on trade. The authors developed a gravity equation for exports/imports of Brazilian states towards/from Brazil’s main trading partners, over the period 2009-2012. They concluded that a potential increase in port infrastructure can result in substantial increases in Brazilian exports, with the impact on imports being relatively lower and more mixed. Their results supported the links between GDP and international trade, as well as showing the ability of port investment to promote international trade flows. These results indicated that maritime infrastructure investments during the studied period generated a 14% increase for export flows and an 11% increase for import flows. Another significant finding of their study was the provision of evidence that there is a possible existence of positive spillover effects of ports, which underlines the possibility to boost international trade by enhancing the connectivity among ports and main production/consumption points.

2.4.3 Methodological Approaches

Port impact on the regional economy is measured in order to assess the economic and social impacts (indirect, direct and induced) of ports in their respective foreland or hinterland (Danielis and Gregori, 2013). There are many differences in the methodologies adopted, in terms of selecting, defining and measuring the various types of socio-economic port-related impacts (Dooms, Haezendonck et al., 2015). Therefore, the economic impact analysis of the port sector has been assessed through various methods in the existing literature.

In general, economic impacts are most commonly measured through the quantification of the number of jobs, sales and tax receipts associated with an activity or investment (Dwarakish and Salim, 2015). Common metrics of economic impacts are wages, employment, valued added and fiscal revenues, which are often reported as evidence that the welfare of a community will be or is being enhanced by an investment or specific activity (Dwarakish and Salim, 2015).

Chang, Shin et al. (2014) argue that the two major methods for assessing economic impact are the computable general equilibrium (CGE) model and input-output analysis. Bichou (2006) on the other hand considers gravity models as a third major methodology.

A further classification of port impact assessment methods was made by Ferrari et al. (2010) who grouped the methods into three approaches:

- Direct surveys based on interviews and questionnaires or microeconomic data on firms (Gripaios and Gripaios, 1995)
- Input-output models(Chang, Shin et al., 2014)
- Models based on productive specialization, using a mix of tools typical of applied economics, such as analysis of productive specializations (Musso, Benacchio et al., 2000)

Port impact studies differentiate among four different types of impact (Ferrari, Percoco et al., 2010):

a) Direct impact – employment and income generated by the direct operation and construction of the port
b) Indirect impact – employment and income generated by the chain of suppliers of goods and services
c) Induced impact – employment and income generated by the direct and indirect effects
d) Catalytic impact – employment and income generated by the role of the port as driver of productivity growth and attractor of new firms

Dooms, Haezendonck et al. (2015), suggested guidelines for the design and application of a potential best-practice on calculating port-related socio-economic impacts. They propose a toolkit which includes the following aspects:

- Inclusion of measures of direct value added, indirect value added and employment impacts, as the core of the study.
- Inclusion of macro-level data, such as GDP growth, trade growth, growth in manufacturing levels, in order to evaluate the linkage between past economic growth figures and changes in the socio-economic significance of ports.
- Explicit definition of the geographic boundaries of the port area.
- Careful definition of the sectoral boundaries of the port area, in order to measure the direct effects, as the distinction between maritime-cluster related industries and non-maritime cluster related industries is the most critical.
- Distinction among socio-economic impacts per broad traffic category.
- Importance of presenting in a transparent and detailed way the results of the socio-economic impact study, in order to define how the impacts were measured and to explicitly describe all assumptions made with respect to the nature of these indirect effects.

2.4.3.1 Input-Output (I-O) Analysis

Input-output analysis is used widely by researchers to estimate the economic impacts and contribution of ports to national economies and to estimate indirect effects (Danielis and Gregori, 2013). In general the I-O models give a description of the functioning of the regional economic system in a disaggregated perspective, and they comprise a system of linear equations, each describing a certain economic branch or sector (Acciaro, 2008). In a port impact study, the I-O model is usually used to calculate indirect effects, measured in terms of value-added, employment, household income and output (Danielis and Gregori, 2013). The estimates cover the direct impacts of the port and the subsequent spill-over effects on other sectors of the regional economy through the use of an I-O table (Danielis and Gregori, 2013). However, I-O analysis has some limitations, such as lack of scale economies, non-input substitution in the production process and production functions with constant technology (Francou, Carrera-Gómez et al., 2007).

Danielis and Gregori (2013) examined the port system of the Friuli Venezia Giulia (FNG) region and the role it plays within its economy. Using a combination of a top-down and bottom-up approach, based on detailed firm data and interviews, they built a bi-regional input-output table of the 12 port-related sectors of the region. The authors conclude that the Port System of FGV plays a vital macroeconomic role in the region that is characterised by a high degree of openness from an industrial, commercial and economic point of view. Finally, it was estimated that if the port system of FVG closed down the total loss for the entire national economic system would be equal to 11,443 people.

Furthermore, Chang, Shin et al. (2014) used the input-output model to investigate the way that port sectors impact a certain economy using the case of South Africa. The authors demonstrated that the port sector is broadly used by other industries in producing their activities (high forward linkage effect), whilst the port sector does not seem to use other industries due to its low backward linkage effect. They also provided empirical evidence that one unit shortage in the port sector, would have incurred a 17% loss to its entire economy in 2002, as the overall impact effect of the port sector per unit shortage on all other products was found to be 1.1705.

2.4.3.2 Computable General Equilibrium (CGE) Models

The CGE models have a level of disaggregation that allows structural change analysis, but also captures the interdependent nature of trade, demand and production within a general equilibrium framework (Danielis and Gregori, 2013). These models incorporate price initiatives and market mechanisms.

The first application of CGE models to port analysis was made by Doi, Tiwari et al. (2001). They used a CGE model to analyse the system-wide impact of the increased efficiency of ports in Japan for the year 1995. In their analysis they considered three transportation sectors: namely shipping, port operations and other transportation. All three sectors were assumed to compete perfectly and operate under constant returns to scale. It was also assumed that there are three factors of production: namely labour, capital and sector-specific fixed intermediate inputs. Their results indicated that technological efficiency in ports reduced the cost of sea transportation, and that the forward and backward linkages of exports and imports introduced positive gains in the national GDP. Finally, they concluded that spill-over affects were more to sea transportation, and to lesser extent on the Japanese economy.

Haddad, Hewings et al. (2010) used a spatial CGE model to simulate the impacts of increases in Brazilian port efficiency. They evaluated three scenarios: namely an overall improvement in Brazilian port efficiency to achieve international standards, efficiency gains linked with decentralisation in port management in Brazil and finally regionally differentiated increases in port efficiency in order to reach the boundary of the national efficiency frontier. Their findings suggested positive impacts on real GDP growth in all three scenarios, underlining that these positive effects are magnified in the long-run. However, in terms of employment, the outcome showed negative results, illustrating a reduction in employment rates led by the weak performance of the construction and transportation sectors. In terms of trade gains, the outcomes of the analysis indicated an increased competitiveness of Brazilian products and a positive trade trend which benefits Brazilian exports in all three scenarios, as export volumes increased faster than import volumes. Finally, if compared to other GDP components, international trade appears to increase its share on national GDP, resulting in a more open Brazilian economy after port efficiency increases.

2.4.3.3 Gravity Models

In order to quantify and model bilateral trade flows, Tinbergen (1962) and Pöyhönen (1963) developed a gravity model, to explain bilateral trade flows by trading partners Gross National Product (GNP) and geographic distance between countries. Wilson, Mann et al. (2003)used gravity models to analyse the relationship between trade facilitation, trade flows and economic development in the Asia-Pacific region. They used four trade facilitation indicators, namely: port efficiency, customs environment, regulatory environment and electronic-business usage. The authors found a large and positive relationship between enhanced port efficiency and positive trade flows.

2.4.3.4 Survey Approach

The survey approach has been used in the port sector as an alternative method of estimating port impact (Acciaro, 2008). It consists of interviews with representatives from different port and port dependent activities, and it is usually linked to the formation of a questionnaire, structured in such a way as to identify the most important impacts and to possibly quantify them (Acciaro, 2008). The most valuable aspects of this methodology is that it can be combined with other impact assessment methodologies and its port specific character. However, its main disadvantage is related to the high subjectivity degree, both in the design and in the interpretation. Some examples of studies that have used the survey approach can be found in Gripaios and Gripaios (1995), who used the survey approach for the evaluation of the impact of the port of Plymouth, and Castro and Millán (1998) who also used this technique to evaluate the significance of the port of Santander tin the Calabria region.

2.4.4 Ports and Employment

An essential measurement of the impact of ports in the economy of a country is the employment generated by the port and port-related industries (Acciaro, 2008). Acciaro (2008) investigated the role of ports in Sardinia's economy, to find that ports generated roughly 3% of the total employment in Sardinia. His results highlight the vital role that ports play in creating added value and as transportation modes; he summarised the arguments that support the positive benefits generated by ports in the economy as follows:

- Impacts generated from improved accessibility – reduction in transportation costs, shift of cargo among transportation modes, gains from the development of distribution and logistics centres;
- Impacts on industrial structure – connection between ports and industrial activities as ports are facilitators in the development of industrial districts;
- Impacts on employment – the shift of port activities from labour intensive to capital intensive have significantly reduced the growth impacts that ports used to generate on employment;
- Impacts deriving from the development of urban and metropolitan areas.

Similarly, Ferrari et al. (2010) estimated the impact of port activity on local development in Italian provinces for the year 2003, focusing on employment impact. They applied a two-stage econometric procedure which estimated separately a traffic and an employment equation, correlating port output with employment level in the province. They assumed that the larger the port the bigger its direct, indirect and induced effect. The analysis showed that the elasticity of employment to maritime traffic depends on the sector under consideration and is equal to about 0.02.

Bottasso, Conti et al. (2013) studied the impact of port activities on local employment, through the analysis of 560 regions located in 10 West European countries, for the time period between 2000 and 2006. Their findings suggested a positive correlation between regional employment and port throughput.

A recent study by Seo and Park (2018), focused on evidence from South Korea, to identify the influence of seaports in regional employment. The research examined all 16 regions of Korea based on panel data for the period 2002-2013, using an economic model of regional unemployment from labour economics, an autoregressive model from econometrics and the Tobit models to estimate unobservable port potentials. The results of the study indicated that port activities significantly reduce regional unemployment rates in Korea. More specifically, if for example cargo throughput increased by 25% over 10 years, it would contribute a total of 2% (or 0.2% annually) lower relative unemployment rate.

As identified from the studies mentioned, it is widely accepted that ports induce positive development impacts on the economy of the region. However, there is also a lot of consensus around the size of the impacts that can vary significantly from region to region, depending on the size of the port and the typology of traffic (Acciaro, 2008). In other words, the impact that a port can have on its local economy depends crucially on the initial conditions and is not necessarily positive (Ferrari, Percoco et al., 2010). The costs encountered by local economies in terms of traffic congestion, environmental problems, land consumption and coast waste are becoming bigger and bigger (Benacchio and Musso, 2001).

Contrary to the aforementioned studies, a number of authors (Goss (1990a), Gripaios and Gripaios (1995), Benacchio and Musso (2001), Jung (2011)) point out that port development and expansion is not necessarily likely to be an efficient tool for economic development strategy. Gripaios and Gripaios (1995) provided empirical evidence, through a detailed examination of UK’s Plymouth port, that the existing and potential role of ports in regional development is often exaggerated. Jung (2011) argued that due to the advancement of logistics and technology, the change of economic structure, and so forth, local economic benefits reducing from ports shows a decreasing trend and that regional economies may no longer greatly benefit from nearby ports.

Goss (1990a) suggests four main reasons for which port development might constitute an inefficient tool for economic development. His first point is related to the potential "leak" of port benefits to users in inland locations. The second point he makes is that assisting a port might mean assisting foreign exporters, who might be enabled to compete more effectively with home producers, hence tending to reduce the number of jobs. Third, any financial public assistance to a port is likely to lead indirectly to higher local taxes, with the risk of making the area less attractive to residents and probably businesses as well. Finally, the author claims that since the aggregate demand for labour within a given economy is determined by macro-economic factors, ports compete among themselves for a share of reasonably fixed level of business. In other words, the expansion of a port belonging to a range could only be at the expense of lost trade in other national or regional ports situated within the same range.

2.4.5 Ports and Sustainable Development

Ports and their operation have a substantial and direct impact on the physical and social environments in which they operate (Santos et al., 2016). Ports must demonstrate eagerness to engage vigorously with civil society and in this way social and environmental management have become part of ports' management which is committed to deal with new social challenges (Santos et al., 2016). Corporate Sustainability (CS) is a concept referred to a firms' engagement with environmental and social issues in addition to their economic activities (Linnenluecke et al., 2013; Santos et al., 2016). Ports have also had to take radical action in this area, as a port's sustainability performance has become of paramount consideration to shipping companies when they are determining which port to use (Lim et al., 2019).

Global regulations, such as the Kyoto Protocol and the MARPOL regulations, are putting great pressure to port authorities to comply societal and regulatory requirements for operational sustainability (Lim et al., 2019). More specifically, in 2015, 193 countries adopted the United Nations (UN) 2030 Agenda for Sustainable Development and its 17 Sustainable Development Goals (SDGs). The recently adopted SDGs Agenda is proposing 17 sustainable development goals and 169 targets for 2030, creating a challenge not only to national governments but also to a wide range industry stakeholders (United Nations 2015; Keesstra, Bouma et al., 2016). This Agenda calls all countries to take action to end poverty and achieve sustainable development by 2030 world-wide, while the SDGs are regarded as an opportunity to transform the world for the better and ensure that all human beings can fulfil their potential in equality and dignity in a healthy environment (United Nations, 2015). Among others, the agenda constitutes a plan of action to protect the planet from degradation, taking urgent action on climate change through sustainable consumption and production and by sustainably managing its natural resources (United Nations, 2015).

The International Maritime Organisation (IMO), as part of the UN family, has formally approved linkages between the Organisation’s technical assistance work and the SDGs, and is actively working towards the 2030 Agenda, as indeed most of its elements can only be realized with a sustainable transport sector which can support world trade and facilitate the global economy (International Maritime Organisation, 2018). Therefore, since ports are nodal points in global supply chains and are embedded in local and regional communities, they must also respond to local, regional and worldwide challenges. Along these lines, on March 2018 nearly 1,000 ports and port-related enterprises signed the charter of the new World Ports Sustainability Program (WPSP) where they all agreed to commit themselves to the UN's 17 SDGs, and more specifically to a set of five goals closely related to port operations (International Association of Ports and Harbors, 2018):

1. Resilient port and port-related infrastructure, which is developed in harmony with local communities, nature and heritage and to respond to the demands of maritime transport and landside logistics;

2. Climate and energy, emphasising on initiatives developed by port community actors to facilitate reduction of CO_2 emissions from port and land-side operations, to enable energy transition and to improve air quality;

3. Community outreach and port-city dialogue, by improving relations between ports and cities;

4. Safety and security, by ensuring safety and security of ship and cargo operations, through the enforcement of applicable laws and regulations in these fields;

5. Governance and ethics, through good corporate governance and the encouragement of all port authorities to maintain high standards of ethics and transparency.

As mentioned in Sections 2.4.2 and 2.4.4, port development and operation can be beneficial for investors and for the economic development of a region, but at the same time, such large infrastructural developments may have negative effects on the ecosystem, which might result in adverse health and social effects (Schipper, Vreugdenhil et al., 2017). These include congestion, accidents, pollution (air, water, noise) and have resulted in increasing pressure on the port sector to improve eco-awareness, increase efficient use of resources and adopt green port policies (Acciaro, Vanelslander et al., 2014). Thus, sustainable port development can positively influence the economy, environment and society (Schipper, Vreugdenhil et al., 2017).

According to Schipper, Vreugdenhil et al. (2017) sustainable port development can be defined as new port or port expansion plans that meet or exceed typical operational requirements and that provide economic growth which is compatible with social and environmental needs, including ways to manage the transition to this new, balanced paradigm. Port sustainability is rooted within the three pillars of sustainable port development which incorporate environmental, social and economic goals (Lim, Pettit et al. 2019). The goals of each of these pillars are summarised by Lim, Pettit et al. (2019) as follows:

- Environmental sustainability: the goal is to minimise the negative impacts generated by a wide range of shipping and operational activities within the proximity of ports;
- Social sustainability: the goal is to contribute to the enhancement of people's life quality through the support of port activities in order to satisfy socio economic priorities such as education for employees, employment opportunities and the enhancement of social stability of the surrounding port area;
- Economic sustainability: the goal is to maximise the economic performance without adversely affecting the environmental and social development.

Therefore, the main purpose of sustainable development is to seek a safe, environmentally friendly, energy efficient, socially acceptable port management approach, while simultaneously maximising economic profits (AAPA, 2007). The evaluation of port sustainability performance only recently has attracted interest and research in this field and has been mainly focused on the link between environmental impact, social impact and economic performance and port competitiveness issues (Lim, Pettit et al., 2019). In order to assess port sustainability performance, indicators should be established in order to understand the structure of sustainable port management and its evaluation. According to Lim, Pettit et al. (2019) typical indicators for the assessment of port sustainability from an environmental perspective include water and air pollution management, energy and resource use and noise control. In terms of the social aspects, safety and health, job generation and security are important while as far as the economic aspects are concerned, Foreign Direct Investment and efficient port operations are considered primary issues.

According to all the above, it can be argued that environmental sustainability and social sustainability in essence form the green port concept, since as it was also referred in Section 2.2.3, the green port concept refers to several measures aimed to achieve sustainability at ports. A port, apart from meeting all environmental standards in its day-to-day operations, also needs to have a long-term plan for improving its environmental performance and reduce its negative health impact on the surrounding communities (Arduino et al., 2011). Therefore, since the environmental sustainability's goal is to minimise the negative impacts generated by a wide range of shipping and operational activities within the proximity of ports, and the social sustainability's goal is to contribute to the enhancement of people's life quality, it can be derived that sustainable and green ports are two interrelated concepts. Consequently, the green port concept has been adopted as a new paradigm which is synonymous to sustainable port (Arof et al., 2021).

Additionally, as was also mentioned in Section 2.2.4, a smart port and a green port are not independent of each other, as under the basis of green ports, smart ports are applying advanced technologies to reduce environmental pollution and simultaneously to achieve the goal of sustainable port development (Chen et al., 2019).

Overall, sustainable, green and smart ports represent a significant direction in port development in recent years. In Figure 2.10 the author summarises the interrelated relationships that exist between the smart port concept, the green port concept and sustainable port development.

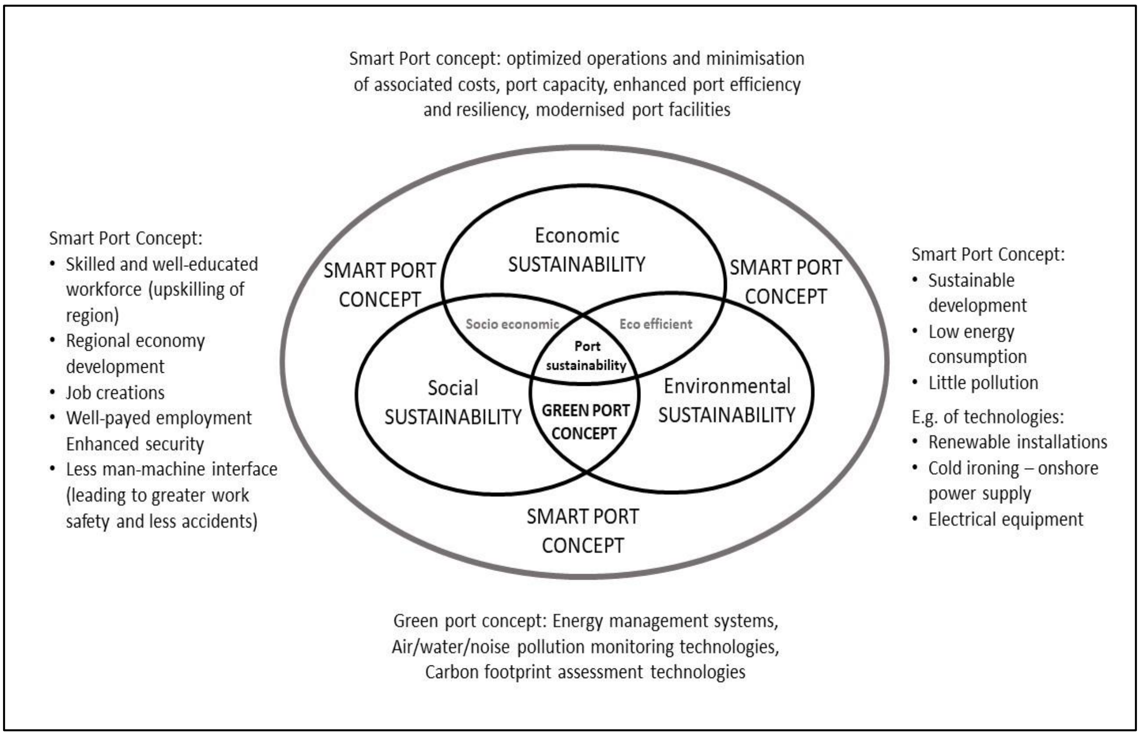

Figure 2.10: The three pillars of port sustainability, the green port concept and the smart port concept

Source: Author

In conclusion, although there are a few studies on sustainable ports and green ports, and relatively few studies concerned with smart ports, scholars usually regard the sustainable, green and smart port dimensions separately, rather than regarding it as a *multi-dimensional emerging trend*. In line with this evidence, an emerging broader perspective includes the *interrelated relationship among sustainable, green ports and smart ports*. As illustrated above in Figure 2.10, these 3 dimensions (sustainable, green and smart) are complementary and interrelated, as in order for a port to be sustainable, it also needs to be green, and if a port is green it uses smart technologies to achieve its green status. Therefore, the green port concept refers to social and environmental sustainability, while all the three dimensions of sustainability generate the smart port which adopts innovative, environmentally friendly and cost-efficient technologies.

2.5 Conclusion

The global key trends in the maritime sector, as described in Chapter 1, are creating a continuously increasing pressure on ports to adapt their role and function to the demanding operational environment. Therefore, in order to respond to the growing demand, ports are pressured to maximise their efficiency. To reach this goal, the use of technological advancements is regarded as a requirement and solution, since their adoption can make port operations faster and safer. The use of advanced technologies, apart from the induced benefits in port operations, can also create benefits in terms of regional economic development, such as employment, accessibility, value added, and can also contribute in the greening of the sector.

The goal of this literature review was to explore the key concepts encompassing the focus of this research and to identify the research gap in the literature. The literature review explored the trends in technological advancements in port operations, port efficiency and performance, economic development induced from port operations, as well as the smart, green and sustainable port concepts.

Therefore, the literature review led to the knowledge gap that this research aims to address. According to the findings of this literature review the knowledge gap remains on how technological advancements in port operations affect the efficiency and performance of a port, and what net benefits are generated for the local communities.

This research aims to bridge this gap and investigate deeper the ways in which technological advancements affect port efficiency and performance, the benefits and impacts generated from the adoption of technological advancements in port operations, the development of smart, green and sustainable ports, as well as the barriers and incentives for the adoption of these strategies and technologies. Attempting to close the identified knowledge gap will help port operators and policy-makers invest prudently, design better policies to enhance port efficiency, collaborate effectively, along with accurately identifying and minimising barriers for technology adoption. Therefore, a more precise and comprehensive interpretation of all the above will contribute in the acceleration of the development of smart, green and sustainable ports leading to the creation of benefits for both port operators and the hinterland.

The findings of the literature review have therefore raised important questions leading to the research objective of this thesis which is **"To investigate the relationship between technological advancements in port operations, port performance, net benefits for the hinterland, benefits to stakeholders and the development of smart, green and sustainable ports"**. Given the growing interest on the topic of technological advancements and the smart, green and sustainable ports concepts this research objective is highly relevant to the current port operating landscape.

Chapter 3. Research Purpose and Design

3.1 Introduction

The literature review revealed that the impact from the application of technological advancements in port operations on port efficiency, port performance and local economic development has not been yet sufficiently studied by the existing literature. Additionally, even though the advent of the Fourth Industrial Revolution is already fundamentally altering the way we live and work, there is little research on the net benefits that can be generated from new technologies' application in port operations. Since there is little research in this field, the multiple dimensions of the application of technological advancements need to be explored further. This research aims to bridge this gap and advance knowledge on the net benefits generated by the application of technological advancements in port operations. Additionally, this research aims to explore the development of smart, green and sustainable ports, focusing on three different levels; a global level by exploring 71 major container ports around the world; a national level by focusing on a UK case study; and on a local level by reporting on the specific case of the Port of Tyne (UK).

On the basis of the identified research gap, this Chapter presents the research objectives and questions, research philosophy, methodology and methods adopted, relevance of the study and overall contribution of this research.

3.2 Research Problem, Objectives and Questions

The aspect of technological advancements is currently one of the most important drivers of port performance that can also generate significant net benefits for the hinterland, which however has not been adequately studied by scholars. In accordance with the identified research gap, that was thoroughly investigated in Chapter 2, the research problem that arises and will be the focus of this research was identified as follows: **scarce research is available on the impact of the application of technological advancements in port operations on both port performance and the hinterland.**

Chapter 2 provided evidence that there is a lack of knowledge related to the net benefits generated by the application of technological advancements in port operations on port performance and the hinterland. Since the importance and industry interest in technological advancements (such as automation, digitalisation, green technologies) is continuously growing during the past few years, the need to explore deeper the net benefits generated by the adoption of technological advancements into both port performance and hinterland, is pivotal. The main focus areas of this research are the exploration of the determinants of port performance, with a focal point on technological advancements' impact, a comprehensive definition of port technological advancements (smart port, green port, sustainable port), the net benefits that are generated for both the port and the hinterland from the application of new technologies in port operations, and the overall relationship among new technologies in port operations, port performance and local economic development.

Based on the gaps identified in the literature, this research raised the following core objective:

- **To investigate the relationship between technological advancements in ports, port performance, net benefits for the hinterland, benefits to stakeholders and the development of smart, green and sustainable ports.**

The following Research Questions (RQs) are associated to the aforementioned objective and were developed in order to address the research problem:

RQ1. Which are the latest technologies and smart, green and sustainability related practices adopted in ports?

RQ2. What is the relationship between port efficiency and local economic development?

RQ3. What are the key characteristics of the world's leading container ports and how can a representative port sample be identified for further analysis?

RQ4. What are the net benefits generated by technological advancements regarding both port performance and the local economy?

RQ5. How do different external factors affect the maximisation of the potential gains for port operators and the local economy?

3.3 Research Philosophy

Research philosophy relates to a system of assumptions and beliefs about the development of knowledge (Saunders, 2016). Every stage of the research process includes a number of types of assumptions, referring to human knowledge (epistemological), the realities encountered in the research (ontological), as well as the ways and extent that the researcher's values influence the research process (axiological) (Burrell and Morgan, 1979; Saunders, 2016). These assumptions shape the research questions, the methods used and the interpretation of the findings (Saunders, 2016). Johnson and Clark (2006) point out that it is crucial for business researchers to be aware of the philosophical commitments made through research strategy choices. Likewise, Mangan, Lalwani et al. (2004) highlighted the pivotal role of a paradigm to the research process. Therefore, the researcher's philosophical worldview influences the research design of the study and the way the data is collected and analysed (Collis and Hussey, 2013).

The differences in the assumptions each researcher makes, include three elements – namely ontology, epistemology and axiology - and can help distinguish the research philosophies (Collis and Hussey, 2013). Ontology refers to assumptions made by the researcher regarding the nature of reality (Saunders, 2016). Epistemology concerns assumptions about what is accepted by the researcher as valid and legitimate knowledge (Burrell and Morgan, 1979; Saunders, 2016). Axiology is concerned with the researcher's view on the role of ethics and values within the research process (Saunders, 2016).

Moreover, a paradigm is a general perception of the nature of scientific endeavour within which a research question is undertaken (Mangan, Lalwani et al., 2004), or, otherwise stated, a paradigm is practically a "world-view" (Wittgenstein, 1961). Each paradigm is interrelated with specific paradigm assumptions (Saunders 2016). In management research the numerous paradigmatic positions have been classified into two principal categories, namely *positivism* (associated with quantitative methodologies) and *phenomenology* (associated with qualitative methodologies) (Collis and Hussey, 2013). Table 3.1 outlines some key features of both paradigms and compares ontology, epistemology and axiology for the positivist and phenomenological paradigms.

		Paradigm	
		Positivist	**Phenomenological**
Basic beliefs	Ontology	The world is external to the research and objective	The world is socially constructed and subjective
	Epistemology	The observer is independent, only the phenomena that can be observed and measured can be regarded as knowledge.	The observer is interdependent, part of what is observed and involved in defining the under study phenomenon
	Axiology	Science is value-free, facts are independent and not affected by the researcher	Science is value-led and driven by human interests
Researcher should		Focus on facts	Focus on meanings
		Search for causality and fundamental laws	Try to interpret what is happening
		Cut down phenomena to simplest events	Consider the totality of each situation
		Firstly formulate hypotheses and then test them	Develop ideas through induction from data
Preferred Scientific Method		Operationalise concepts in order for them to be measured	Use multiple methods to establish distinct views of phenomena under-study
		Deductive: Hypothesis testing	Inductive: theory building
		Reductionist approach	Holistic approach
Preferred data collection techniques		Experimental, large samples used	Interpretation, small samples investigated in-depth over time
		High reliability, low validity	Low reliability, high validity

Table 3.1: Comparison between positivist and phenomenological paradigms

Source: Author adapted based on (Mangan, Lalwani et al., 2004; Easterby-Smith, Thorpe et al. 2012; Collis and Hussey, 2013; Saunders, 2016).

There is rich literature that covers the philosophical underpinnings of research, and thus there are many names and alternative terms for these two paradigms (Gummesson, 2000; Mangan, Lalwani et al., 2004). The positivist paradigm is alternatively referred to in literature as objectivist, experimentalist, scientific or quantitative paradigm, while the phenomenological paradigm is also referred to as subjectivist, interpretivist, humanistic or qualitative paradigm (Mangan, Lalwani et al., 2004; Saunders, 2016).

The positivist approach was adopted by social scientists because of the previous success of this approach in plethora of natural sciences (Mangan, Lalwani et al., 2004). However, according to Mangan, Lalwani et al. (2004), social scientists quickly began to argue against positivism, highlighting that physical sciences are dealing with objects which are outside people, while on the other hand social sciences deal with behaviour and action which both generate from within the human mind. Moreover, social scientists argued that the interrelationship between the investigator and phenomena under-study in social sciences was impossible to be detached (Mangan, Lalwani et al., 2004). As a result from the aforementioned debate, the phenomenological paradigm emerged for application in social sciences (Mangan, Lalwani et al., 2004).

However, in areas relevant to this research (economics, business management, transportation and logistics) where quantitative methodologies prevail (positivist paradigm), researchers support the necessity of triangulating qualitative and quantitative methodologies (Mangan, Lalwani et al., 2004). The paradigm adopted in this research is connected to both the methodology selected and the research methods used, considering that the selection of paradigm guides the whole research. It is therefore of critical importance, when selecting the paradigm, to not only take into consideration the researcher's opinion, but also to take into account the nature of the research problem (Collis and Hussey, 2013). The research questions that are framing this research do not fit into solely one research philosophy. In order to interpret the net benefits generated from the application of technological advancements in port operations, it is crucial to analyse both the industry angle, as well as the different viewpoints of pivotal stakeholders, scholars, governments and scientists. Thus, the adoption of more than one philosophical approach, methodologies and methods is required in order to provide the best and holistic answer to the research problem.

Pragmatism allows the combination of methodologies, methods and perspectives, in order to better address the research questions. The research 'onion' developed by Saunders (2016) helps to understand the position of pragmatism, which is located along the continuum between positivism and phenomenalism. Figure 3.1 illustrates the position of pragmatism in connection with the two predominant paradigms.

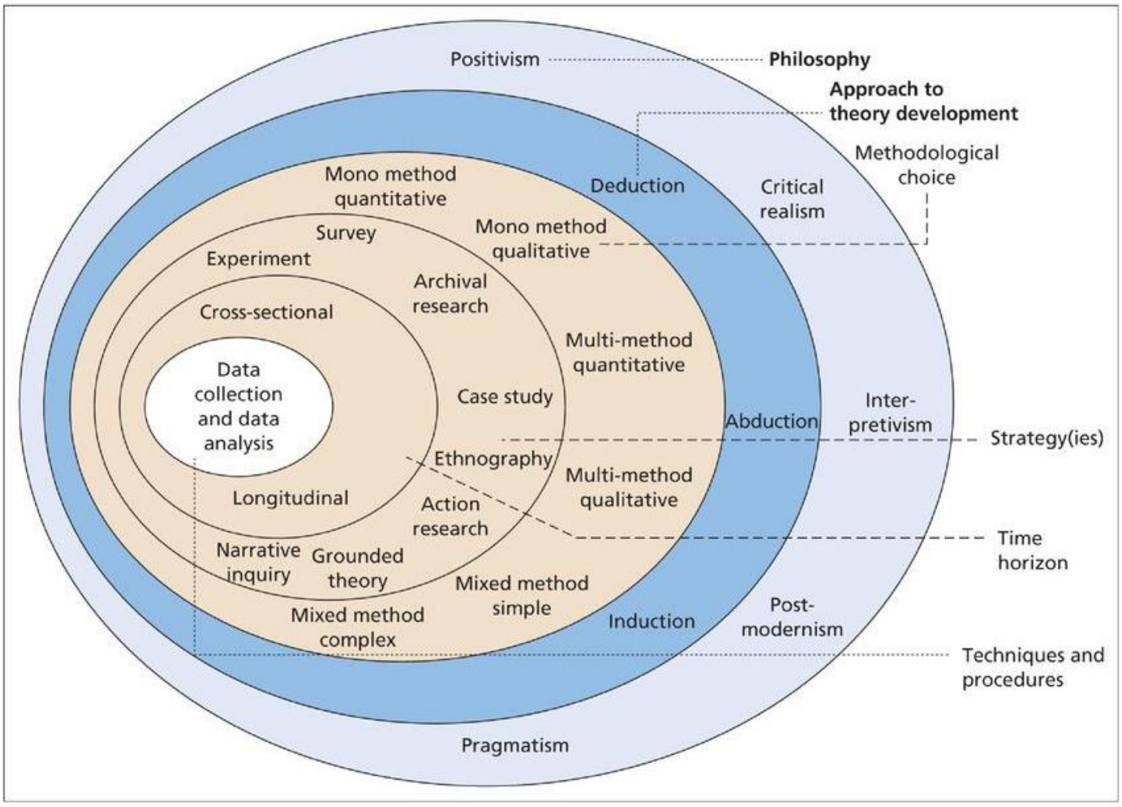

Figure 3.1: The research 'onion'

Source: Saunders (2016).

Table 3.2 presents the main features of pragmatism:

Pragmatism	
Ontology (nature of reality or being)	Multiple, complex, external, selected to fit the research questions in the most valid and holistic way.
Epistemology (what constitutes acceptable knowledge)	Practical meaning of knowledge in particular contexts. Focus on practices, problems and relevance. Both subjective meanings and observable phenomena can provide acceptable knowledge on the basis pf the research questions.
Axiology (role of values)	Value-driven research, researcher's values and beliefs play a pivotal role in the interpretation of phenomena under-study, the researcher adopts both objective and subjective viewpoints
Typical scientific methods used	Combines inductivism and deductionism, follows research problem and questions.
Data collection techniques used	Mixed, multiple methods integrated for data collection analysis, both qualitative and quantitative. Action research, emphasis is given on practical solutions and outcomes.

Table 3.2: Main features of pragmatism

Source: Author based on Saunders (2016).

Pragmatism supports that concepts are only pertinent where they support action (Kelemen and Rumens, 2008) and it endeavours to harmonize both objectivism and subjectivism (positivism and phenomenalism), facts and values, different contextualised experiences, as well as rigorous and accurate knowledge (Saunders, 2016). This paradigm is a combined approach, reflecting the fact that the exploration for knowledge is not necessarily framed within these two opposite paradigms/poles, but is placed somewhere along the continuum that connects positivism with phenomenalism (Easterby-Smith, Thorpe et al., 2012). For a pragmatist, research commences with a problem and focuses on providing practical solutions that enlighten future practice (Saunders, 2016). In order to answer the questions that are shaping this research, the adoption of a range of philosophical perspectives is required. The choice of pragmatism as the paradigm adopted in this research, guided the selection of the methodology and methods, which is described in detail is Section 3.5.

Together with the philosophical paradigm, the theoretical drive of the research influences the selection of the methodology of the research. A mixed methods research design may use inductive, deductive or abductive approach to theory development (Saunders, 2016). Thus, a particular theory may be adopted to provide a research focus and limit its scope (Tashakkori and Teddlie, 2010). Deductive reasoning occurs when the conclusion of the research is derived logically through a set of hypotheses, and the conclusion is true only when all the hypotheses are true (Ketokivi and Mantere, 2010). In contrast, inductive reasoning includes a gap in the logic argument between the premises observed and the conclusion, with the conclusion being judged to be defended by the observations made (Ketokivi and Mantere, 2010). Additionally, an alternative approach to developing theory is the abductive reasoning, beginning with a 'surprising fact' being observed (Ketokivi and Mantere, 2010). In this approach, instead of moving from theory to data (deduction) or from data to theory (induction), the abductive approach moves back and forth, basically combining deduction and induction within the same research (Suddaby, 2006).

In short, according to Saunders (2016):

- with deduction a theory and a hypothesis (-es) are developed and a research strategy is developed in order to test the hypothesis,
- with induction data are collected and a theory is developed as a result from the data analysis,
- with abduction data are used in order to explore a phenomenon, themes are identified, and patterns are explained, in order to generate a new or modified existing theory which is next tested, generally with additional data collection.

This research incorporates inductive and deductive methodologies and is therefore adopting an abductive approach to theory development.

3.4 Methodology and Methods

This research adopted the pragmatist paradigm as was stated previously in Section 3.3. Thus, the paradigm of pragmatism drove the selection of the methodological approach of the research. According to Saunders (2016), the most important determinant in order to frame the research design process and strategy, is the research problem addressed and the research questions. Pragmatism enables to work with various types of knowledge and methods within one study, reflecting that the use of multiple methods is many times the most appropriate research strategy (Saunders, 2016). Mixed methods research design is the category of multiple methods research and combines the use of qualitative and quantitative data collection techniques and analytical procedures (Saunders, 2016). The methodology used in this research, following the principles of pragmatism, borrowed from a number of techniques and methodologies in order to answer achieve its aim. Thus, in order to provide a holistic and detailed approach to the phenomenon under study, the methodology in this research used mixed methods, in other words combined qualitative and quantitative methods.

The use of more than one source of data and method of collection is a form of triangulation (Saunders, 2016). According to Saunders (2016), triangulation is employed to confirm the credibility, validity and authenticity of research data, analysis and interpretation. Hussey and Hussey (1997) pointed out that triangulation refers to the adoption of different research techniques, methods and approaches in the same study, thus enabling the researcher to overcome the potential bias of single methods approaches. Triangulation has the purpose of using two or more independent data sources and methods of data collection within one study, to ensure that the data is comprehended correctly and to ascertain if the findings from one method mutually confirm the findings form the other method used (Saunders, 2016).

Mangan, Lalwani et al. (2004) support that there is evident notion among researchers in recent decades, to move towards the development of methods and approaches which provide middle-ground and bridging between the two extreme philosophical approaches (Easterby-Smith, Thorpe et al., 2012). Easterby-Smith, Thorpe et al. (1991) classified triangulation into four types:

1. Data triangulation: data are collected either at different times or from different sources;

2. Investigator triangulation: more than one investigators independently collect data;

3. Methodological triangulation: both quantitative and qualitative methodologies are used;

4. Triangulation of theories: a theory is taken from one discipline and is utilised to explain a phenomenon of a different discipline.

This research adopted the methodological type of triangulation, as it can compensate for the flaws and leverage the strengths of the numerous available methodologies (Mangan, Lalwani et al., 2004). In order to adopt the most suitable research design and achieve the aim of this thesis, the researcher performed a detailed examination of the available approaches and methodologies. After this meticulous examination, a triangulated research approach was selected as the most appropriate research design to address the research problem. The research design combined quantitative and qualitative methodologies, inductive and deductive approaches to enable a better understanding of the relationship between technological advancements and generated net benefits for the port and the hinterland.

The final layer of the research 'onion' illustrated in Figure 3.1 (Saunders, 2016), addresses how the researcher collected the data and how they were analysed. According to Saunders (2016), data collection methods include sampling (probability sampling, non-probability sampling), use of secondary data (documentary, multiple source, survey), and/or collection of primary data (observation, interviews, questionnaires). This research used both primary and secondary data collection. The methods used for collection and confirmation of data are thoroughly discussed in each of the empirical Chapters.

Figure 3.2 illustrates the structure of this thesis, as well as how the different research questions and objectives and the corresponding chapters are grouped into six phases, each of which related to the research questions.

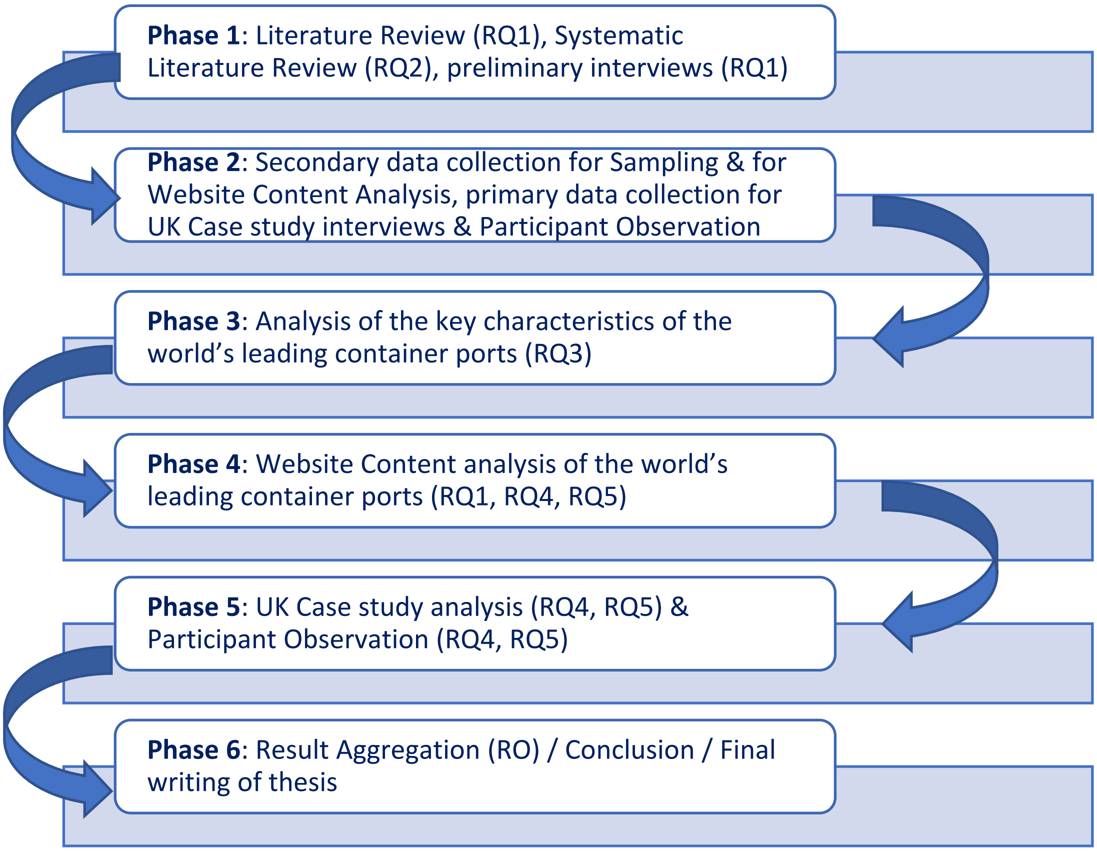

Figure 3.2: Phases of research project

Moreover, Table 3.3 presents the overall research design.

Research Objective	Research Questions	Method / Approach
RO. To investigate the relationship between technological advancements in port operations, port performance, net benefits for the hinterland, benefits to stakeholders and the development of smart, green and sustainable ports.	**RQ1.** Which are the latest technologies and smart, green and sustainability related practices adopted in ports?	Literature Review Preliminary Interviews – Scoping Study Website Content Analysis
	RQ2. What is the relationship between port efficiency and local economic development?	Systematic Literature Review
	RQ3. What are the key characteristics of the world's leading container ports and how can a representative port sample be identified for further analysis?	Sampling
	RQ4. What are the net benefits generated by technological advancements regarding both port performance and the local economy?	UK Case Study – 12 Interviews Participant Observation
	RQ5. How do different external factors affect the maximisation of the potential gains for port operators and the local economy?	Systematic Literature Review UK Case Study - 12 Interviews Participant Observation

Table 3.3: Overall research design

To achieve the objective this research, the project has been divided into six phases, each phase including several tasks. What follows is a description of the six phases of the project.

➢ **Phase 1** includes the general desk research of the subject, the definition of the problem, the literature review (to address Research Question 1), the systematic literature review (to address Research Question 2) and the scoping study based on the preliminary interviews which contributed to refining the phenomenon under study and guided the subsequent focus of the PhD research topic.

➢ **Phase 2** includes the data collection, which comprises of secondary and primary data. The secondary data collection consists of two tasks, the first regarding the elaboration of a dataset to analyse the key characteristics of the world's leading container ports and to be used for the Website Content Analysis, while the second relates to the Website Content Analysis and the data collection linked with this task, which described in detail in Chapter 7. On the other hand, the primary data collection refers to the twelve interviews conducted by the author and the Participant Observation study, and are thoroughly described in Chapters 8 and 9.

➢ **Phase 3** consists of the elaboration and analysis of the key characteristics of the world's leading container ports (RQ3).

➢ **Phase 4** addresses the Website Content Analysis (RQ1, RQ4, and RQ5).

➢ **Phase 5** is linked to the UK Case Study and the Participant Observation study (RQ4, RQ5).

➢ **Phase 6** refers to the overall result aggregation and discussion, as well as the final writing of the thesis. This task aims to link all concepts analysed in order to achieve the main objective of this research.

The adoption of this multi-phased approach facilitates the researcher to achieve the aim and address the knowledge gap in the most holistic, multi-perspective and valid way possible. In order to address the research questions, mixed approaches were selected. The following table outlines the philosophy, theoretical framework, methodology and methods that were adopted in this thesis.

Element	**Selection**
Paradigm	Pragmatism
Theoretical Framework	Abductive approach
Methodology	Mixed methodology
Methods	Mixed methods

Table 3.4: Summary of the selected research design

3.4.1 Literature Review

The concepts of technological advancements, port efficiency, port performance, economic development, smart, green and sustainable port were explored. A green port and a smart port are not independent of each other, as under the basis of green ports, smart ports are applying advanced technologies to reduce environmental pollution and they contribute simultaneously to achieve the goal of sustainable port development. Even though there are studies on smart ports, green ports and sustainable ports, scholars usually regard separately the smart port and sustainable port dimensions, rather than regarding it as a multi-dimensional emerging trend.

3.4.2 Scoping Study

The author in Chapter 4 outlines a Scoping Study that was performed at the outset of the research and aimed at gaining a deeper understanding of the current port operational landscape, before scoping out the main direction of this research. This Scoping Study comprises four preliminary semi-structured interviews with key stakeholders and explored the current issues and opportunities faced by ports.

Semi-structured interviewing was used to reflect the experiences and insights of the stakeholders in regards to the current state of the port industry. This type of interviewing provides the chance to investigate further a response when the interviewer wants from the interviewee to build on, explain further on their previous answers (Saunders, 2019).

3.4.3 Systematic Literature Review

A systematic literature review (qualitative) was conducted to identify the relationship between port efficiency and local economic development, as well as the factors affecting port efficiency. The systematic literature review scrutinized the **relationship between port efficiency and economic development**, in each selected paper.

In contrast to traditional literature review, which might be influenced by the preferences of the reviewer and availability bias, systematic review synthesizes literature in a transparent, systematic and replicable way (Tranfield, Denyer et al., 2003; Wang and Notteboom, 2014). The aim of this technique is to summarise and analyse the body of knowledge in regard to a given concept or a relationship between concepts, and to investigate whether gaps exist (Gligor and Holcomb 2012).

A systematic literature review is a process that contains five stages including (Cooper, 1982; Whittemore and Knafl, 2005):

1. problem formulation;
2. literature search;
3. evaluation of research;
4. research analysis and interpretation; and
5. presentation of results

The stages and steps followed to apply the systematic review are explained in detail in Chapter 5.

3.4.4 Understanding Ports – Perspective and Sample identification

The author in this phase of the research explored the key characteristics of the world's leading container ports. The focus of this step was to investigate the factors that affect the ports' performance and efficiency and to determine a representative sample for the Website Content Analysis (CA) conducted for Chapter 7. This phase therefore acts as a "supporting sampling study" and constitutes the basis for Chapter 7, where the author investigated the smart status of the world's leading container ports.

3.4.5 Website Content Analysis

A **Website Content Analysis** (qualitative) was undertaken to explore deeper the strategies adopted by ports and terminal companies regarding the use of new technologies in order to become "environmentally-friendly", "sustainable", "smart-digital-innovative", "community-oriented". This task has helped the researcher identify current trends in the adoption of technological advancements and realise the validity of the Systematic Literature Review, the conducted interviews, as well as to enhance knowledge on the current status of ports when it comes to smart, green, sustainable, etc. A total of 71 port websites were analysed to study how each port perceives and adopts the current trends in digitalisation, smart port operation, sustainability and green port development.

Content Analysis (CA) is an analytical technique that through the coding and categorisation of qualitative data analyses the data quantitatively (Saunders, 2016). This method is extensively used in transport studies as it can generate quantified data from non-quantified sources (Karamperidis, 2013). There are various definitions of Content Analysis, which generally rely on an early definition given by Berelson (1952): "*Content Analysis is a* *research technique for the objective, systematic and quantitative description of the manifest content of communication*". This definition includes the key concepts that content analysis is based on such as "systematic", "objective", "quantitative description" and "manifest content" that help us understand this technique better (Saunders, 2016). Likewise, Krippendorff (2018) suggests that content analysis "*is a research technique for making replicable and valid inferences from text (or other meaningful matter) to the content of their use*".

In the past, content analysis has been mainly used for the analysis of written mass media content by scholars of journalism, communication and advertising (Herring, 2009). Nonetheless, CA is a flexible method that can be also applied to numerous types of media, as during the past years CA techniques have been increasingly used to analyse web-based content (Kim et al., 2010; Hasim et al., 2018; Yoon et al., 2021; Rafiq et al., 2021). Considering the fact that during the past decades the internet has been commonly accepted as an organisational tool for communication, it is thus being used by corporations to post information related to organisational matters, practices and other related data (Hasim et al., 2018). Likewise, ports use their websites as a medium to communicate their mission, vision and values statement, organisational responsibilities, environmental commitment, equipment, policies and practices, Certifications, and other relevant information. Therefore, for this phase of the research the author has ascertained that website content analysis is a legitimate research tool to conduct research on the extent of smart, green, and sustainability adoption in ports and to investigate their commitment towards these aspects.

Further details and results of the Website Content Analysis are reported in Chapter 5.

3.4.6 UK Case study - Interviews

For further exploration and insight of the examined phenomenon - technological advancements in ports and their effect on port efficiency and the hinterland - interviews (qualitative) with relevant stakeholders were conducted. Semi-structured interviews were chosen as a further method for this research, in order to explore holistically and in-depth points that could have not be derived from the Literature Review, as well as to validate the results of the Systematic Literature Review (Saunders, 2016). The expectation was that the interviews could contribute to: (i) explore the effects of technological advancements in port operations, (ii) increase the validity of the research and describe the industry's reality more meticulously. Interviewees were selected among key stakeholders involved in the port sector, in order to provide an industrial view and raise further themes and multi-dimensional aspects on the under-study phenomenon that only by having a dialogue with the stakeholders could have been achieved.

To identify the themes and patterns that arose from the interviews conducted, the author employed the qualitative method of **Thematic Analysis (TA)**. Thematic analysis is one of the most common and flexible methods for analysing interviews and other qualitative data. According to Braun and Clarke (2006), thematic analysis offers a theoretically flexible and accessible approach to analysing qualitative data. TA is therefore a *"method for identifying, analysing and reporting patterns (themes) within data"* (Braun and Clarke, 2006). TA is therefore describing in detail the dataset and the insights provided by the respondents and is not linked to any pre-existing theoretical framework (Braun and Clarke, 2006).

More specifically, according to Braun and Clarke (2006) TA is a technique which systematically identifies, analyses and organizes data into patterns of meanings, called themes. A *theme* captures something significant about the data related to the research question, and basically represents a *patterned* type of meaning or response within the data set (Braun and Clarke, 2006). This demands the generation of *codes* while analyzing the data. Coding is a process which aids in the organisation of the text included in the transcripts and also supports the identification of patterns across the extensive amount of text included in the transcripts, which would be otherwise impossible to discover (Auerbach and Silverstein, 2003). According to Braun and Clarke (2006) the six steps of TA are presented in Table 3.5:

Phase	Description of the process
1. Familiarizing yourself with your data	Transcribing data (if necessary), reading and re-reading the data, noting down initial ideas.
2. Generating initial codes	Coding interesting features of the data in a systematic fashion across the entire data set, collating data relevant to each code.
3. Searching for themes	Collating codes into potential themes, gathering all data relevant to each potential theme.
4. Reviewing themes	Checking if the themes work in relation to the coded extracts (Level 1) and the entire data set (Level 2), generating a thematic 'map' of the analysis.
5. Defining and naming themes	Ongoing analysis to refine the specifics of each theme, and the overall story the analysis tells, generating clear definitions and names for each theme.
6. Producing the report	The final opportunity for analysis. Selection of vivid, compelling extract examples, final analysis of selected extracts, relating back of the analysis to the research question and literature, producing a scholarly report of the analysis.

Table 3.5: Phases of the Thematic Analysis technique

Source: Braun and Clarke (2006)

The themes identified, coded and analysed are an accurate reflection of the content of the *whole* dataset generated from the twelve semi-structured in-depth interviews. Moreover, the deductive or 'top down' approach was selected for the identification of themes and patterns within the data. More specifically, according to Braun and Clarke (2006) the researcher has to select between an inductive or 'bottom up' approach and a theoretical or deductive or 'top down' approach for the identification of the themes within the data. The themes identified through the inductive approach have a little relation to the specific questions that were asked by the researcher, a strong connection to the data themselves and the form of thematic analysis is therefore *data-driven*. On the other hand, the deductive approach, which was selected by the author and otherwise called 'theoretical thematic analysis', tends to be driven by the researcher's analytic or theoretical interest in the area of research, and is hence more *analyst-driven*. The way in which the data was coded was based on this choice, as when coding with a deductive or theoretical approach the researcher is coding for a specific research question, whereas when coding with an inductive approach the research question can be generated through the coding process (Braun and Clarke, 2006).

3.4.7 Participant Observation

Finally, the completion of the UK Case study, led also to a Participant Observation study, to explore deeper the transformational journey of a traditional UK port with the aim of becoming smart, green and sustainable. The author started this research from a global study (Website Content Analysis), followed by a national study (UK case study) and completed the progression form the general to the particular with a single port study focusing on the Port of Tyne.

Observation can be rewarding and enlightening to conduct, as it adds remarkably to the richness of the research data (Saunders et al., 2019). If the research question(s) and objectives are focusing on what people do and how they interact, the most appropriate way to investigate this is to listen and watch them do it (Saunders et al., 2019). According to Saunders (2019) this is fundamentally what observation implicates: *the systematic viewing, recording, description, analysis and interpretation of people's behaviour in a given setting.* According to Saunders at al. (2019) there are three observation methods: participant observation, structured observation and Internet-mediated observation.

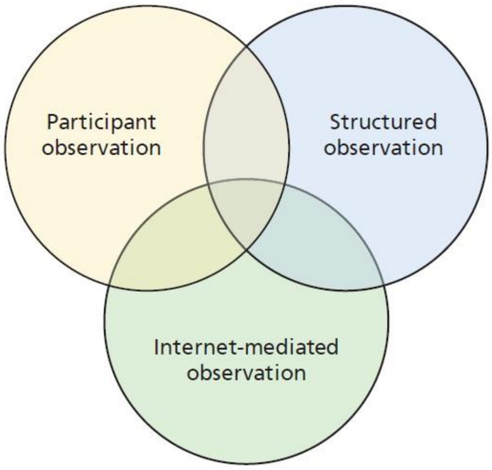

Figure 3.3: Overlap among types of observation

Source: Saunders (2019)

Participant Observation is a qualitative technique that originates from the early twentieth century social anthropology work and is focused on investigating the meanings that people attribute to their actions and social interactions (Saunders, 2019). On the other hand, Structured Observation is a quantitative technique and is more interested in the frequency of actions (Saunders, 2019). Finally, Internet-mediated Observation involves the gathering of data from online communities. This last approach adapts traditional observation by modifying its mode from visual/oral/near to digital/textual/virtual to give the opportunity to researchers merely to observe or to engage with members of an online community to gather data (Saunders, 2019). Fundamentally, these methods can overlap, as shown above in Figure 3.3. The author selected the Participant observation method for the purposes of this study, as this method was deemed the most suitable to reach the objectives of the research.

3.5 Relevance and Contribution

Efficient development and operation of ports is fundamental in an era shaped by the advent of the Fourth Industrial Revolution and characterised by the emergence of maximisation of the efficiency of global supply chains. The reorientation of ports demands each node to be as efficient, smart, green and sustainable as possible. Thus, the factors affecting the maximisation of port's efficiency are crucial and need to be deeply investigated in order to understand under which circumstances the efficiency of a port can be maximised through the use of technological advancements in its operations. Moreover, it is pivotal to explore the net benefits generated from the application of the technological advancements in port operations through the development of smart, green and sustainable ports. The increasingly growing interest of scholars, industry stakeholders, and governments on the topic of technological advancements and smart ports, shows that the efficiency of ports and terminals has become an excessively important issue for port managers, operators and their customers.

This research filled in the identified knowledge gap by investigating the relationship between technological advancements and the generated net benefits for both ports and the hinterland. It explored the factors affecting port efficiency, focusing on the aspect of technological advancements, therefore contributing to better assess the net benefits generated from their application in port operations. In addition, the generated net benefits for regional communities were identified, in terms of accessibility, employment, added value, social and environmental impacts. Finally, the findings of this thesis will yield significant insights into the strained relationship among the development of smart, green and sustainable ports and the benefits generated from this development.

Overall, the contribution of this research can be summarised as follows:

- Comprehensive review of the technological advancements presently adopted in port operations;
- Understanding of the relationship between port efficiency and economic development, as well as the factors affecting port efficiency;

- Understanding of the key characteristics of container ports and provision of a method of identification of a representative sample;
- Contribution to understanding the different net benefits that are generated from the application of technological advancements in port operations, as far as port performance and the hinterland are concerned;
- Provision of insights and benchmarking of the world's major ports with regard to their smart, green and sustainability related practices and efforts, according to their website disclosure and reported practices;
- Provision of detailed information on the factors behind the barriers for the maximisation of the potential gains generated for both port operators and local communities from the application of technological advancements in port operations;
- Contribution to fill the identified gap in the literature by providing empirical evidence from the UK case study.

3.6 Conclusion

This Chapter presented the research questions and objectives of this thesis. On the basis of these, the choice of the research philosophy framing this thesis and the methodological approaches were justified.

The research adopted the philosophical paradigm of pragmatism, a mixed methods research design and mixed methodology, based on the methodological triangulation approach, incorporating both qualitative and quantitative techniques (inductive and deductive in nature). Finally, the contribution and relevance of the research were described.

Chapter 4. Scoping Study

4.1 Introduction

At the outset of the research, the researcher conducted a series of preliminary interviews with key industry stakeholders to gain a deeper understanding of the current port operational landscape. The purpose of the preliminary interviews was to set the scene and to provide a means of exploration around the current issues faced by ports, as it ultimately contributed to the background and direction of this research.

Section 4.2 outlines the data collection process. Section 4.3 discusses the results and main findings provided by the preliminary interviews, thus setting the scene of the research area, while Section 4.4 concludes with the main aim of the scoping study within this research.

4.2 Data Collection

Four semi-structured interviews with a predetermined list of questions were held between November 2018 and January 2019 via video or telephone. Table 4.1 provides an overview of the interview participants. Due to confidentiality reasons neither interviewee nor company names are provided. The researcher aimed to cover more than one geographical area and all spans of companies in this background investigation.

Interviewee Reference	Position	Geographical Region
A1	Lead transport specialist at International Development Bank	Latin America and the Caribbean
A2	Chief Executive at Trade Association representing large commercial ports	United Kingdom
A3	Managing Director at Port Consultancy	Germany
A4	Product Manager, Digital & Supply Chain Services in one of the leading and most advanced Container Terminal Operators	Netherlands

Table 4.1: Respondents of preliminary semi-structured interviews

The preliminary semi-structured interviews comprised 7 questions as outlined in Table 4.2. The list of predetermined questions was designed with the aim to explore the main technological advancements that are currently employed in ports, the way in which technological advancements affect port efficiency, and to capture a top-level view of the benefits / impacts they bring to the local community. The key themes and insights retrieved from the responses contributed to refining the phenomenon under study and guided the subsequent focus of the PhD research topic.

Question 1	Do you regard the following technological advancements as valid? Are there any other technological advancements that come to mind? • Terminal automation, Artificial Intelligence (AI), Internet Of Things (IoT), Information and Communication Technology (ICT) infrastructures, Robotics, Blockchain technology, Carbon footprint assessment technologies. Sub-question: What makes a terminal technologically advanced?
Question 2	How do technological advancements affect terminal efficiency?
Question 3	What kind of benefits (and impacts, if any) do you consider that technological advancements bring to the port region?
Question 4	Are there any technologies that increase terminal efficiency while simultaneously improving the carbon footprint of a terminal?
Question 5	Which are the main external factors that affect the maximisation of the benefits generated by technological advancements in terminal operation (such as regulation, port governance, etc.)?
Question 6	Are there any barriers to transfer the benefits generated by technological advancements in ports to the local community?
Question 7	Are any of the technological advancements that we have discussed applicable only to certain categories of ports, and if so, why is this the case?

Table 4.2: Questionnaire for preliminary semi-structured interviews

4.3 Results

Analysis of the interview insights showed that the current port operational landscape is shaped by:

- the fast-paced adoption of new technologies in port operations,
- the environmental regulatory framework, the green agenda of ports and thereby the embracement of technologies that play a key role in eliminating emissions from port operations,
- shifting patterns in port employment and required skillsets,
- the need for overall efficiency in the whole supply chain and the pivotal role of ports in this process.

Respondents were asked if the seven technologies identified by the researcher (Question 1) were the main ones spanning the ports industry at the time of the interviews. Interviewees highlighted the fact that automation is one of the main technological features applied in ports nowadays. On the other hand, there was a consensus among respondents that blockchain technology is very hard to be applied in ports, mainly due to data privacy issues. According to the respondents, although blockchain would greatly benefit the supply chain, companies are reluctant to share their private data (financial, operational, etc.) with competitors. Therefore, companies that develop blockchain technology find it very hard to persuade partners to join their platforms. One respondent also added that since ports do not have any direct efficiency gains from applying blockchain technology, there will be major problems for this sector to join the platforms.

Most of the respondents pointed out that ICT infrastructures and digital platforms are also widely used in the sector and constitute an increasingly important aspect to the current development of ports and their efficient operation. Interestingly, one respondent suggested that Artificial Intelligence (AI) has limited application now, but it is the future in port operations and decision-making. According to another respondent, AI is the use of algorithms to make decisions, and therefore a critical tool for decision-making that port operators and policy-makers should use for strategic planning to improve port competitiveness.

When it comes to terminal automation, there are two types according to their degree of automation; fully automated can be regarded one terminal that has all its yard and yard-dock movements automated, whereas a semi-automated terminal has its yard movements automated but its yard-dock movement are performed by conventional means or vice versa.

Subsequently, and considering the elements that make a terminal technologically advanced, one of the respondents pointed out that an automated terminal is clearly considered advanced. However, if it is not automated this does not necessarily imply that it is not technologically advanced. This is due to the fact that automation might not be viable for some terminals, as for example there should be a minimum amount of cargo handled to justify the need for automation. According to this respondent, there are smaller ports around the world that are advanced, but do not have automated type of equipment. The reason behind this is that they might have clever IT solutions and they can be efficient and advanced because they use clever algorithms (AI) for their operations. He interestingly noticed that terminal automation could include more than just only cargo handling equipment automation. It can include decision-making, automated processes (planning, administration tasks), and thus a terminal can be efficient because it uses AI, even though it might not be automated in its cargo handling equipment. Most of the respondents also pointed out that terminals which use digital platforms are also considered technologically advanced.

Respondents indicated that technological advancements generate improved productivity, efficiency, capacity and reduce operating costs. One of the respondents pointed out IoT and ICT platforms as some of the main technologies that improve terminal efficiency. This is due to the enhanced visibility they bring to all stakeholders that are part of the port operation process. In this way, operations are planned better as all parties are trying to optimise their part and overall, the efficiency is increased. With regard to processes, one of the respondents stressed the need to improve customs operations and clearance, as these can contribute greatly to the improvement of the overall port, but also supply chain, efficiency.

Another aspect mentioned by respondents that is benefited through technological advancements is reduced truck waiting times and reduced traffic congestion. One respondent indicated that the use of vehicle booking systems (VBS) can significantly improve the flow of trucks in and out the port. If a driver has to book a specific slot for his truck to visit the port, then the system has to allocate this slot to match the time when the cargo is scheduled to arrive and ready to be picked up. In this way, when the truck arrives the cargo is ready to be collected and thus there is no congestion in the port and in the road nearby the port either. The trucks do not need to wait in port (with their engines running generating emissions), emissions are thereby reduced, and the efficiency of the whole process is enhanced.

Regarding the benefits and impacts that are brought to the port region due to the implementation of technological advancements in port operations, respondents indicated that job loss is one of the main impacts that is generated due to the adoption of new technologies. Labour unions have always been resistant to automation, as dockworkers for example fear they will lose their jobs due to the automation of cargo handling equipment. Therefore, many ports have unionised workforces that oppose and fight against automation to protect their jobs. However, one of the respondents pointed out that for a port located in a condensed urban setting, where the expansion of the physical capacity is not possible, automation is the only solution to face the continuously increasing need of fast-paced container handling. In this case, there are great efficiency gains from automation, and no one loses their job, as the number of the workforce might remain the same, but the capacity handled can double.

Undoubtedly, and according to all respondents, the benefits generated for the region are also significant and can vary from work safety to up-skilling of the local economy. In particular, automation requires different skills, higher qualifications and IT trained workforce. The different set of skills needed requires highly skilled people and this leads to the upskilling of the local economy. In turn, this upskilled workforce will be paid higher, and as consequence higher income taxes will be generated.

Moreover, according to one respondent, work safety is enhanced as serious accidents are prevented as the workforce is mainly employed in offices rather in the dockyards, where accidents might happen more often. Another interesting benefit highlighted by one of the respondents, was that physical connectivity is greatly enhanced because of the adoption of technological advancements in ports. Road and rail links are improved to enable the need of the port operations, and consequently these benefits are also passed to the port region.

When considering technologies that can enhance the port's efficiency, while simultaneously improving its carbon footprint, respondents indicated that ICT application can provide significant environmental benefits, apart from only efficiency gains. If ports employ ICT technology to inform people on time, port gates for example will not be congested and trucks will not consume unnecessary fuel waiting with their engines running, as the cargo will be picked quickly due to on-time information. Likewise, another respondent highlighted that AI can also contribute to the greening of ports, as planning optimisation processes will be more efficient and therefore driving time will be reduced and in turn energy consumption will be reduced.

Some of the external factors that affect the maximisation of benefits generated by technological advancements in port operation, were mainly the openness of port authorities to the adoption of new technologies and the availability of skilled workforce. The port sector's ability to place well-trained and competent staff familiar with the new technologies has not kept pace, and thus the benefits of technological advancements might take longer to be seen in port operations. Another aspect mentioned by one respondent, was the ability of electric power supply (stability of the power grid). Although this aspect might be taken for granted in Western countries, in other parts of Asia it could limit the application of certain technologies, as the non-stability of the power grid could create huge problems in the adoption of some technologies. Another factor indicted by one respondent, was that the less government involvement there is in port operations, the more maximised efficiency gains are generated from the use of new technologies in ports. This respondent highlighted that if there is increased private investment the productivity of a port is also increased. Private investment can improve connectivity, given that it would improve port infrastructure.

Interestingly, the results of the interviews showed that the barriers that exist and stop benefits being transferred to the local community are mainly due to the lack of collaboration and coordination among all relevant stakeholders. For example, according to one respondent, the local government needs to communicate with the port on how to plan the use of roads better so that the peaks of the road use can be smooth. This is pivotal, as all the gains that might be developed in other processes, such as emissions reduction, might be lost in this as for example trucks might wait a lot in endless queues in road congestion.

4.4 Conclusion

Overall, the preliminary interviews and the deeper understanding they provided to the main challenges that the port industry faces gave the author the ability to refine the phenomenon under study and to shape the focus of the subsequent research.

Chapter 5. Systematic Review on Port Efficiency and Economic Development

5.1 Introduction

Chapter 5 explores through a systematic literature review the relationship between port efficiency and economic development to understand how these two concepts interact. Considering that ports handle over 80 per cent of world merchandise trade in volume, their efficiency and use can determine the growth and prosperity of the global and local economy (Park and Min, 2014; UNCTAD, 2018). Academic research has to date focused on measuring port efficiency, identifying its drivers, investigating the overall economic impacts of ports and quantifying these impacts. However, to the author's knowledge, no study has analysed in a systematic way the relationship between port efficiency and economic development.

In order to fill this gap, the author conducted a systematic literature review to answer the following review question: **What is the relationship between port efficiency and regional economic development?**

Next, Section 5.2 presents the data collection and results of the systematic review. Section 5.3 provides the descriptive analysis of the selected papers, while Section 5.4 discusses the results. Finally, Section 5.5 summarises the findings of the systematic literature review on the concept of the relationship between port efficiency and regional economic development.

5.2 Data Collection

In order to explore the relationship that exists between economic development and port efficiency, the systematic review technique was employed.

In the present study, the available literature was researched by examining the dataset of Scopus (Elsevier), one of the largest databases of peer-reviewed literature. In line with the five-steps involved in the systematic review technique, the review question was formulated (Denyer and Tranfield, 2009; Gligor and Holcomb, 2012). Next, the extensive research was performed through ad hoc queries using a string of words consistent with the review question, in the main title, in the abstract and in the keywords of the available papers and conference proceedings. Keyword search was performed using the *words ("port efficiency"*

OR "port productivity" OR "seaport efficiency" OR "seaport productivity") AND ("economic development" OR "impact" OR "growth") in the title, abstract or keywords of papers and conference proceedings. Following, the studies selection and evaluation was conducted through the use of the Critical Appraisal Skills Program (CASP) checklist (Appendix A) (Wang and Notteboom, 2014). From the results, 15 articles were selected.

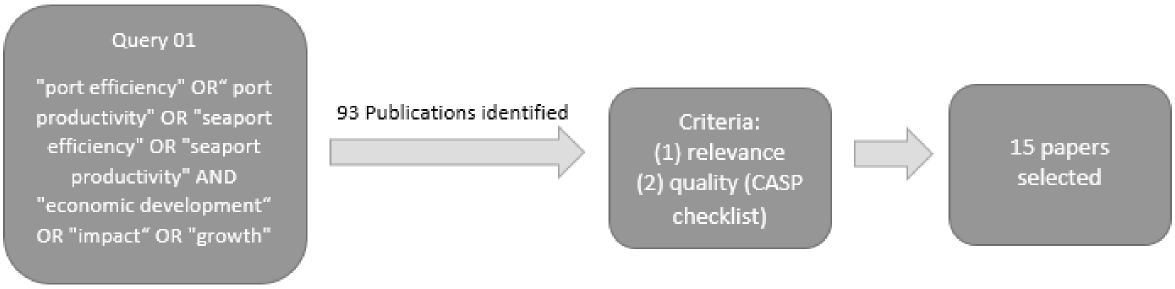

Figure 5.1: Graphical illustration of the literature search and selection process

The fourth step was to analyse and synthesize the selected studies. Finally, the results of the synthesis were reported and confirmed that the studies were consistent.

The table below lists the selected articles:

No.	Author / Year	Title	Name of journal
1	Sant' Anna and Kannebley Júnior (2018)	Port efficiency and Brazilian exports: a quantitative assessment of the impact of turnaround time	The World Economy
2	Xu et al. (2017)	A study on transport costs and China's exports: An extended gravity Model	Journal of Systems Science and Complexity
3	Sun et al. (2017)	Performance evaluation of Chinese port enterprises under significant environmental concerns: An extended DEA-based Analysis	Transport Policy
4	Feenstra and Ma (2014)	Trade facilitation and the extensive margin of exports	The Japanese Economic Review
5	Haralambides and Gujar (2012)	On balancing supply chain efficiency and environmental impacts: An eco-DEA model applied to the dry port sector of India	Maritime Economics & Logistics
6	Mann (2012)	Supply chain logistics, trade facilitation and international trade: A macroeconomic policy view	Journal of Supply Chain Management
7	Haddad, Hewings et al. (2010)	Regional effects of transport infrastructure: a spatial CGE Application to Brazil	International Regional Science Review
8	Ng and Tongzon (2010)	The transportation sector in India's Economy: Dry ports as catalysts for regional development	Eurasian Geography and Economics
9	Chin and Low (2010)	Port performance in Asia: Does production efficiency imply environmental efficiency?	Transportation Research Part D
10	Ferraz and Haddad (2008)	On the effects of Scale economies and Import barriers on Brazilian Trade performance and Growth: an Interstate CGE analysis	Studies in Regional Science
11	Wilmsmeier et al. (2006)	The impacts of port characteristics on international maritime transport costs	Research in transportation economics
12	Zhou and Chen (2005)	Seaport Service Efficiency, Maritime Shipping Cost and Trade Growth of China	Proceedings of International Conference on Services Systems and Services Management, 2005
13	Clark, Dollar et al. (2004)	Port efficiency, maritime transport costs and bilateral trade	Journal of Development Economics
14	Wilson, Mann et al. (2003)	Trade Facilitation and Economic Development: A new approach to quantifying the impact	The World Bank Economic Review
15	Doi, Tiwari et al. (2001)	A computable general equilibrium analysis of efficiency improvements at Japanese ports	Review of Urban and Regional Development Studies

Table 5.1: Papers that satisfied the relevance and quality criteria

5.3 Descriptive analysis of selected papers

The 15 papers identified were published between 2001 and 2018 and relate to port efficiency and how it impacts the economic development of a region. There has been a concentration of publications in 2010, with 3 papers and accounting for 20% of the total being published that year, suggesting that the link between port efficiency and economic development represented an emerging field of research, attracting gradually academic interest towards this topic.

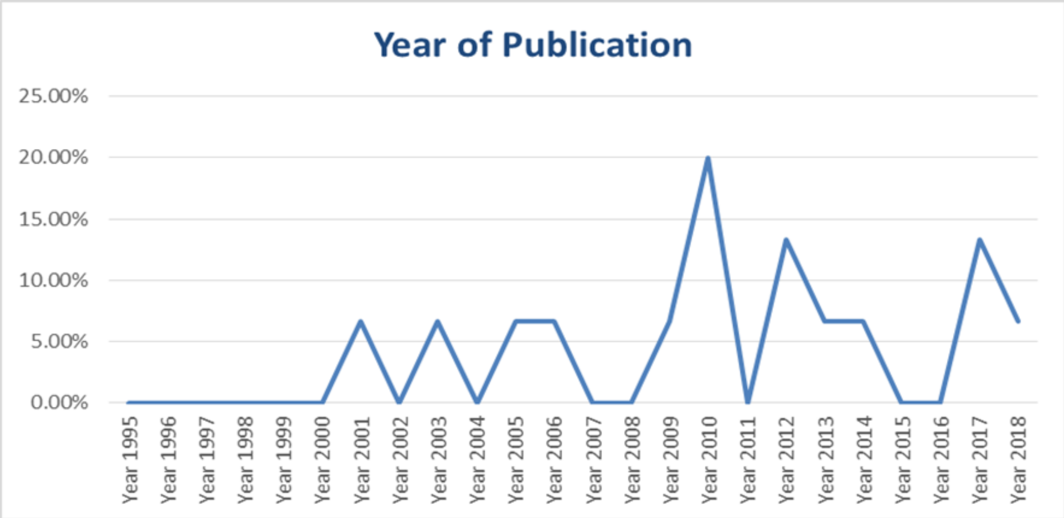

Figure 5.2: Percentage of articles by year of publication

Moreover, the geographical scope of the papers was analysed in order to identify the geographical distribution of academic interest in this topic. The highest percentage of ports that were the focus of most papers were in China (27%), with 4 papers targeting Chinese ports for their research. Figure 5.3 illustrates the proportion of research studies relating to the port's geographical location. Assessing port efficiency in Asian ports has seen a growing interest over the past decade, given that the region is the home to the busiest and largest container ports around the world, and identifying how this can relate to the economic development of the wider region has a great significance for the local and national governments.

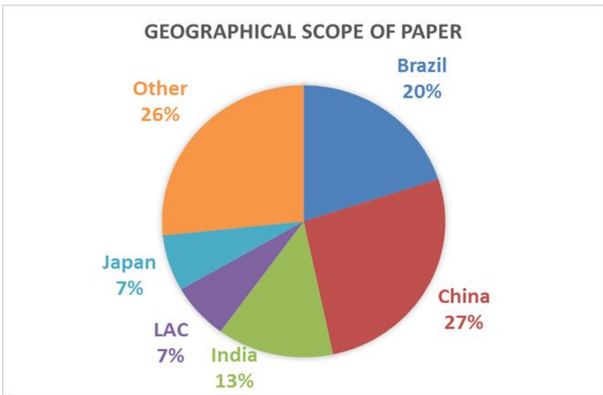

Figure 5.3: Distribution of the geographical scope of papers

Next, the author classified the articles based on the methodology used by the researchers for the scope of their study. Most researchers used Gravity Models (33%) in order to evaluate the link between port efficiency and economic development, followed by Data Envelopment Analysis (27%) and the Computable General Equilibrium (CGE) model (20%). This is primarily because the economic impacts of a concept are commonly measured by CGE models and gravity models, as was also described in Sections 2.4.3.2 and 2.4.3.3. Figure 4.4 illustrates the percentage of articles per each methodological approach.

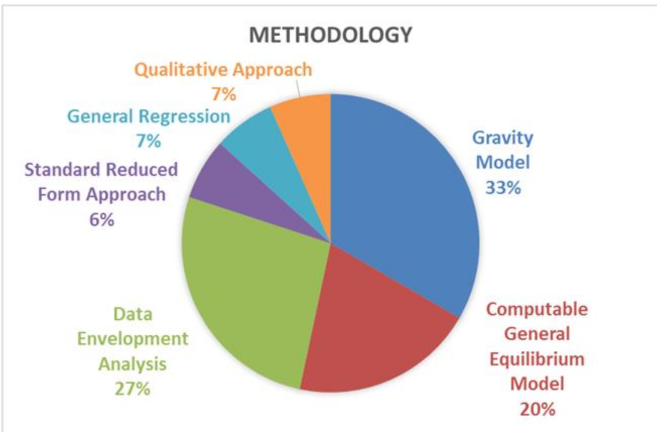

Figure 5.4: Research methods and data analysis techniques of papers

5.4 Analysis of Results

After the third stage of the systematic literature review process, where the literature research and selection were conducted, the researcher continued with the fourth stage which involved the analysis of results. The analysis of the selected literature gave insights into the link between port efficiency and economic development, as ***enhanced port efficiency appears to generate a positive and significant effect on trade flows and trade facilitation measures*** (Wilson, Mann et al., 2003; Clark, Dollar et al., 2004; Zhou and Chen, 2005; Ferraz and

Haddad, 2008; Haddad, Hewings et al., 2010; Feenstra and Ma, 201;, Sant' Anna and Kannebley Júnior, 2018).

Mann (2012) underlines that trade facilitation is the procedure that covers the research and policy analysis to reduce bottlenecks to cross-border trade. Increasingly, policy makers are focusing on these measures as part of an agenda to increase international trade and therefore enhance economic growth for their country. The common view is that policies such as the increase of port efficiency, or the use of information technologies will improve the environment for businesses to invest, sell or buy across borders, and thus drive more effective and efficient trans-border supply chains (Mann, 2012). According to Mann (2012), ICT networks and globally linked financial institutions are pivotal to today's trade facilitation policy analysis. Therefore, trade facilitation research provides a macroeconomic perspective on how policy makers should adjust the environment facing business to promote economic growth and international trade. On the other hand, the microeconomic perspective of supply chain logistics examines the way that a business should organise its operations, given the existing policy environment.

Research shows that the links between improved trade facilitation policies through international trade are positive. More specifically, the study by Sant' Anna and Kannebley Júnior (2018) argues that port efficiency, port infrastructure, port cost, as well as efficiency in customs procedures are among the most significant determinants affecting trade facilitation. Through their study they highlight the significance of turnaround time by estimating the impacts of turnaround times in ports on Brazilian exports. Their results indicated the presence of a bottleneck in the flow of Brazilian production to the international markets as the sample ports presented an average downtime (waiting time to dock and time to the start of operations) of 47.17% in 2012. The necessity of improvements in port capacity to reduce the inefficiency that generates high percentages of downtime in Brazilian ports was highlighted. Their empirical results suggested that a reduction in turnaround time can provide Brazilian exports better access to the international markets, as according to their estimates a 10% reduction in total turnaround time could increase local export by 5.1%.

In a similar study, Wilmsmeier, Hoffmann et al. (2006) examined the effect of port efficiency, delay in customs clearance, port infrastructure, private sector participation and inter-port connectivity on international maritime costs. The authors found that doubling port efficiency at both ends has the identical effect on international maritime transport costs as would have a "move" of the examined ports 50 per cent closer to each other (i.e. reducing the distance between them by half). The positive effect of port efficiency on trade flows is most likely related to both its effects on the quality of maritime transport services and also on the international maritime transport costs. Port improvements, apart from the strong impacts on trade costs, do not only lead to lower freight rates but also by provide enhanced services so that ports can attract additional liner services and cargo. Therefore, both cost savings and increased trade competitiveness are achieved through improvements in ports.

In order to assess the impacts of transport costs and port efficiency on China's exports Xu, Lai et al. (2017) employed a conventional gravity model design, to provide strong evidence that upgrading China's transport service networks could offer greater scope for increasing and maintaining its competitive edge in low cost production. The authors found that a 10% increase in port efficiency leads to approximately 7.7% increase in major port cities' exports in China, suggesting that ports need to be expanded and their efficiency level is crucial for China's export trade level. Another main finding is that the estimated elasticity of railroad transport costs on port cities exports is much smaller compared to that of road transport costs, suggesting that the construction of rail networks to connect ports with cities, is achieving apart from cost savings a relief in port-generated traffic congestion in port cities in China.

Moreover, Feenstra and Ma (2014) examined the link between trade facilitation and export variety, by measuring trade facilitation through port efficiency. They explored what factors contribute to facilitating trade, by providing empirical evidence on the impacts of different sources of trade costs, and more specifically on the extensive margin of trade. By an extensive margin, it is meant the variety that a country exports and imports. Their findings indicate that port efficiency significantly contributes to the extensive margin of exports. They also included the bilateral import tariff in their analysis, to conclude that it negatively affects the variety of exports.

The study of Haddad, Hewings et al. (2010) simulated the impacts of increases in port efficiency on Brazilian economic growth, to conclude that potential increases in port efficiency may generate greater bilateral trade with other countries. They underlined the interrelated character of regional economies with port efficiency, as the improvement of port efficiency in one region might divert investment and commerce from neighbouring regions.

Ng and Tongzon (2010) reviewed the development of dry ports in India, which are part of a broader national program to eliminate transportation bottlenecks, enhance transport efficiency and spur economic development. Even though their results indicated that the efficiency level of dry ports has not yet reached a high level, they emphasize the fact that dry ports can act as a catalyst for India's economy if their efficiency is improved through government policies to enhance private participation in order to increase efficiency.

Ferraz and Haddad (2008) examined how the distribution of the economic activity may reshape as Brazil opens up to foreign trade. They presented a set of simulations in order to illustrate the significant role played by the quality of infrastructure and geography on the country's interregional and foreign trade performance. Their findings showed the relative importance of port efficiency, import tariffs, and maritime transport costs for the country's trade relations and regional growth.

Zhou and Chen (2005) conducted an empirical analysis of the effect of seaport efficiency on maritime costs and trade growth of China. Through the analysis of China's trade records, a potential improvement in the seaport service from 25th to 75th percentiles can reduce shipping costs by more than 15%, and that in turn a decrease in inefficiency associated to shipping costs from 25th to 75th percentiles can imply an increase of around 25% in bilateral trade.

Clark, Dollar et al. (2004), through a sample based on data from the U.S Import Waterborne Databank for the years 1996, 1998 and 2000, have also provided evidence that an improvement in port efficiency from the 25th to the 75th percentile could reduce shipping costs by 12%. They also indicated that inefficient ports increase handling costs, one of the components of shipping costs. Finally, they indicated that reductions in country's inefficiencies linked to transport costs, from the 25th to 75th percentiles increase bilateral trade by 25%.

The relationship between trade facilitation and trade flows in the Asia-Pacific region was the focus of the study by Wilson, Mann et al. (2003). The authors examined country-specific data for port efficiency, customs environment, regulatory environment and e-business usage to construct indicators for measuring trade facilitation. They showed that enhanced port efficiency has a significantly large and positive effect on trade flows. Their results also indicated that regulatory barriers deter trade, improvements in customs environment promote trade, and finally that greater e-business usage significantly expands trade.

Finally, Doi, Tiwari et al. (2001) investigated the system-wide impact of increased efficiency in Japanese ports, and provided empirical evidence that the technological efficiency in ports reduces significantly the costs of shipping transportation, and that the forward and backward linkages of exports and imports introduce positive gains in the national Gross Domestic Product (GDP). Their analysis also proved the existence of substantial spillover effects on shipping transportation and to a lesser extent to Japanese economy.

With regard to the environmental effects of ports and their link to regional development, Sun, Yuan et al. (2017) suggested that when evaluating port efficiency, environmental factors should be also taken into consideration. Since the achievement of both operational efficiency and effective environmental protection is a major goal for port enterprises and governments, the authors propose a DEA model which incorporated environmental factors when analysing a port's efficiency. Their results indicated that the average efficiency for the Chinese-listed enterprises they considered, was low when environmental factors were considered. Similarly, Haralambides and Gujar (2012) in an effort to highlight the importance of ports' share in atmospheric pollution, proposed a new eco-DEA model that simultaneously evaluates the desirable and undesirable outputs of port service production. The results of their study reveal that when evaluating port efficiency, levels are highly altered once environmental aspects are factored into the model. The study of Chin and Low (2010) is also recognizing the importance of negative externalities in the production of port services in East Asia, and is also incorporating environmental impacts of shipping. Their findings suggest that technically efficient shipping is more likely to achieve environmental efficiency.

5.5 Discussion

The present systematic literature review scrutinized the relationship between port efficiency and economic development in each selected paper and provided evidence of the critical relationship between port efficiency and economic development. The results also indicated that there is limited academic work available on this field. Figure 5.5 illustrates the relationships among all the pivotal concepts analysed in the discussion of the systematic literature review (SLR).

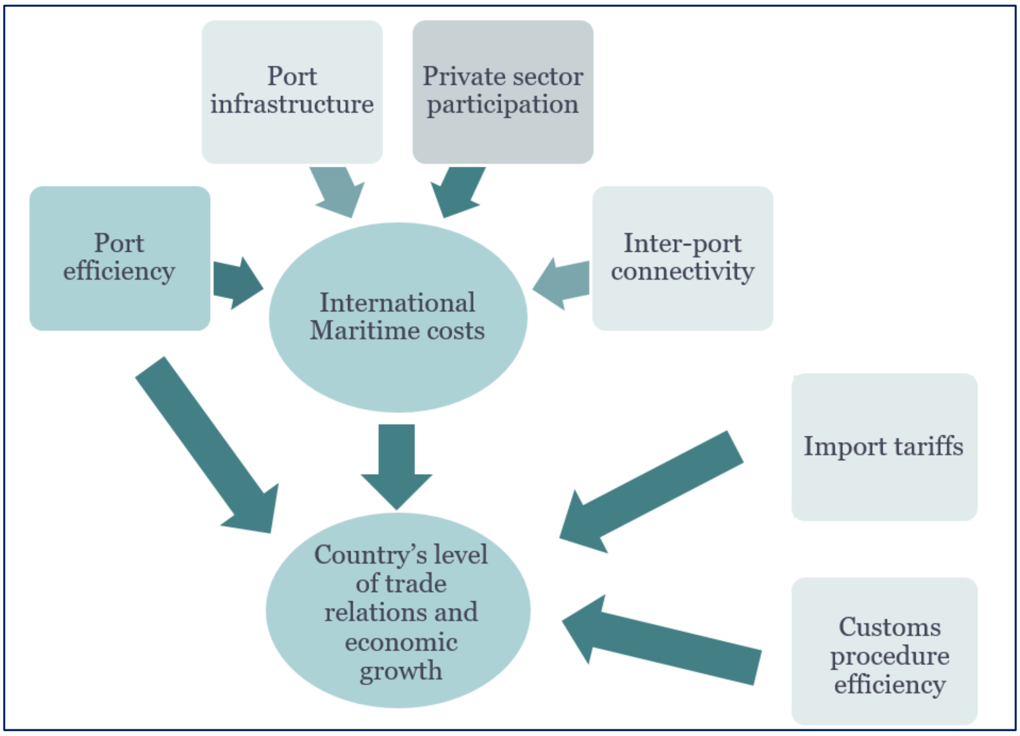

Figure 5.5: Relationship among critical concepts under scrutiny in the SLR

From all the above it can be argued that international maritime costs are affected by port efficiency, port infrastructure, private sector participation and inter-port connectivity. In turn, a country's level of trade relations and economic growth is affected by international maritime costs, import tariffs and customs' procedure efficiency. Therefore, *a country's level of economic development is indirectly impacted by the ports' efficiency level*.

Moreover, the SLR identified the barriers and drivers of the expansion and shrinkage of trade. On one hand, transport costs and regulatory barriers negatively affect trade, and on the other hand improvements in customs procedures and greater e-business usage play a key role in the expansion of trade.

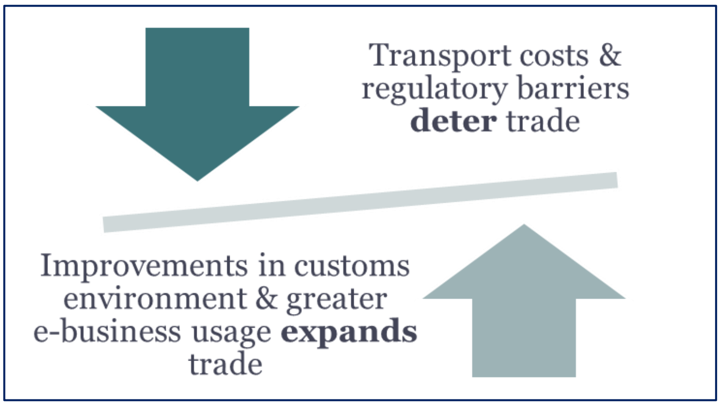

Figure 5.6: Barriers and drivers of trade

Overall, and given the relationships illustrated in Figures 5.5 and 5.6, it can be concluded that an improvement in port efficiency reduces international maritime costs and improves the quality of maritime transport. As an outcome, an increase in bilateral trade is induced, which translates into a large and positive effect on trade flows, which consecutively lead to the economic development of a region or country.

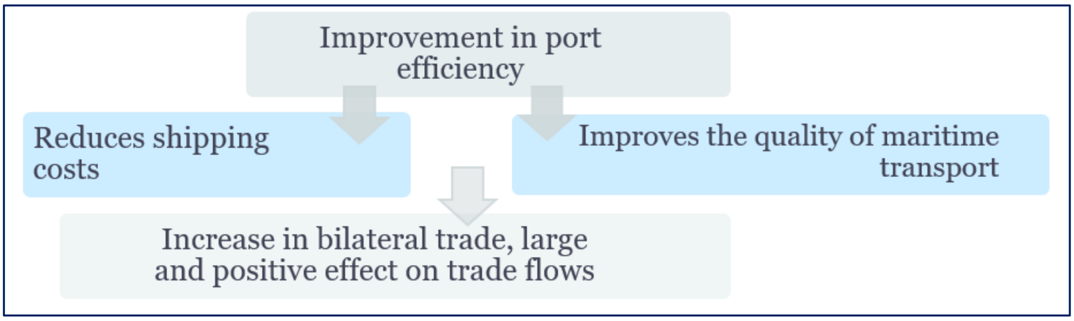

Figure 5.7: Relationship between port efficiency and international trade

5.6 Conclusion

In conclusion, the systematic literature review identified gaps and limited academic work in the existing literature in evaluating the relationship between port efficiency and economic development. Although academic research has so far focused on the measurement of port efficiency, on the identification of its drivers and also on port impact studies separately, it has not sufficiently addressed the link between port efficiency and the impact it creates on regional economic development. The SLR therefore demonstrated the link between port efficiency and economic development and highlighted its importance for a region's or country's economic prosperity.

Having provided evidence of the critical relationship between port efficiency and economic development, the systematic review concluded that international maritime costs, which dictate the country's level of trade relations and economic growth, are affected by port efficiency, as well as by port infrastructure, private sector participation and inter-port connectivity. Apart from port efficiency, the customs' procedure efficiency and the import tariffs also have an effect on international maritime costs. Moreover, the findings highlight that an improvement in port efficiency can generate a reduction in shipping costs and can improve the quality of maritime transport, thus increasing bilateral trade and creating a large and positive effect on the country's/region's trade flows.

Chapter 6. Understanding Ports – Perspective and sample identification

6.1 Introduction

In this Chapter the author explored the key characteristics of the world's leading container ports, thus answering the third question of this research (RQ3). Accordingly, the focus of this Chapter was to investigate the factors that affect the ports' performance and efficiency and to determine a representative sample for the Website Content Analysis (CA) conducted for Chapter 7. Based on these grounds, Chapter 6 acts as a "supporting sampling chapter" and constitutes the basis for Chapter 7, where the author investigated the smart status of the world's leading container ports.

6.2 Benchmarking Port Performance

Ports are central to the economic development of countries and the way a port performs is a pivotal element in the cost of international trade for a country (World Bank and IHS Markit, 2021). Additionally, the fierce competition that characterises the container port industry has generated a significant interest in the efficiency with which it handles its resources (Cullinane and Wang, 2006). Therefore, the performance of ports needs careful consideration and is monitored through a series of indicators (Pallis and Notteboom, 2021).

Port performance is a pivotal indicator of trade efficiency that dictates trade costs and connectivity (UNCTAD, 2019). It is widely associated with measures of partial productivity, which are commonly described as ratios of output volume to input volume, and also with different measures of efficiency (Serebrisky et al., 2016). Based on these grounds, two different concepts emerge: **port efficiency and port productivity**. Although often treated as synonymous, these two concepts differ especially when comparing the performance of firms (Gonzalez and Trujillo, 2009).

On one hand, port efficiency analyses established relationships between inputs (e.g. a port's physical facilities and labour force) and outputs (e.g. throughput or movements in ports) (Suárez-Alemán et al., 2016). For this purpose, it is essential to estimate a production or cost frontier (i.e., the set of minimum inputs given the different levels of outputs, or the set of maximum outputs given different levels of inputs), where the production frontier represents the optimum combination of inputs (Suárez-Alemán et al., 2016). In other words, port efficiency analyses the capability of a port to generate the maximum output under a given set of inputs or a given output with the minimum number of inputs. To gain efficiency, a movement towards a situation closer to optimal is necessary. On the other hand, the concept of port productivity refers to the ratio of outputs over inputs. It is often used to compare and measure the performance of ports and analyses how well a port employs its inputs to produce its outputs (Suárez-Alemán et al., 2016). Changes in port productivity can be generated due to efficiency gains or can be derived from changes in technology or through new handling equipment, and in a production frontier context would mean a move of the frontier upwards (Gonzalez and Trujillo, 2009). Productivity indicators are often linked to time variables that aim to evaluate, for example, how fast is the cargo handled (Serebrisky et al., 2016). Examples of productivity indicators include among others ship dwell time, ship productivity, moves per ship-hour, ship delay, moves per crane-hour. These port indicators provide significant operational efficiency measures and can generate a detailed image of performance at each stage of maritime transport (Serebrisky et al., 2016).

According to Gonzalez and Trujillo (2009), the main idea behind the analogous use of the concepts of port efficiency and port productivity, is that a firm's performance improves as it becomes more productive and efficient. At the same time, the fact that changes in productivity are generated due to changes in efficiency, among other elements, may have had an influence in regarding both terms as synonymous. Gonzalez and Trujillo (2009) indicated that total factor productivity is defined as "*the ratio of a function that adds the outputs and of a function that adds the inputs*", while efficiency "*rests on the comparison of observed values of outputs and inputs with many optimum relative values, arising from the evidence provided by other firms*.

Moreover, it is important to highlight that the concept of port performance is also composed by two interrelated elements; efficiency and effectiveness (Notteboom at al., 2021). Efficiency lies within "doing things right", while effectiveness refers to "doing the right things" (Notteboom at al., 2021). More specifically, efficiency refers to the operational performance of ports and the maximisation of the output produced with a given set of resources or alternatively, the production of a given output with the less possible resources (Notteboom at al., 2021). It is a fundamental concept in the economics field and is mainly concerned with the economic use of resources (known as inputs) for production (Cullinane and Wang, 2006). On the other hand, effectiveness is concerned with the performance of a port when it comes to achieving the expectations and delivering the required services to its users (Notteboom at al., 20211). It assesses how well the firm uses its structures, tasks and strategies to reach its declared goals and mission.

As port's individual performance greatly influences the competitiveness of whole supply chains, port performance assessment and selection by its users has become a significant factor for competitiveness (Fahim et al., 2021). Every hour that a ship can save in a port, helps ports, shippers and carriers save money on port infrastructure investments, inventory holding costs of goods and capital expenditures on ships (UNCTAD, 2019). Therefore, a shorter time in port is a positive indicator of a port's trade competitiveness and efficiency. The *"median time of ship spent in port during one port call"* can constitute a means for shippers and carriers to select a port, as ports with shorter turnaround times are more attractive to carriers and shippers than other competing ports that have longer turnaround times (UNCTAD, 2019). Ports with shorter turnaround times have more calls as well, as if the turnaround time is shorter, then a port with the same number of berths can handle more port calls. Accordingly, countries that trade more tend to have more port calls and will also generate more income for investment in efficient port operations (UNCTAD, 2019).

When measuring container terminal performance, if taking into consideration the port call time of container ships, it is pivotal to highlight that on average, 75-85 per cent of the port call time is spent by container operations (time between first and last container lift), whereas the remaining time may be taken by mooring, pilotage, customs procedures, and other procedural or operational requirements (UNCTAD, 2020). Therefore, the efficiency of the container operation part of the port call is influenced by the combination of the quantity of cranes deployed (crane intensity) multiplied by crane speed. Crane intensity is however highly influenced by the call size and can be constrained by the availability of cranes, the ship's overall length and stowage plans (UNCTAD, 2020). The lead metric of port turnaround times is the average of total port hours per port call, where port hours are counted from when a ship reaches the port boundaries (anchorage or pilot station) until the time that operations are completed, and it departs from the berth. It thus includes berth time, steaming-in time and idle/waiting time. However, it does not account for the time spent to steam out of the ports limits, as it is very homogenous and it is not affected by port effectiveness.

Performance measurement has thus always been a pivotal issue for ports, as port managers need to organise their operations and processes efficiently and effectively. Since an inefficient port will result in higher costs for importers and exporters, slower economic growth and lower employment, port performance indicators can provide vital feedback to government policy makers and port operators for assessing whether their strategic targets were met (Notteboom and Pallis, 2021; World Bank and IHS Markit, 2021). Therefore, performance indicators constitute analytical tools that can contribute to the understanding of the nature and extent of issues that are faced by ports and the shipping industry and can play a key role in the assessment of the potential impact of policy choices (UNCTAD, 2019). Table 6.1 summarises the performance indicators proposed by UNCTAD in 1976.

Financial Indicators	**Operational indicators**
Tonnage handled	Arrival Date
Berth occupancy revenue per hour	Waiting time
Cargo handling revenue per ton of cargo	Service time
Labour expenditure	Turnaround time
Capital expenditure per ton of cargo	Tonnage per ship
Contribution per ton of cargo	Fraction of time berthed ships handled
Total contribution	Number of gangs employed per ship per shift
	Tons per ship-hour in port
	Tons per gang hours
	Fraction of time gangs idle

Table 6.1: Summary of Port Performance Indicators (PPIs)

Source: UNCTAD (1976)

Consequently, analysing the performance of container ports is of great importance to the survival of the players in the container port industry, as this type of analysis is a strong management tool for port operators, as well as a significant input for advising national and regional port planning and operations (Cullinane and Wang, 2006). Indicators can also play a part in self-assessment and benchmarking, two elements that are pivotal to policymaking, as they can constitute elements that can help appraise progress towards set targets and goals (UNCTAD, 2019).

6.3 Sample

To define the input and output variables for the measurement of performance, the objectives of each port consist the most critical tool. Cullinane, Ji et al. (2005) point out that the input and output variables should reflect substantial objectives and the process of port production as precisely as possible. For example, a port is more likely to use advanced technologies and state-of-the-art equipment to improve its productivity if its objective is to maximise cargo throughput. On the other hand, a port is more likely to use cheaper equipment if its objective is simply to maximise profits.

The sample of ports used for this research comprises the top 3 ports by TEU throughput, of each of the top 20 countries ranked by UNCTAD, according to their total container port throughput for the year 2017 (Appendix B). Out of these 20 countries, Hong Kong and Singapore only have one port, so the author collected data also for the top 3 ports of the next 4 countries (no 21-24 in UNCTAD ranking), namely Turkey, Saudi Arabia, Philippines and Australia. The ports included in Vietnam and Thailand, due to lack of data, are only the top 2 for each country instead of the top 3. The author also included 6 further container ports from China ranked among the leading 20 global container ports for 2017 according to UNCTAD, in order to have included all major container ports in the world (Appendix C). Thus, the sample is consisting of 71 ports.

The required secondary data was mainly taken from the "2019 – 2020 Ports & Terminals Guide" issue published by IHS Markit. This issue was used to collect the required data such as the total berth length of the container terminals, the draught, the number of container cranes and the total TEU throughput for the year 2017. As this trade publication collects information directly from ports under study on an annual basis, it is regarded as the most reliable and comprehensive secondary source available. However, the data for the terminal area was taken from the ports' websites, as well as from the terminal operators' websites were necessary, since no consistent data was included in the "2019 – 2020 Ports & Terminals Guide".

A container terminal's production greatly depends on the efficient use of equipment, land and labour. Although labour is a significant input variable, unfortunately labour data were not available in this study. Thus, the author has chosen cargo handling equipment as a labour proxy, under the assumption that labour employed by a port differs proportionately with its cargo handling equipment and is derived from a predetermined and highly correlated relationship to terminal facilities (Park and De 2004; Gonz, xe et al., 2009). Based on the grounds of the literature review, the terminal area, total quay length, the number of quayside cranes and the draught were considered to be the most suitable factors to be incorporated as input variables for data collection.

As far as the output variables are concerned, cargo throughput is undoubtedly the most substantial and widely accepted indicator of terminal or port output (Cullinane, Ji et al. 2005). The reason behind this selection is because cargo throughput is closely linked to the port's need for cargo-related services and facilities and is the basis upon which ports are compared particularly in assessing their activity levels, relative size and investment magnitude. Therefore, the output used in the analysis is the total number of TEUs handled in each port for the year 2017, as this was identified as the most appropriate output measure. The focus in this analysis lies within assessing the extent to which physical resources and facilities (inputs) are optimally utilised. Through the literature review, the author generated these inputs as the most appropriate. Thus, the terminal related secondary data is linked to all these factors and were used as input variables into the models.

The key characteristics of the container ports in the sample are presented in Table 6.2.

Country	Port Name	Automation	TEU	Berth Length (m)	Terminal Area (sqm)	Draught (m)	Gantry cranes
BELGIUM	Antwerp	Semi automated	10500000	9041	5481073	14.8	81
BELGIUM	Zeebrugge	No Automation	1520000	1405	480000	16.0	7
BELGIUM	Ghent	No Automation	30290	712	250000	12.5	2
GERMANY	Bremerhaven	No Automation	5509000	4930	3000000	14.5	26
GERMANY	Hamburg	Fully/semi-automated	8860000	7702	4200000	15.6	79
GERMANY	Wilhelmshaven	No Automation	481720	1725	1300000	18.0	8
ITALY	Genoa	No Automation	2620000	3281	1613000	14.1	21
ITALY	Gioia Tauro	No Automation	2450000	1755	1600000	15.5	22
ITALY	La Spezia	No Automation	1473000	2005	371000	12.3	17
SPAIN	Algeciras	Semi automated	4389836	3236	1027740	15.5	26
SPAIN	Barcelona	Semi automated	3010000	2862	1600000	15.3	24
SPAIN	Valencia	No Automation	4779749	4222	1803114	14.8	38
TURKEY	Ambarli	No Automation	3122504	4554	522338	14.3	38
TURKEY	Mersin	No Automation	1550000	1912	220000	11.3	16
TURKEY	Izmir	No Automation	4555038	1410	152000	13.0	12
NETHERLANDS	Amsterdam	No Automation	56191	586	15000	8.8	3
NETHERLANDS	Rotterdam	Fully automated	13730000	15418	7839000	13.2	122
NETHERLANDS	Moerdijk	No Automation	500000	1378	230000	9.0	2
UK	Felixstowe	No Automation	4300000	3274	1841000	14.7	33
UK	London	Semi automated	2450000	3155	2144525	14.3	21
UK	Southampton	No Automation	2000000	1895	1000000	14.8	17
JAPAN	Kobe	No Automation	2910000	5300	1604080	14.5	31
JAPAN	Tokyo	Semi automated	4730000	4675	1521520	13.0	34
JAPAN	Yokohama	No Automation	2930000	5013	1934900	15.0	46
SAUDI ARABIA	Dammam	No Automation	1580000	2740	1910000	15.0	23
SAUDI ARABIA	Jeddah	No Automation	4150000	4435	2906000	15.8	45
SAUDI ARABIA	Jubail	No Automation	326258	1000	457219	14.0	5
BRAZIL	Paranagua	No Automation	782348	426	302800	12.0	12
BRAZIL	Rio Grande	No Automation	684903	900	735000	12.1	9
BRAZIL	Santos	No Automation	3854000	5207	1623000	13.8	34
AUSTRALIA	Brisbane	Semi automated	1224829	2495	1020000	14.0	13
AUSTRALIA	Melbourne	Fully automated	2800000	2188	1244000	14.2	21
AUSTRALIA	Port Botany Sydney	Fully/semi-automated	2431737	3637	1510000	15.1	19
INDIA	Chennai	No Automation	1494831	1717	530600	14.2	14
INDIA	Jawaharlal Nehru	No Automation	4833397	3320	2217600	13.8	40
INDIA	Mundra	No Automation	4110000	2722	640000	14.9	22
SOUTH KOREA	Busan	Semi automated	20470000	12515	7091000	15.0	128
SOUTH KOREA	Incheon	Semi automated	3050000	2683	1346262	13.1	19
SOUTH KOREA	Yosu	No Automation	2220000	4598	1906000	14.5	30
CHINA	Ningbo - Zhoushan	No Automation	26000000	9626	3149000	16.5	104
CHINA	Qingdao	Fully automated	18300000	7273	4300000	17.2	62
CHINA	Shanghai	Fully automated	40300000	13664	11219298	13.6	158
CHINA	Shenzhen	No Automation	26000000	17720	7045000	14.7	185
CHINA	Guangzhou	No Automation	20300000	7087	4168000	11.1	41
CHINA	Tianjin	Fully automated	15200000	8414	3751000	14.6	89
CHINA	Xiamen	Fully automated	10300000	8818	3650100	15.1	56
CHINA	Dalian	No Automation	9900000	4334	1471896	14.8	33
UNITED STATES	Long Beach	Fully automated	7544507	8184	5223000	14.8	89
UNITED STATES	Los Angeles	Fully automated	9340000	10009	6884000	13.5	79
UNITED STATES	New York & New Jersey	Semi automated	6700000	9919	6260000	12.9	58
INDONESIA	Belawan	No Automation	320515	950	158464	11.0	5
INDONESIA	Tanjung Perak/Surabaya	Semi automated	3318550	3920	513110	11.0	32
INDONESIA	Tanjung Priok/Jakarta	No Automation	6070000	3170	993000	14.2	31
SINGAPORE	Singapore	Semi automated	33700000	19710	8170000	13.8	208
HONG KONG	Hong Kong	No Automation	20770000	10691	3437500	14.6	125
MALAYSIA	Port Klang	No Automation	11980000	8266	1450000	14.8	84
MALAYSIA	Tanjung Pelepas	No Automation	8377243	5040	1800000	16.3	57
MALAYSIA	Penang Port	No Automation	1520000	1620	425000	11.5	13
TAIWAN	Kaohsiung	Semi automated	10271018	7957	750000	14.2	62
TAIWAN	Taichung	No Automation	1660663	2380	530950	13.8	15
TAIWAN	Taipei	Semi automated	1561743	1355	1110000	16.0	13
VIETNAM	Ho Chi Minh City/Saigon	No Automation	5940000	1598	454050	10.7	13
VIETNAM	Cai Mep	No Automation	2440000	3120	2167000	14.6	27
THAILAND	Laem Chabang	No Automation	7780000	6399	2630240	14.6	48
THAILAND	Bangkok	No Automation	1950000	1229	148200	8.2	14
UAE	Dubai/Jebel Ali	Semi automated	15400000	10705	4020000	15.8	117
UAE	Khor Fakkan	No Automation	4000000	1460	700000	16.0	24
UAE	Khalifa Port	Semi automated	1530000	1200	89475	15.0	12
PHILIPPINES	Manila	No Automation	4820000	2527	1374000	10.6	18
PHILIPPINES	Davao	No Automation	594497	1095	88000	10.0	4
PHILIPPINES	Batangas	No Automation	200255	450	150000	15.0	2

Table 6.2: Key characteristics of the world's main container ports

Important summary statistics relating to the sample are listed in Table 6.3.

	Output	**Inputs**			
	Container throughput (TEU)	Berth length (m)	Terminal Area (sqm)	Draught (m)	Quayside gantry cranes (number)
Mean	6,712,093	4,815	2,189,719	13.9	43
Standard Deviation	8,088,070	4,204	2,312,061	1.9	43.8
Range	40,269,710	19,284	11,204,298	9.8	206
Minimum	30,290	426	15,000	8.2	2
Maximum	40,300,000	19,710	11,219,298	18.0	208
Count	71	71	71	71	71

Table 6.3: Summary Statistics for the sample

This table indicates that there is a great variation in the magnitudes of variables among the examined container ports, which demonstrates the fact that the sample includes gateway ports of different sizes ranging from very small to large. The great variation in the magnitudes led the author to divide the sample in sub-groups according to size, but also according to their geographical region, to observe differences and patterns among the ports in the sample.

One of the key assumptions in measuring the efficiency of decision-making units (DMUs) is that they are *homogenous units,* i.e., ports provide the same services, by using similar technologies, and operate under the same business environment and market conditions (Kutin et al., 2017). The homogeneity of outputs and inputs constitutes the fundamental assumption under which the accuracy efficiency measure is based. Thus, the comparison of the efficiency of ports operating in different regions or of different sizes can be problematic.

One way to encounter this issue, is to form homogenous groups of ports according to the geographical region they belong. Therefore, segmentations of the sample were deemed necessary to be made. The author divided the container ports in the sample according to the *geographical region* they belong to, namely “Europe”, “Asia” and “Rest of the World” (Brazil, Australia, United States). Tables 6.4, 6.5 and 6.6 below represent the Summary Statistics for the groups of ports according to geographical region.

	Output	Inputs			
	Container throughput (TEU)	Berth length (m)	Terminal Area (sqm)	Draught (m)	Quayside gantry cranes (number)
Mean	3,708,920	3,640	1,747,132	13.91	29
Standard Deviation	3,529,426	3,445	1,969,335	2.21	30
Range	13,699,710	14,832	7,824,000	9.25	120
Minimum	30,290	586	15,000	8.75	2
Maximum	13,730,000	15,418	7,839,000	18	122
Count	21	21	21	21	21

Table 6.4: Summary Statistics for Europe

	Output	Inputs			
	Container throughput (TEU)	Berth length (m)	Terminal Area (sqm)	Draught (m)	Quayside gantry cranes (number)
Mean	8,861,194	5,426	2,292,157	13.95	501
Standard Deviation	9,747,163	4,590	2,426,714	1.96	50.43
Range	40,099,745	19,260	11,131,298	8.98	206
Minimum	200,255	450	88,000	8.20	2
Maximum	40,300,000	19,710	11,219,298	17.18	208
Count	41	41	41	41	41

Table 6.5: Summary Statistics for Asia

	Output	Inputs			
	Container throughput (TEU)	Berth length (m)	Terminal Area (sqm)	Draught (m)	Quayside gantry cranes (number)
Mean	3,929,147	4,773	2,755,755	13.59	37
Standard Deviation	3,187,660	3,754	2,589,477	1.08	30.58
Range	8,655,097	9,583	6,581,200	3.08	80
Minimum	684,903	426	302,800	12	9
Maximum	9,340,000	10,009	6,884,000	15.08	89
Count	9	9	9	9	9

Table 6.6: Summary Statistics Rest of the World

The descriptive statistics of the variables, when it comes to comparing the three groups according to their geographical region, show on average that the throughput level in Asia is more than twice the average throughput in Europe and that there are substantial differences between ports in terms of their inputs, but mostly in terms of their output. Moreover, the maximum throughput in Asia is 40,300,000 TEU (Shanghai port) is three times the maximum throughput of Europe's biggest port which is 13,730,000 TEU (Rotterdam port). The ports located in the Rest of the World, show a smaller range in their crane number and draught level. Finally, the mean number in the summary statistics shows that a typical port in Asia has the highest number of quayside gantry cranes, the longest berths, as well as the largest terminal areas, compared to typical container ports located in Europe and the Rest of the world.

Automation is also an important consideration when analysing the key characteristics of container ports and their terminals. The next Section describes in detail the concept of automation and describes the level of port automation adoption across the world.

6.4 Port Automation

Automation can be described as the use of remotely and robotised controlled handling systems coupled with the transition from manual techniques to automated processes (UNCTAD, 2018). The improvement of productivity and efficiency are the main drivers of automation adoption, as automation secures a competitive advantage to ports in the race to satisfy the need for accommodating mega ships and to achieve productivity gains and lower handling costs (ITF, 2021). Fully automated terminals are those where the yard stacking operations (using automated rail-mounted gantry cranes / RMGs or rubber tyred gantry crane / RTGs or other automated stacking cranes / ASCs) and the horizontal transfer between the quay and the yard (using automated Guided Vehicles / AGVs, automated straddle carriers, or other automated equipment) is automated, while semi-automated terminals are those where only the yard stacking operations are automated.

Although container ports are increasingly starting to use higher levels of automation, Table 6.1 indicates that there are only few ports around the world with semi or fully automated terminals. In general, across the world there are in total around 53 automated container terminals (Appendix B), representing only around 4% of the total global container terminal capacity (ITF, 2021). Container terminal automation is therefore still at relatively early stages of adoption, as 96% of world container port terminals are not automated.

From the total of automated terminals around the world, the sample of this research includes ports with 40 out of the 53 automated terminals. From the total of 71 ports that are included in the sample, 25 ports have terminals within their operation that are either semi or fully automated. The countries that have some level of automation and are at the forefront with all their three ports (as the author included the top 3 ports for each country in the sample) are the United States, Australia, while from the 8 ports included in China, half have some level of automation within their operations. There are 2 ports in Spain, Taiwan, United Arab Emirates, South Korea from the total of 3 included in each of these countries that are automated, indicating that these countries are also in a good position in the adoption of automation. On the other hand, the countries in Europe that have no ports with automated terminals are Italy and Turkey, while Belgium, German, the United Kingdom and the Netherlands have 1 port each with some level of automation.

Overall, Asian ports represent a quite high percentage across the sample with automated ports, whereas other regions such as Brazil in our sample has no level of automation. Table 6.7 presents the terminals within each of the ports in the sample that include semi or fully automated terminals, also indicating the year that the terminals were automated and the type of automated equipment / processes in each of the terminals.

Terminal	Port	Year	Quay cranes	Transfer	Yard
ECT Delta	Rotterdam	1993		AGV	ARMG
Pasir Pa	Singapore	1997			
APMT-R	Rotterdam	2000		AGV	AMRG
Thamesport	London	2000			ARMG
Altenwerder	Hamburg	2001	DTQC	AGV	ARMG
Fishermans Island	Brisbane	2002		Auto SC	Auto SC
Wai Hai	Tokyo	2003			ARMG
Evergreen Marine	Kaoshiung	2005			ARMG
DPW Gateway	Antwerp	2007			ARMG
Korean Express Busan	Busan	2007			ARMG
Euromax	Rotterdam	2008		AGV	ARMG
Newport (Hanjin, HMM)	Busan	2009			ARMG
Newport (DPW)	Busan	2009			ARMG
Isla Verde	Algeciras	2010			ARMG
Taipei Port CT	Taipei	2010			ARMG
Kao Ming	Kaoshiung	2010			ARMG
Burchardkai	Hamburg	2010			ARMG
Khalifa CT	Khalifa Port – Abu Dhabi	2012			ARMG
BEST	Barcelona	2012			ARMG
London Gateway	London	2013		ALV	ARMG
Global Terminal	New York & New Jersey	2014			ARMG
TraPac	Los Angeles	2014		Auto SC	ASC
Yuan Hai	Xiamen	2014		AGV	ARMG
DP World	Brisbane	2014			ARMG
HPH Brisbane	Brisbane	2014			ARMG
SICT-HPH	Sydney	2014			ARMG
Lamong Bay	Surabaya	2014			ARMG + ARTG
Jebel Ali 3	Jebel Ali - Dubai	2014			ARMG
APMT-MV2	Rotterdam	2015	Remote	Lift AGV	ARMG
Rotterdam World Gateway	Rotterdam	2015	Remote	AGV	ARMG
Patrick Stevedoring	Sydney	2015		Auto SC	Auto SC
PPT	Singapore	2015			ARMG
Middle Harbor	Long Beach	2016			ARMG
Hanjin Incheon CT	Incheon	2016			ARMG
Victoria International CT	Melbourne	2016		Auto SC	ARMG
Yangshan Phase 4	Shanghai	2017	Remote	AGV	ARMG
Qianwai CT	Qingdao	2018	Remote	AGV	ARMG
Tianjin FICT	Tianjin	2019			
Long Beach CT	Long Beach	2021			
APMT	Los Angeles	2021		Auto SC	Auto SC

Table 6.7: Automated container terminals in the sample

Source: ITF (2021) and author elaborations

From Table 6.7 it is important to highlight that Australia has the highest number of automated terminals, as 6 of a total of 40 automated terminals included in the sample belong to Australian ports. Ports located in the United States also have a high degree of automation as 5 terminals belong to ports located in the US. Ports in China also have a high number of automated terminals, with 4 ports having one either fully or semi-automated terminal.

The Port of Rotterdam in the Netherlands has 5 automated terminals and was also the first port to ever have an automated terminal, when in 1993 ECT Delta terminal started its automation. Quay cranes in almost all container terminals are operated from driver sitting inside a cabin located on the top or sides of the girder and boom (ITF, 2021). It is only recently that few container terminals, with the port of Rotterdam being the first in 2015 to introduce remote quay operations, where the operator is in an operations centre on the port remises and operates the crane form a distance. This has set the standard for this innovation to be subsequently adopted in other terminals.

As far as other European ports in the sample are concerned, Table 6.7 shows that the only other ports apart from Rotterdam that have automated container terminals within their operation, are the ports of Algeciras (1 automated terminal) and Barcelona (1auotmateda terminal) in Spain, the port of Hamburg in Germany (2 automated terminals) and the port of London in the UK (2 automated terminals). It can be therefore highlighted that automation is primarily adopted in Asian and US ports compared to European ports, with the exception of the above.

6.5 Key performance indicators for ports

Port performance is a critical consideration for container shipping lines operating liner services on fixed schedules, based on fixed turnaround times, as delays at any of the scheduled ports could disrupt the entire schedule (World Bank and IHS Markit, 2021). Therefore, port turnaround time and port efficiency are increasingly significant factors to port operators. Policy makers, as well as maritime and port authorities, use performance indicators to track and assess performance of their countries' shipping and ports' businesses and they provide analytical tools that help guide their policymaking with regards the sustainable development of the maritime sector.

Ports use various indicators to measure their performance and can be either quantitative or qualitative factors or variables that help in the assessment of the performance of a port, measure achievements and can also reflect the changes linked to an intervention (Notteboom and Pallis, 2021). The most common indicators to measure terminal operations efficiency (productivity) are turnaround time, berth occupancy, revenue per ton of cargo, capital equipment expenditure per ton of cargo and the number of gangs used to facilitate cargo operations (Notteboom and Pallis, 2021). Policy makers, as well as maritime and port authorities, use performance indicators to track and assess performance of their countries' shipping and ports' businesses and they provide analytical tools that help guide their policymaking with regards the sustainable development of the maritime sector (UNCTAD, 2019). Port waiting time and shipping connectivity are proxy measures of efficiency, infrastructure capability, access to markets, trade facilitation and other sustainability parameters (UNCTAD, 2019).

One of the port performance indicators that has been used in the past few years, is median time ships spend in port, based on automatic identification system (AIS) data. Port waiting time and shipping connectivity are proxy measures of efficiency, infrastructure capability, access to markets, trade facilitation and other sustainability parameters (UNCTAD, 2019). Thus, the author considered port turnaround time as a proxy for a port's efficiency. Accordingly, Table 6.8 below presents port call and performance statistics, such as time spent in ports, vessel age and size for the year 2018.

Country	Median time in port (days)	Average age of vessels	Average size (GT) of vessels	Maximum size (GT) of vessels	Average container carrying capacity (TEU) per container ship	Maximum container carrying capacity (TEU) of container ships
World	0.7	13	38520	217673	3538	21413
Australia	1.2	12	47387	94483	4361	8530
Belgium	1.02	12	53883	217673	4882	21237
Brazil	0.81	8	62765	118945	5746	11000
China	0.62	11	50155	217673	4645	21413
Hong Kong	0.54	12	41422	217617	3836	20388
Taiwan	0.46	14	29444	217617	2728	20388
Germany	0.79	11	42651	217673	3901	21413
India	0.93	13	47363	141868	4362	13154
Indonesia	1.09	14	15430	141635	1440	13100
Italy	0.82	14	40870	194849	3693	18400
Japan	0.35	12	17334	217617	1650	20388
South Korea	0.6	13	31178	217673	2884	20776
Malaysia	0.76	13	41587	217673	3793	21413
Netherlands	0.78	12	31216	217673	2886	21413
Philippines	0.87	15	18115	217673	1737	20776
Saudi Arabia	0.76	11	80721	214286	7297	19630
Singapore	0.77	12	52721	217673	4858	21413
Spain	0.66	13	35327	217673	3219	20776
Thailand	0.79	12	22391	145647	2080	14052
Turkey	0.63	15	33910	153744	3075	15226
UAE	0.91	14	48162	217673	4354	20776
United Kingdom	0.73	13	37344	217673	3464	21413
USA	1	13	59644	171542	5326	14568
Viet Nam	0.97	13	21126	175343	1922	16020

Table 6.8: Port call and performance statistics: time spent in ports, vessel age and size, annual 2018

Source: UNCTAD secretariat calculations, based on data provided by MarineTraffic, and author elaborations

Container shipping companies request the loading and unloading of their ships to be performed in the fastest possible times in order to minimise costs and to keep vessels on restricted schedules to avoid delays in the overall schedule (Stahlbock and Voss, 2008). A shorter time in port therefore suggests a positive level of port efficiency and trade competitiveness and in turn this is a positive indicator for a port’s performance, as ships tend to spend less time in more efficient ports.

Among the 24 countries in the sample, the fastest median turnaround time was in Japan at 0.34 days, followed by Taiwan at 0.44 days, Hong Kong at 0.52 days and China and Tukey both at 0.62 days. The longest average time in port was in Australia at 1.2 days, followed by the United States at 1 day, Indonesia at 1.09 days and Belgium at 1.02 days. Turkey and the Philippines recorded the highest average age of ships, while Indonesia recorded the smallest average size of vessel. Asia is therefore the region with the most countries in the sample scoring the fastest median turnaround times, while ports in European countries score an average of 0.78 days.

6.6 Container Port Performance Index (CPPI)

One major challenge to stimulating improvement of port performance has been the lack of a comparable, consistent and reliable basis on which operational performance across different ports can be compared (World Bank and IHS Markit, 2021). The Container Port Performance Index (CPPI 2020), generated by the World Bank’s Transport Global Practice in collaboration with IHS Markit present in a reliable and robust manner. The Index intends to identify opportunities for improvement and gaps that will benefit stakeholders from consumers to national governments to shipping lines. The analysis of the CPPI is based on total port hours per ship call, defined as the time in between when a vessel reaches a port to its departure from the berth having its operations completed. CPPI 2020 uses data up to the end of the June 2020, and includes ports that had, within a six-month period in the previous twelve months, a minimum of 10 valid port calls. The focus of CPPI is solely on quayside performance to be reflective of the ship operator’s experience, which is the main customer of the port.

To account for critical differences in ship calls driven by: (i) lesser or greater workloads; and (ii) larger or smaller capacity ships, the calls were analysed in ten narrow call size groups and five ship size groups (Appendix A). The CCPI was developed on the basis of two different methodological approaches, namely a statistical approach using factor analysis (FA); and an administrative approach using a pragmatic methodology that reflects expert judgement and knowledge. It is based on two different approaches to ensure that the rankings of container port performance reflected as accurately as possible actual port performance, while simultaneously being statistically robust.

The use of FA generates a statistic (total score) which equals the sum of weighted average of indices for each of the same vessel sizes. The indices for each vessel size are an estimate of the time expired in the port and a number of unknown factors, which cannot be seen but do impact on port performance. The total scores are standardised, with a negative score indicating a better performance than the average. On the other hand, the administrative approach is constructed based on index points, which is an aggregate of the port’s performance weighted relative to the average across call and vessel size. Therefore, the score can be negative, when a port compares poorly to the average on one vessel size and call size category. Neither methodology is better than the other, and therefore the author considers both rankings for this analysis. Out of the 502 ports of which IHS Markit receives port call information, a total of 352 ports are included in the CPPI 2020. From the 71 ports included in the sample for this research (Table 5.1), 65 of these can be found in the CPPI 2020. The ports of Ghent, Amsterdam, Moerdijk, Chennai, Shenzhen and Khor Fakkan are *not* included in the CPPI 2020. The author extracted the ports that are included in the sample for this research from the overall CPPI 2020 and compiled the data in Table 6.9.

Statistical Approach				Administrative Approach		
Port Name	**Rank**	**Total score**		**Port Name**	**Rank**	**Index Points**
Yokohama	1	-5.995		Yokohama	1	130
Guangzhou	2	-5.162		Qingdao	2	102
Kaohsiung	3	-4.669		Kaohsiung	3	99
Hong Kong	4	-4.276		Guangzhou	4	92
Qingdao	5	-3.860		Hong Kong	5	89
Algeciras	6	-3.597		Zhoushan	6	88
Tanjung Pelepas	7	-3.342		Tanjung Pelepas	7	86
Port Klang	8	-3.334		Singapore	8	83
Singapore	9	-3.279		Port Klang	9	78
Kobe	10	-3.127		Taipei	10	75
Zhoushan	11	-2.963		Cai Mep	11	68
Jubail	12	-2.898		Dalian	12	66
Yosu	13	-2.831		Tianjin	13	64
Khalifa	14	-2.795		Khalifa	14	60
Taipei	15	-2.681		Xiamen	15	58
Dalian	16	-2.506		Algeciras	16	53
Incheon	17	-2.422		Busan	17	51
Tokyo	18	-2.418		Incheon	18	51
Bremerhaven	19	-2.265		Yosu	19	48
Cai Mep	20	-1.932		Jeddah	20	46
Mundra	21	-1.902		Mundra	21	43
Busan	22	-1.887		Barcelona	22	42
Jeddah	23	-1.862		Rio Grande	23	42
Laem Chabang	24	-1.807		Shanghai	24	41
Jawaharlal Nehru	25	-1.786		Kobe	25	39
Ambarli	26	-1.783		Laem Chabang	26	39
Xiamen	27	-1.541		Wilhelmshaven	27	39
Shanghai	28	-1.532		Tokyo	28	38
Tanjung Priok	29	-1.521		Jubail	29	33
Santos	30	-1.376		Jebel Ali	30	33
Rio Grande	31	-1.332		Ambarli	31	32
Barcelona	32	-1.224		Jawaharlal Nehru	32	31
London	33	-1.117		Antwerp	33	31
Antwerp	34	-1.011		Tanjung Priok	34	31
Zeebrugge	35	-0.988		Santos	35	28
New York & New Jersey	36	-0.969		Mersin	36	25
Taichung	37	-0.814		Bremerhaven	37	24
Dammam	38	-0.737		Rotterdam	38	22
Batangas	39	-0.663		Dammam	39	20
Rotterdam	40	-0.611		Paranagua	40	16
Wilhelmshaven	41	-0.598		New York & New Jersey	41	10
Saigon	42	-0.375		Batangas	42	8
Penang	43	-0.367		Taichung	43	8
Gioia Tauro	44	-0.344		Saigon	44	7
Davao	45	-0.341		Davao	45	6
Tanjung Perak	46	-0.269		Tanjung Perak	46	3
Belawan	47	0.104		London	47	1
Mersin	48	0.275		Hamburg	48	0
Tianjin	49	0.310		Belawan	49	-2
La Spezia	50	5.548		Gioia Tauro	50	-4
Brisbane	51	0.569		Zeebrugge	51	-6
Paranagua	52	0.659		Penang	52	-7
Bangkok	53	1.024		Brisbane	53	-8
Izmir	54	1.136		Bangkok	54	-15
Hamburg	55	1.176		Izmir	55	-18
Valencia	56	1.211		Manila	56	-19
Southampton	57	1.404		La Spezia	57	-24
Melbourne	58	1.676		Valencia	58	-34
Felixstowe	59	2.006		Melbourne	59	-40
Genoa	60	2.420		Suthampton	60	-45
Manila	61	2.445		Felixstowe	61	-55
Jebel Ali	62	2.482		Port Botany	62	-63
Los Angeles	63	2.889		Genoa	63	-74
Long Beach	64	3.175		Los Angeles	64	-82
Port Botany	65	3.907		Long Beach	65	-96

Table 6.9: Ranking of ports in the sample according to CPPI 2020

Source: CPPI 2020 (World Bank and IHS Markit, 2021) and author elaborations

In general, a broad consistency emerges between the two approaches, with only some exceptions, with Jebel Ali and Tianjin reflecting significant discrepancies. The top ranked container port in the sample, based on CPPI 2020, is Yokohama port in Japan, for both approaches. East Asian ports dominate the first places, with Algeciras port in Spain being the highest ranked port in Europe in the statistical approach, followed by Bremerhaven in Germany. Algeciras is the highest ranked European port also for the administrative approach, followed this time by Barcelona in Spain.

Conversely, the lowest ranked ports are found in the US and Australia, as ports of Los Angeles, Long Beach and Port Botany are found in the lowest rankings in both approaches. The three lowest positions are complimented by Jebel Ali in the statistical approach and Genoa port in the administrative approach, accordingly.

Table 6.10 includes the overall characteristics for the ports in the sample, namely median time in port (days), automation, TEUs handled, berth length, terminal area, draught, gantry cranes, and CPPI 2020 scores and index points for both approaches, in order to bring together all of the key information pertaining to the ports in our research sample.

Country	Median Time in Port (days) 2018	Port Name	Automation	TEU	Berth Length (m)	Terminal Area (sqm)	Draught	Gantry cranes	CPPI Stat. Approach 2020	CPPI Admin. Approach 2020
Belgium	1.02	Antwerp	Semi	10500000	9041	5481073	14.8	81	-1.011	31
		Zeebrugge	No	1520000	1405	480000	16.0	7	-0.988	-6
		Ghent	No	30290	712	250000	12.5	2	Not in CPPI	Not in CPPI
Germany	0.79	Bremerhaven	No	5509000	4930	3000000	14.5	26	-2.265	24
		Hamburg	Fully/semi	8860000	7702	4200000	15.6	79	1.176	0
		Wilhelmshaven	No	481720	1725	1300000	18.0	8	-0.598	39
Italy	0.82	Genoa	No	2620000	3281	1613000	14.1	21	2.420	-74
		Gioia Tauro	No	2450000	1755	1600000	15.5	22	-0.344	-4
		La Spezia	No	1473000	2005	371000	12.3	17	5.548	-24
Spain	0.66	Algeciras	Semi	4389836	3236	1027740	15.5	26	-3.597	53
		Barcelona	Semi	3010000	2862	1600000	15.3	24	-1.224	42
		Valencia	No	4779749	4222	1803114	14.8	38	1.211	-34
Turkey	0.63	Ambarli	No	3122504	4554	522338	14.3	38	-1.783	32
		Mersin	No	1550000	1912	220000	11.3	16	0.275	25
		Izmir	No	4555038	1410	152000	13.0	12	1.136	-18
Netherlands	0.78	Amsterdam	No	56191	586	15000	8.8	3	Not in CPPI	Not in CPPI
		Rotterdam	Fully	13730000	15418	7839000	13.2	122	-0.611	22
		Moerdijk	No	500000	1378	230000	9.0	2	Not in CPPI	Not in CPPI
United Kingdom	0.73	Felixstowe	No	4300000	3274	1841000	14.7	33	2.006	-55
		London	Semi	2450000	3155	2144525	14.3	21	-1.117	1
		Southampton	No	2000000	1895	1000000	14.8	17	1.404	-45
Japan	0.35	Kobe	No	2910000	5300	1604080	14.5	31	-3.127	39
		Tokyo	Semi	4730000	4675	1521520	13.0	34	-2.418	38
		Yokohama	No	2930000	5013	1934900	15.0	46	-5.995	130
Saudi Arabia	0.76	Dammam	No	1580000	2740	1910000	15.0	23	-0.737	20
		Jeddah	No	4150000	4435	2906000	15.8	45	-1.862	46
		Jubail	No	326258	1000	457219	14.0	5	-2.898	33
Brazil	0.81	Paranagua	No	782348	426	302800	12.0	12	0.659	16
		Rio Grande	No	684903	900	735000	12.1	9	-1.332	42
		Santos	No	3854000	5207	1623000	13.8	34	-1.376	28
Australia	1.2	Brisbane	Semi	1224829	2495	1020000	14.0	13	0.569	-8
		Melbourne	Fully	2800000	2188	1244000	14.2	21	1.676	-40
		Port Botany Sydney	Fully/semi	2431737	3637	1510000	15.1	19	3.907	-63
India	0.93	Chennai	No	1494831	1717	530600	14.2	14	Not in CPPI	Not in CPPI
		Jawaharlal Nehru	No	4833397	3320	2217600	13.8	40	-1.786	31
		Mundra	No	4110000	2722	640000	14.9	22	-1.902	43
South Korea	0.6	Busan	Semi	20470000	12515	7091000	15.0	128	-1.887	51
		Incheon	Semi	3050000	2683	1346262	13.1	19	-2.422	51
		Yosu	No	2220000	4598	1906000	14.5	30	-2.831	48
China	0.62	Ningbo - Zhoushan	No	26000000	9626	3149000	16.5	104	-2.963	88
		Qingdao	Fully	18300000	7273	4300000	17.2	62	-3.860	102
		Shanghai	Fully	40300000	13664	11219298	13.6	158	-1.532	41
		Shenzhen	No	26000000	17720	7045000	14.7	185	Not in CPPI	Not in CPPI
		Guangzhou	No	20300000	7087	4168000	11.1	41	-5.162	92
		Tianjin	Fully	15200000	8414	3751000	14.6	89	0.310	64
		Xiamen	Fully	10300000	8818	3650100	15.1	56	-1.541	58
		Dalian	No	9900000	4334	1471896	14.8	33	-2.506	66
United States	1	Long Beach	Fully	7544507	8184	5223000	14.8	89	3.175	-96
		Los Angeles	Fully	9340000	10009	6884000	13.5	79	2.889	-82
		New York & New Jersey	Semi	6700000	9919	6260000	12.9	58	-0.969	10
Indonesia	1.09	Belawan	No	320515	950	158464	11.0	5	0.104	-2
		Tanjung Perak/Surabaya	Semi	3318550	3920	513110	11.0	32	-0.269	3
		Tanjung Priok/Jakarta	No	6070000	3170	993000	14.2	31	-1.521	31
Singapore	0.77	Singapore	Semi	33700000	19710	8170000	13.8	208	-3.279	83
Hong Kong	0.54	Hong Kong	No	20770000	10691	3437500	14.6	125	-4.276	89
Malaysia	0.76	Port Klang	No	11980000	8266	1450000	14.8	84	-3.334	78
		Tanjung Pelepas	No	8377243	5040	1800000	16.3	57	-3.342	86
		Penang Port	No	1520000	1620	425000	11.5	13	-0.367	-7
Taiwan	0.46	Kaohsiung	Semi	10271018	7957	750000	14.2	62	-4.669	99
		Taichung	No	1660663	2380	530950	13.8	15	-0.814	8
		Taipei	Semi	1561743	1355	1110000	16.0	13	-2.681	75
Vietnam	0.97	Ho Chi Minh City/Saigon	No	5940000	1598	454050	10.7	13	-0.375	7
		Cai Mep	No	2440000	3120	2167000	14.6	27	-1.932	68
Thailand	0.79	Laem Chabang	No	7780000	6399	2630240	14.6	48	-1.807	39
		Bangkok	No	1950000	1229	148200	8.2	14	1.024	-15
United Arab Emirates	0.91	Dubai/Jebel Ali	Semi	15400000	10705	4020000	15.8	117	2.482	33
		Khor Fakkan	No	4000000	1460	700000	16.0	24	Not in CPPI	Not in CPPI
		Khalifa Port	Semi	1530000	1200	89475	15.0	12	-2.795	60
Philippines	0.87	Manila	No	4820000	2527	1374000	10.6	18	2.445	-19
		Davao	No	594497	1095	88000	10.0	4	-0.341	6
		Batangas	No	200255	450	150000	15.0	2	-0.663	8

Table 6.10: Overall Table with world's major container ports key characteristics

Source: Author elaborations, CPPI 2020, UNCTAD secretariat calculations based on data provided by MarineTraffic

Notably, although Australia and the United States have high levels of automation in their ports, they score quite low in the CPPI. It is often assumed that ports with automation are more productive than their counterparts. However, in general, automated ports are not more productive and efficient than their conventional counterparts, as port specialisation and organisation, as well as port size and geographical location are more significant determinants of port performance than automation (ITF, 2021). This fact might probably be the reason why the adoption of automation by container ports across the world is still very limited to date.

The effects of port automation are also ambiguous on port efficiency, as from Table 6.10, and since median time spent in port is taken as a proxy for efficiency, it is also obvious that countries with a high degree of automation in their ports do not appear to score a fast median turnaround time. Australia and the US have the longest average times spent in port, although their 3 ports in the sample all have some degree of automation.

6.7 Conclusion

This Chapter presented the key characteristics of the world's leading container ports and the patterns that arose from their performance indicators. The contributions from this analysis include: (1) to identify best performing ports as exemplars to lower performing counterparts, in order to help them optimise their performance by following their strategies; (2) to explore how container ports geographical location and level of automation can affect their efficiency and performance; (3) to inform policy-makers and decision-makers, both political and commercial, that they should carefully investigate their own specific situation and set of circumstances when deciding to invest in port infrastructure. This also suggests that port managers should primarily focus on improving their management practices based on the market requirements of container ports, and then container ports can achieve their objectives and be subject to improving their efficiencies.

Key insights – key characteristics of the world's main container ports

- Asia is the region with the most countries in the sample scoring the fastest median turnaround times.
- Higher automation levels were found in Australia, the United States, in Chinese ports and at the port of Rotterdam in the Netherlands.
- East Asian ports dominate port performance rankings, according to CPPI 2020 for the ports in the sample, with Algeciras port in Spain being the highest ranked port in Europe for both the statistical and administrative approaches.

- In general, automated ports are not more productive and efficient than their conventional counterparts, as port specialisation and organisation, as well as port size and geographical location are more significant determinants of port performance than automation.

Chapter 7. Website Content Analysis

7.1 Introduction

In Chapter 6 the researcher discussed the patterns that arose from the analysis of the performance of the world's leading container ports and answered RQ3. In this Chapter, the researcher addresses RQ1 and investigates, in combination with the Literature Review presented in Chapter 2 and the preliminary interviews conducted reported in Chapter 4, the latest technologies and smart, green and sustainability related practices adopted in ports. For this purpose, a Website Content Analysis was conducted to explore to what extent, if any, the world's major ports disclose information in their corporate websites focusing on their smart, green and sustainability related practices and efforts. This Chapter will therefore benchmark the world's major ports with regards to their smart status and derive results to classify them according to their website disclosure and reported practices.

7.2 Sample

The development of smart ports is a pivotal progress in the application of emission reduction, energy conservation and adoption of intelligent technologies in the context of global maritime shipping sectors and ports (Chen, 2019). This phase of the research aims to explore the strategies adopted by major ports and to benchmark their current smart status and to analyse the inherent relationships among various structural factors that formulate the concept of a smart port, based on their corporate website disclosure.

To analyse the disclosure of the specific predefined factors per port, which will be described in Section 7.3, the Website Content Analysis technique was applied. Website CA is the most suitable method for identifying themes, patterns and categories in the case of new and emerging subjects, and was performed across the selected ports to analyse their status with regards to technologies adopted and smart, green and sustainability related practices (Schreier, 2012; Yoon et al., 2020). A total of 71 ports were analysed, through their websites, to investigate the extent to which each port perceives and adopts the current trends in smart, green and sustainable port operation and development. The sample of ports used was the same with the one used in Chapter 6, for consistency purposes within the research.

As described in Chapter 6, the sample of ports comprised of the top 3 ports by TEU throughput, of each of the top 20 countries ranked by UNCTAD, according to their total container port throughput for the year 2017. The researcher, to include all major container ports in the world, added to the sample 6 further container ports from China ranked among the leading 20 global container ports for 2017 according to UNCTAD. Moreover, with the aim of including as many ports as possible, the author collected data also for the top 3 ports of the next 4 countries (no 21-24 in UNCTAD ranking), namely Turkey, Saudi Arabia, Philippines and Australia. The ports included in Vietnam and Thailand, due to lack of data, are only the top 2 for each country instead of the top 3. Thus, the sample consists of 71 ports, and incorporates both large and medium-sized ports. The scope of the analysis is also wide as it covers ports from five trade regions, namely Europe, Asia, South America, North America and Oceania.

7.3 Data Collection

A significant number of studies have used content analysis to analyse corporate websites, recording the presence - or absence - and the number of words dedicated to specific topics (Kim et al. 2010; Halpern et al., 2013; Santos et al. 2016; Hasim et al. 2018; Yoon et al. 2020; Rafiq et al., 2021). First, a web search was undertaken to identify ports with a website from the total of 71 ports in the sample, through which 64 websites were identified. More specifically, from the 71 ports included in the sample only 2 ports, namely Xiamen port in China and Taipei port in Taiwan did not have a corporate port website. Moreover, the data for the 3 ports in the Philippines, namely Manila, Davao and Batangas, was collected from the Philippines Port Authority website and was the same for all 3 ports. Likewise, the data for the 2 ports in Thailand, was collected from the Port Authority of Thailand and was the same for both ports. Finally, the same was also valid for the 3 ports in Saudi Arabia, where the data for all 3 ports was collected from Saudi Ports Authority. Thus, taking into account that for 3 countries, their ports were all listed under the same website, the websites that were analysed were 64 in total.

The overall port or port authority were targeted for the Website CA, instead of the terminal operators' websites, since the port authority and the affiliated government departments are the port developers, planners and promoters. Therefore, the data was collected from the official websites of the respective ports in the sample. The analysis is not based on terminal operators, because its focus is the ports' overall efforts regarding smart, green and sustainability related practices, and not those of individual companies or terminals.

To record the presence or absence of smart, green and sustainability related practices for each port, a list of 20 factors was created. A bullet point (●) was attributed when a factor was addressed within the webpages of each port’s website. The content of the standalone reports (such as annual reports, financial reports, etc.) incorporated in the port websites was excluded, but the presence or absence of Sustainability and Environmental reports was recorded.

The data collection from the websites of the sampled ports occurred between November 2019 and January 2020. The researcher downloaded the entire port websites using NCapture for NVivo and PDFmyURL.com, where NCapture was not suitable, and analysed their content using the NVivo 12 Pro qualitative analysis software. After downloading all the webpages and information included on the websites of each port, separate folders corresponding to each port website were created. Next, the ‘Text Search’ was used for each port’s folder to identify which of the predefined factors were addressed in each port.

To compare the 71 ports in terms of their endeavours with regards to smart port adoption, the researcher systematically investigated and compared the main aspects of smart port marketing in each port. The list of the 20 predefined factors used for the Website CA is presented in Table 7.1. The rationale for selecting and using these factors, was that studying the literature review, which is presented in Chapter 2 - and more specifically Section 2.2.3, Section 2.2.4 and Section 2.4.5, which describe the green port concept, the smart port concept and sustainability in ports - showed that these were the commonly used indicators and descriptors for smart, green and sustainability related practices within ports. These words/phrases were the most relevant for investigating the extent to which each port perceives and adopts the current trends in smart, green and sustainable port operation and development, and were also consistent with the research objectives of this analysis. Therefore, a checklist consisting of 20 factors grouped in 5 categories was created, as per Table 7.1 and Table 7.2.

Content Analysis of online communication	
1.	Sustainability in Menu Bar
2.	Environment in Menu Bar
3.	Digital-smart-innovation in Menu Bar
4.	Community-social-society in Menu Bar
5.	Sustainable matters in corporate mission/vision/values
6.	Environmental matters in corporate mission/vision/values
7.	Digital-smart-innovation matters in corporate mission/vision/values
8.	Community/social matters in corporate mission/vision/values
9.	Air monitoring
10.	Water monitoring
11.	Noise monitoring
12.	Energy monitoring
13.	Online standalone Sustainability Report
14.	Online standalone Environmental Report
15.	Environmental ISO 14001 Certification
16.	Existence of Renewable Energy sources in port (wind, solar, etc.)
17.	Shore-side power supply – cold ironing
18.	Fee incentives-reductions for clean vessels
19.	Port Community System
20.	Blockchain

Table 7.1: List of 20 factors used for the Website Content Analysis

The core question to be answered is: how do ports reflect in their websites their smart status, which if deconstructed consists of 5 main categories, namely: “Environment, Sustainability and Community”, “Monitoring”, “Certification and Reporting”, “Energy Sources and Incentives”, “Technology and Innovation”. Therefore, after identifying the 20 factors listed in Table 7.1, the researcher grouped them in 5 categories (Table 7.2) to perform the analysis of the results, namely:

1. Environment, Sustainability and Community (6 factors)
2. Monitoring (4 factors)
3. Certification and Reporting (3 factors)
4. Energy Sources and Incentives (3 factors)
5. Technology and Innovation (4 factors)

Category	Factors
Environment, Sustainability and Community	Environment in Menu Bar
	Environmental matters in mission/vision/values
	Sustainability in Menu Bar
	Sustainability matters in mission/vision/values
	Community/social/society in Menu Bar
	Social/community matters vision/mission/values
Monitoring	Air monitoring
	Water monitoring
	Noise monitoring
	Energy monitoring
Certification and Reporting	Online Standalone Environmental Report
	Environmental ISO 14001 Certification
	Online Standalone Sustainability Report
Energy Sources and Incentives	Renewable Energy Sources
	Shore-side power supply – cold ironing
	Fee incentives for clean vessels
Technology and Innovation	Digital/smart/innovation in Menu Bar
	Digital/smart/innovation matters in corporate mission/vision/values
	Port Community System
	Blockchain

Table 7.2: Categories and corresponding factors

The next step was to categorise the level of disclosure as “Nothing-N”, “Low-L”, “Medium-M”, “High-H”, in order to indicate the status of each port when it comes to smart port marketing. The objective was to highlight to what extent, if any, and in what ways the world’s major ports advertise their smart port initiatives. Hence, the level of a port’s extent of engagement in each category that forms the smart port concept, can be characterised accordingly.

The coding process for the level of disclosure and thus the extent of smart practice adoption follows to some extent the study by Santos et al. (2016). “H” represents high or significant effort into the corresponding category, “N” represents no effort in the category, while “L” and “M” represent low and medium engagement, respectively. Depending on the total number of factors included in each category, the level of adoption was classified as is depicted in Figure 7.1.

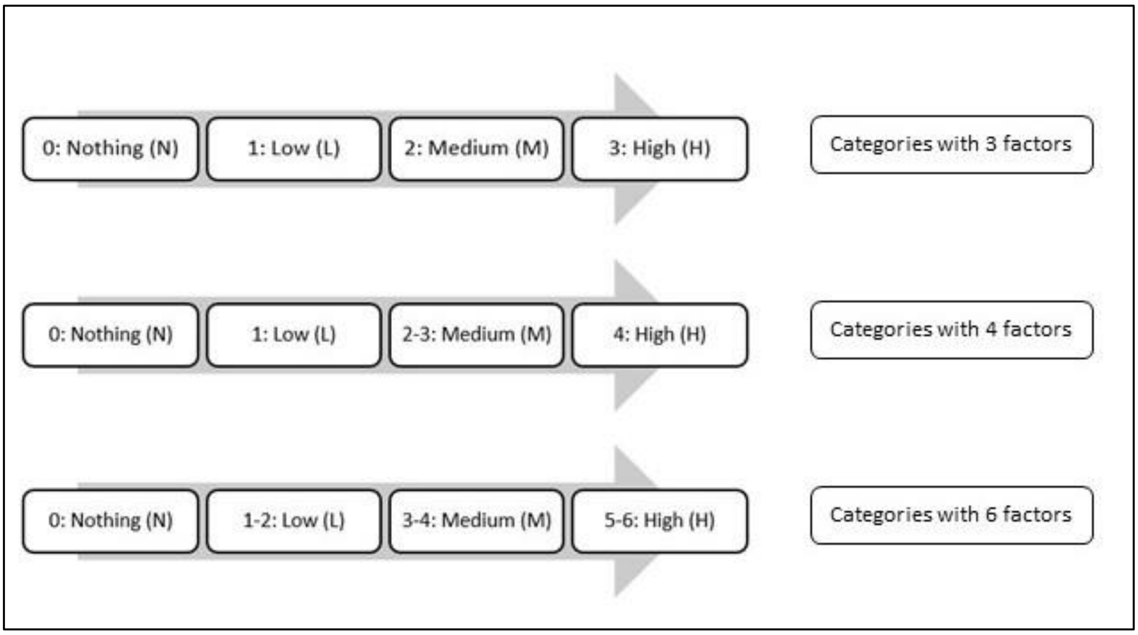

Figure 7.1: Coding of level of disclosure/adoption of smart practices

Every factor within the category is equally weighted, but not all factors across all categories are equally weighted, as each category has a different total number of factors that compose it. In other words, if for example a port is characterised as High level in the category "Certification and Reporting" it needs to score 3 out of 3 factors, while if a port is characterised as High level in the category "Environment, Sustainability and Community" it needs 5 or 6 factors.

7.4 Results – Data Analysis

Table 7.3 shows the results of the incidence of keywords that derived from the Website C.A.

COUNTRY	PORT	AUTOM.	MENU BAR				VISION/MISSION/VALUES				MONITORING				REPORTING		CERTIFIC.	RENEWABLE SOURCES & INCENTIVES			TECHNOLOGY	
			SUSTAINABILITY	ENVIRONMENT	DIGITAL-SMART	COMMUNITY	SUSTAINABLE	ENVIRONMENT	INNOVATION	COMMUNITY	AIR	WATER	NOISE	ENERGY	STAINABIL	IRONMEN	ISO 14001	RENEW. ENE	SHORE-SIDE	FEE INCENTIVES	P C SYSTEM	BLOCKCHAIN
BELGIUM	ANTWERP	SEMI	•	•	•	•	•	•	•	•	•	•			•			•	•		•	•
	ZEEBRUGGE		•		•		•		•	•								•	•	•	•	
	GHENT		•				•		•	•								•	•	•	•	
GERMANY	BREMERHAVEN			•				•										•		•		
	HAMBURG	FULLY/SEMI			•		•	•	•									•	•	•	•	
	WILHELMSHAVEN		•				•	•						•	•	•			•	•		
ITALY	GENOA			•			•	•	•	•	•	•	•	•			•	•	•		•	
	GIOIA TAURO																					
	LA SPEZIA			•			•	•	•	•	•	•						•	•		•	
SPAIN	ALGECIRAS	SEMI		•	•	•	•			•					•		•	•		•	•	
	BARCELONA	SEMI	•	•		•			•	•	•				•		•			•	•	
	VALENCIA			•		•	•	•		•	•	•	•			•	•			•	•	
TURKEY	AMBARLI						•	•	•	•												
	MERSIN			•		•			•								•					
	IZMIR																					
NETHERLANDS	AMSTERDAM		•		•	•	•	•	•	•	•	•	•		•			•	•		•	
	ROTTERDAM	FULLY	•	•	•	•	•	•	•	•					•			•	•	•	•	•
	MOERDIJK		•	•			•			•	•	•	•			•	•					
UK	FELIXSTOWE					•				•	•					•	•	•			•	
	LONDON	SEMI															•					
	SOUTHAMPTON		•					•	•		•							•				
CHINA	NINGBO ZHOUSHAN						•		•													
	SHENZHEN																					
	GUANGZHOU								•	•												
	XIAMEN	FULLY																				
	SHANGHAI	FULLY	•		•		•	•	•	•					•							
	QINQDAO	FULLY						•	•	•												
	TIANJIN							•	•	•												
	DALIAN																					
INDONESIA	BELAWAN								•	•												
	TANJUNG PERAK/	SEMI						•	•	•												
	TANJUNG PRIOK									•											•	
SINGAPORE	SINGAPORE	SEMI		•	•	•			•						•						•	
HONG KONG	HONG KONG																					
VIETNAM	HO CHI MINH						•															
	CAI MEP		•	•			•	•		•					•							
TAIWAN	KAOHSIUNG	SEMI									•	•				•			•	•		
	TAINGHUNG								•		•	•	•			•		•	•	•		
	TAIPEI	SEMI																				
PHILLIPINES	MANILA						•	•	•	•												
	DAVAO						•	•	•	•							•					
	BATANGAS						•	•	•	•												
MALAYSIA	KLANG						•	•		•	•	•							•		•	
	TANJUNG PELEPAS			•		•	•	•	•		•	•				•	•		•	•	•	
	PENANG							•														
SOUTH KOREA	BUSAN	SEMI					•		•	•					•							
	INCHEON	SEMI						•		•												
	YEOSU			•			•			•												
JAPAN	KOBE																					
	TOKYO	SEMI		•														•		•		
	YOKOHAMA							•		•												
INDIA	CHENNAI						•		•	•												
	JAWAHARLAL NEHRU		•			•	•		•		•	•				•	•	•			•	
	MUNDRA		•			•	•	•		•					•			•				
THAILAND	LAEM CHABANG					•	•	•	•		•	•										
	BANGKOK					•	•	•	•		•	•										
UAE	DUBAI JEBEL ALI	SEMI	•				•	•		•		•		•				•				
	KHOR FAKKAN						•	•	•	•							•					
	KHALIFA	SEMI	•	•	•	•	•		•		•	•			•		•				•	
SAUDI ARABIA	DAMMAM							•	•	•												
	JEDDAH							•	•	•												
	JUBAIL							•	•	•												
BRAZIL	PARANAGUA			•		•	•	•			•	•	•									
	RIO GRANDE			•			•	•		•		•	•			•		•			•	
	SANTOS																				•	
US	LONG BEACH	FULLY	•	•		•	•	•	•	•	•	•				•		•	•	•		
	LOS ANGELES	FULLY	•	•		•	•	•		•	•	•			•		•	•	•	•	•	
	NY NJ	SEMI	•				•	•	•	•	•						•		•	•		
AUSTRALIA	BRISBANE	SEMI	•			•	•	•	•		•	•			•	•	•	•				
	MELBOURNE	FULLY	•	•		•	•		•	•					•		•					
	BOTANY	FULLY/SEMI	•	•		•	•				•	•	•		•			•		•		
		TOTAL	21	22	9	21	40	38	39	41	23	21	8	3	16	11	17	22	16	17	21	2

Table 7.3: Results from Website Content Analysis

This phase investigated the ports' status and analysed the disclosure of smart, green and sustainability related content of the world's major ports' websites. To identify patterns and trends arising from the results of the Website Content Analysis and to benchmark the smart status of the various ports, only simple scoring and comparison was used, as other types of analysis such as cross-case analysis was not considered.

Next, the researcher totalled the sum of factors that each port scored in each category and then labelled the corresponding level of adoption in accordance with the rubric outlined in Figure 5.1: Nothing (N), Low (L), Medium (M), High (H). To assess the *overall effort of all port cases (industry level)* in each aspect of each category, the researcher counted *vertically* the number of bullets ("•"). On the other hand, to assess *the efforts of each individual port (individual port level)*, the researcher counted *horizontally* the number of bullets ("•"), and next depending on the sum of factors-bullets, characterised the port with the respective level of adoption (N, L, M, H). Finally, the author has highlighted with green colour the ports that scored a High (H) level in each category.

7.4.1 Results for "Environment, Sustainability and Community" category

There are in total 6 factors included in the category "Environment, Sustainability and Community", as described in Table 7.2. The efforts in environmental, sustainability and community/social-oriented strategies can be sought from a port's vision, mission, values statements and goals. The port's top management team lays down these statements, setting the direction of the port, of whether environmental, sustainability, community/social responsibility is being considered in its development and operations. The overall port strategy was examined through these statements found in each port's website. The level of importance that the port gives to these specific aspects can also be represented through the use or not of the tabs Environment, Sustainability, Community / social / society in the port websites' Menu Bar. The researcher in Table 7.4 below has listed the sum of factors that each port scored in the 1st category.

COUNTRY	PORT	MENU BAR			VISION/MISSION/VALUES			TOTAL=6	
		SUSTAINAB.	ENVIRON.	COMMUN.	SUSTAINAB.	ENVIRON.	COMMUN.	SUM OF FACTORS	LEVEL OF PORT
BELGIUM	ANTWERP	●	●	●	●	●	●	6	H
	ZEEBRUGGE	●			●		●	3	M
	GHENT	●			●		●	3	M
GERMANY	BREMERHAVEN		●			●		2	L
	HAMBURG				●	●		2	L
	WILHELMSHAVEN	●			●	●		3	M
ITALY	GENOA		●		●	●	●	4	M
	GIOIA TAURO							0	N
	LA SPEZIA		●		●	●	●	4	M
SPAIN	ALGECIRAS		●	●	●		●	4	M
	BARCELONA	●	●	●			●	4	M
	VALENCIA		●	●	●	●	●	5	H
TURKEY	AMBARLI				●	●	●	3	M
	MERSIN		●	●				2	L
	IZMIR							0	N
NETHERLANDS	AMSTERDAM	●		●	●	●	●	5	H
	ROTTERDAM	●	●	●	●	●	●	6	H
	MOERDIJK	●	●		●		●	4	M
UK	FELIXSTOWE			●			●	2	L
	LONDON							0	N
	SOUTHAMPTON	●				●		2	L
CHINA	NINGBO ZHOUSHAN				●			1	L
	SHENZHEN							0	N
	GUANGZHOU						●	1	L
	XIAMEN							0	N
	SHANGHAI	●			●	●	●	4	M
	QINQDAO					●	●	2	L
	TIANJIN					●	●	2	L
	DALIAN							0	N
INDONESIA	BELAWAN						●	1	L
	TANJUNG PERAK/SURABAYA					●	●	2	L
	TANJUNG PRIOK						●	1	L
SINGAPORE	SINGAPORE		●	●				2	L
HONG KONG	HONG KONG							0	N
VIETNAM	HO CHI MINH				●			1	L
	CAI MEP	●	●		●	●	●	5	H
TAIWAN	KAOHSIUNG							0	N
	TAINGHUNG							0	N
	TAIPEI							0	N
PHILLIPINES	MANILA				●	●	●	3	M
	DAVAO				●	●	●	3	M
	BATANGAS				●	●	●	3	M
MALAYSIA	KLANG				●	●	●	3	M
	TANJUNG PELEPAS		●	●	●	●		4	M
	PENANG					●		1	L
SOUTH KOREA	BUSAN				●		●	2	L
	INCHEON					●	●	2	L
	YEOSU		●		●		●	3	M
JAPAN	KOBE							0	N
	TOKYO		●					1	L
	YOKOHAMA					●	●	2	L
INDIA	CHENNAI				●		●	2	L
	JAWAHARLAL NEHRU	●		●	●			3	M
	MUNDRA	●		●	●	●	●	5	H
THAILAND	LAEM CHABANG			●	●	●		3	M
	BANGKOK			●	●	●		3	M
UAE	DUBAI JEBEL ALI	●			●	●	●	4	M
	KHOR FAKKAN				●	●	●	3	M
	KHALIFA	●	●	●	●			4	M
SAUDI ARABIA	DAMMAM					●	●	2	L
	JEDDAH					●	●	2	L
	JUBAIL					●	●	2	L
BRAZIL	PARANAGUA		●	●	●	●		4	M
	RIO GRANDE		●		●	●	●	4	M
	SANTOS							0	N
US	LONG BEACH	●	●	●	●	●	●	6	H
	LOS ANGELES	●	●	●	●	●	●	6	H
	NY NJ	●			●	●	●	4	M
AUSTRALIA	BRISBANE	●		●	●	●		4	M
	MELBOURNE	●	●	●	●		●	5	H
	BOTANY	●	●	●	●			4	M
	TOTAL (industry level)	21	22	21	40	38	41		

Table 7.4: Results for “Environment, Sustainability and Community” category

Based on Table 7.4, when considering the industry level for each factor included in the category, results show that 40 ports, more than half of the ports in the sample, included sustainability and sustainable development in their mission statement, while 38 and 41 respectively, included environment and community/social matters in their mission and strategy. They have thus emphasised the goal to achieve green and sustainable port status in the long-run and to be socially responsible and engaged with the community. It can also be seen that the majority of the large ports in the industry, such as Shanghai, Dubai/Jebel Ali, Rotterdam, Klang, Antwerp, Los Angeles, Tanjung Pelepas and Laem Chabang, ranked among the top 20 ports by TEU in 2017 (UNCTAD, 2018), are significantly interested in setting as priority in their vision/mission/values the aspects of environment, sustainability and community/social responsibility. These ports have scored either Medium or High level of disclosure of the factors in this category.

Firstly, if focused on the environmental and sustainability information and practices, findings reveal that ports in Europe, United States (US) and Australia tended to be leaders, since they include more factors on environmental and sustainability communication in terms of the level of disclosure. More specifically, European, Australian and US ports, compared to Asian ports, scored higher as almost all of them, with the exception of Gioia Tauro in Italy, Izmir in Turkey and London in UK, scored mostly Medium and High levels of disclosure. The port of Mundra, the largest private port in India, also makes significant efforts towards being green and sustainable in the long run, as it scores 5 factors in this category and thus a High level of effort.

The ports that presented the highest levels of green and sustainable communication in their mission/vision/values statement, as well as through the inclusion of Menu Bars for all 3 factors in the category, were the ports of Los Angeles and Long Beach in US, the port of Rotterdam in Netherlands and the port of Antwerp in Belgium. These ports scored 6 out of 6 factors in this category. In general, it is observed that ports in Europe show a high level of consideration in these aspects in their long-term plans, as most ports located in Europe scored either High or Medium levels of disclosure, with only 5 ports scoring a Low level, namely Bremerhaven and Hamburg in Germany, Mersin in Turkey and Felixstowe and Southampton in the UK.

Next, Table 7.5 and Figure 7.2 represent the total number of ports that scored either N, L, M, or H levels across the industry. The 3rd column in Table 5.5 represents the percentage of ports that scored N, L, M, H in this category out of the total percentage of ports in the sample.

TOTAL	ENVRONMENT, SUSTAINABILITY & COMMUNITY	% OF PORTS OUT OF TOTAL
TOTAL OF NOTHING LEVEL	12	16.90%
TOTAL OF LOW LEVEL	23	32.39%
TOTAL OF MEDIUM LEVEL	27	38.03%
TOTAL OF HIGH LEVEL	9	12.68%
TOTAL # OF PORTS	71	100%

Table 7.5: Sum of N, L, M, H level of adoption for “Environment, Sustainability and Community” category

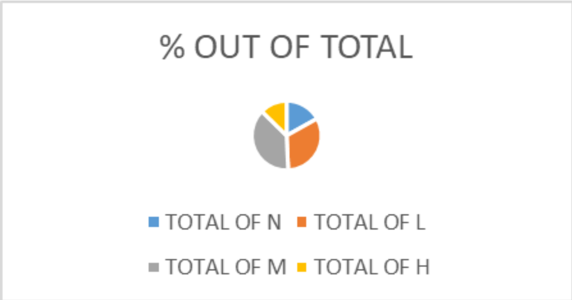

Figure 7.2: Pie chart of the percentage of N, L, M, H out of the total for the 1st category

As indicated in Table 7.5, more than half of the ports include a Medium or High level of disclosure of the factors included in the category “Environment, Sustainability and Community”. Results show that 27 ports or 38% of the ports have Medium level of disclosure with 3 or 4 factors out of 6, while 13% of the ports have High level of disclosure with 5 or 6 factors. This reflects that ports currently have an active approach towards being green, sustainable, and community-oriented, setting as primary these strategic objectives. The pressure to become greener, sustainable and to have an active corporate social responsibility towards the community, have become pivotal strategies set by ports of the world to respond to the current goals set by the International Maritime Organisation (IMO) for zero emissions, the United Nations (UN) for sustainable development goals and by the shipping industry as a whole.

Moreover, there are 23 ports or 32% that only score 1 or 2 (L level) of the 6 factors included in the category. These findings reveal that a significant amount of ports, 25 or 35% are not significantly engaging these aspects in their strategy statement and have not included these sections in their Menu Bars. Finally, a small percentage of ports, 17% have no level of disclosure when it comes to the factors in the category.

7.4.2 Results for "Monitoring" category

There are in total 4 factors included in the category "Monitoring". Nowadays, ports effectively commit themselves to improving their air quality, thus contributing to minimal transboundary emissions. Through monitoring the air, ports can take responsibility and act towards air quality improvement measures to minimise air pollution in the port area and the port city. Moreover, monitoring the water quality in the docks at regular intervals is also one of the pivotal actions taken by the Port Authorities, as checks need to be carried out to ensure compliance with environmental quality standards with significant attention given to chemical and dangerous substances.

Additionally, sound meters can monitor the levels of noise pollution generated by port operations to improve the operations that generate the vast percentage of noise emissions, while the improvement and optimisation of energy efficiency can be achieved through precise energy consumption monitoring. Table 7.6 below shows the scores for the factors in the 2nd category.

COUNTRY	PORT	MONITORING				TOTAL=4	
		AIR	WATER	NOISE	ENERGY	SUM OF FACTORS	LEVEL OF PORT
BELGIUM	ANTWERP	●	●			2	M
	ZEEBRUGGE					0	N
	GHENT					0	N
GERMANY	BREMERHAVEN					0	N
	HAMBURG					0	N
	WILHELMSHAVEN				●	1	L
ITALY	GENOA	●	●	●	●	4	H
	GIOIA TAURO					0	N
	LA SPEZIA	●	●			2	M
SPAIN	ALGECIRAS					0	N
	BARCELONA	●				1	L
	VALENCIA	●	●	●		3	M
TURKEY	AMBARLI					0	N
	MERSIN					0	N
	IZMIR					0	N
NETHERLANDS	AMSTERDAM	●	●	●		3	M
	ROTTERDAM					0	N
	MOERDIJK	●	●	●		3	M
UK	FELIXSTOWE	●				1	L
	LONDON					0	N
	SOUTHAMPTON	●				1	L
CHINA	NINGBO ZHOUSHAN					0	N
	SHENZHEN					0	N
	GUANGZHOU					0	N
	XIAMEN					0	N
	SHANGHAI					0	N
	QINQDAO					0	N
	TIANJIN					0	N
	DALIAN					0	N
INDONESIA	BELAWAN					0	N
	TANJUNG PERAK/SURABAYA					0	N
	TANJUNG PRIOK					0	N
SINGAPORE	SINGAPORE					0	N
HONG KONG	HONG KONG					0	N
VIETNAM	HO CHI MINH					0	N
	CAI MEP					0	N
TAIWAN	KAOHSIUNG	●	●			2	M
	TAINGHUNG	●	●	●		3	M
	TAIPEI					0	N
PHILIPPINES	MANILA					0	N
	DAVAO					0	N
	BATANGAS					0	N
MALAYSIA	KLANG	●	●			2	M
	TANJUNG PELEPAS	●	●			2	M
	PENANG					0	N
SOUTH KOREA	BUSAN					0	N
	INCHEON					0	N
	YEOSU					0	N
JAPAN	KOBE					0	N
	TOKYO					0	N
	YOKOHAMA					0	N
INDIA	CHENNAI					0	N
	JAWAHARLAL NEHRU	●	●			2	M
	MUNDRA					0	N
THAILAND	LAEM CHABANG	●	●			2	M
	BANGKOK	●	●			2	M
UAE	DUBAI JEBEL ALI		●		●	2	M
	KHOR FAKKAN					0	N
	KHALIFA	●	●			2	M
SAUDI ARABIA	DAMMAM					0	N
	JEDDAH					0	N
	JUBAIL					0	N
BRAZIL	PARANAGUA	●	●	●		3	M
	RIO GRANDE		●	●		2	M
	SANTOS					0	N
US	LONG BEACH	●	●			2	M
	LOS ANGELES	●	●			2	M
	NY NJ	●				1	L
AUSTRALIA	BRISBANE	●	●			2	M
	MELBOURNE					0	N
	BOTANY	●	●	●		3	M
	TOTAL	23	21	8	3		

Table 7.6: Results for “Monitoring” category

As far as the air, water, noise and energy monitoring is concerned, results show that 23 ports monitor their air quality, 21 ports monitor their water quality, 8 ports monitor their noise levels, while only 3 ports monitor their energy. There is a clear predominance of air quality monitoring, which suggests that ports aim to minimise their air pollution impact and reduce their carbon footprint. On the other hand, the aspect that is less monitored is energy performance with only 3 ports monitoring it, namely Wilhelmshaven in Germany, Genoa in Italy, and Dubai/Jebel Ali in UAE.

Interestingly, none of the ports located in China report any monitoring of air, water, noise and energy in their corporate websites. Similarly, most Asian ports do not report to monitor their air, water, noise and energy levels, as ports located in Indonesia, Vietnam, Singapore, Hong Kong, Philippines, South Korea, Japan and Saudi Arabia do not report any monitoring. On the contrary ports in Europe, Brazil, US, and Australia report mostly Medium levels of monitoring.

TOTAL	MONITORING	% OF PORTS OUT OF TOTAL
TOTAL OF N	45	63.38%
TOTAL OF L	5	7.04%
TOTAL OF M	20	28.17%
TOTAL OF H	1	1.41%
TOTAL # OF PORTS	71	100%

Table 7.7: Sum of N, L, M, H level of adoption for “Monitoring” category

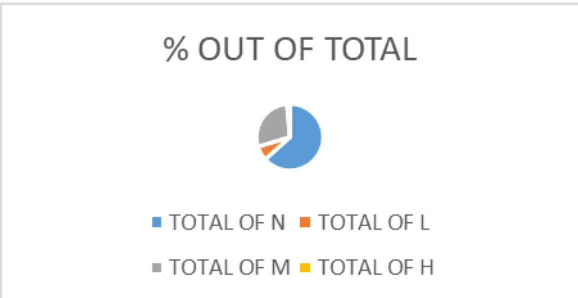

Figure 7.3: Pie chart of the percentage of N, L, M, H out of the total for the 2nd category

Results reveal that 45 ports or 63% of the ports did not disclose any information regarding the monitoring of air, water, noise and energy. As for the remaining 26 ports, there were ports that monitored only 1 aspect (5 ports), other ports monitored 2 or 3 aspects (20 ports) and only 1 port monitored all 4 aspects.

The port of Genoa in Italy is the leader in monitoring, as it reports to monitor all 4 factors in this category. On the contrary, the vast majority of ports that reported no level of monitoring are mostly Asian, with 32 out of the 45 ports that had No level of disclosure situated in Asia. From the rest, 11 were European ports, plus the ports of Melbourne and Santos in Australia and in Brazil respectively. The other 9 Asian ports have Medium level of monitoring, with most ports measuring 2 factors and only the port of Taichung in Taiwan measuring 3 factors.

Overall, results reflect that the majority of ports are not engaged in air, water, noise and energy monitoring.

7.4.3 Results for "Certification and Reporting" category

There are in total 3 factors included in the category "Certification and Reporting". Ports are increasingly reporting their green and sustainability efforts through dedicated Sustainability and Environmental Reports. These reports reflect the practices adopted by ports to become greener and more sustainable by outlining results, goals and strategies towards gaining a real stance on these two pivotal aspects of smart port development.

Moreover, ports develop their own Environmental Management Systems (EMS), which represent a practical tool to address, monitor and minimise the impacts of ports' activities on the environment, and to report the positive outcomes generated by the green initiatives. The EMS also ensures a continuous commitment to regulatory compliance in a proactive manner. The general goal of the EMS is to generate continuous and systematic improvements in environmental aspects, through the implementation of a policy which evaluates current and planned practices based on their potential environmental impact. Ports obtain the ISO14001 Certification by the International Organisation for Standardisation (ISO) when the EMS used by the port is consistent with the specified requirements outlined by ISO to enhance the organisation environmental performance. ISO14001 Certification is intended to be used by organisations in any sector that seeks to manage their environmental responsibilities systematically to contribute to the environmental pillar of sustainability. It maps out a framework and sets out the criteria that a company or organisation can follow to develop an effective EMS. This certification provides assurance to external stakeholders, employees and to company management that environmental impact is being measured and enhanced (International Organization for Standardization, 2015). Therefore, it assists the organisation in achieving the intended results of its EMS, which generate value for the organisation itself, the interested parties and most importantly for the environment. The intended outcomes for an EMS among others include the achievement of environmental goals, the improvement of environmental performance and completion of compliance obligations. Table 7.8 below shows the scores for the factors of the 3rd category.

COUNTRY	PORT	REPORTING		CERTIFICATION	TOTAL=3	
		SUSTAINABILITY	ENVIRONMENTAL	ISO 14001	TOTAL	LEVEL OF PORT
BELGIUM	ANTWERP	●			1	L
	ZEEBRUGGE				0	N
	GHENT				0	N
GERMANY	BREMERHAVEN				0	N
	HAMBURG				0	N
	WILHELMSHAVEN	●	●		2	M
ITALY	GENOA			●	1	L
	GIOIA TAURO				0	N
	LA SPEZIA				0	N
SPAIN	ALGECIRAS	●		●	2	M
	BARCELONA	●		●	2	M
	VALENCIA		●	●	2	M
TURKEY	AMBARLI				0	N
	MERSIN			●	1	L
	IZMIR				0	N
NETHERLANDS	AMSTERDAM	●			1	L
	ROTTERDAM	●			1	L
	MOERDIJK		●	●	2	M
UK	FELIXSTOWE		●	●	2	M
	LONDON			●	1	L
	SOUTHAMPTON				0	N
CHINA	NINGBO ZHOUSHAN				0	N
	SHENZHEN				0	N
	GUANGZHOU				0	N
	XIAMEN				0	N
	SHANGHAI	●			1	L
	QINQDAO				0	N
	TIANJIN				0	N
	DALIAN				0	N
INDONESIA	BELAWAN				0	N
	TANJUNG PERAK/SURABAYA				0	N
	TANJUNG PRIOK				0	N
SINGAPORE	SINGAPORE	●			1	L
HONG KONG	HONG KONG				0	N
VIETNAM	HO CHI MINH				0	N
	CAI MEP	●			1	L
TAIWAN	KAOHSIUNG		●		1	L
	TAINGHUNG		●		1	L
	TAIPEI				0	N
PHILLIPINES	MANILA				0	N
	DAVAO			●	1	L
	BATANGAS				0	N
MALAYSIA	KLANG				0	N
	TANJUNG PELEPAS		●	●	2	M
	PENANG				0	N
SOUTH KOREA	BUSAN	●			1	L
	INCHEON				0	N
	YEOSU				0	N
JAPAN	KOBE				0	N
	TOKYO				0	N
	YOKOHAMA				0	N
INDIA	CHENNAI				0	N
	JAWAHARLAL NEHRU		●	●	2	M
	MUNDRA	●			1	L
THAILAND	LAEM CHABANG				0	N
	BANGKOK				0	N
UAE	DUBAI JEBEL ALI				0	N
	KHOR FAKKAN			●	1	L
	KHALIFA	●		●	2	M
SAUDI ARABIA	DAMMAM				0	N
	JEDDAH				0	N
	JUBAIL				0	N
BRAZIL	PARANAGUA				0	N
	RIO GRANDE		●		1	L
	SANTOS				0	N
US	LONG BEACH		●		1	L
	LOS ANGELES	●		●	2	M
	NY NJ			●	1	L
AUSTRALIA	BRISBANE	●	●	●	3	H
	MELBOURNE	●		●	2	M
	BOTANY	●			1	L
	TOTAL	16	11	17		

Table 7.8: Results for “Certification and Reporting” category

Table 7.8 suggests that only 16 ports had stand-alone sustainability reports, while 11 ports had stand-alone environmental reports. Sustainability reporting practices in Europe are mostly followed by Netherlands (2 ports), Spain (2 ports), Belgium (1 port) and Germany (1 port). It was also found that Australia was the leader in Sustainability reporting, as all 3 Australian ports included stand-alone Sustainability Reports in their corporate websites. The other 6 ports that included Sustainability reports were Asian. This indicated European and Australian ports are generally active in sustainability efforts, since they report in detail through their Sustainability reports the actions that they take towards achieving a higher level of sustainability.

On the other hand, Environmental reporting was adopted by 4 European ports, 4 Asian ports, 1 Australian, 1 Brazilian and 1 US port. Moreover, when it comes to certification it is observed that 17 ports are ISO14001 certified, which represents a quite low percentage of 24% of the overall ports examined. From these, 8 ports were European, 5 ports were Asian, 2 ports were located in Australia and 2 ports in the US. European port authorities therefore seem to give more attention in obtaining an ISO14001 Certification, with Australian and US ports also succeeding to rank high in Certification.

Finally, Wilhelmshaven and Brisbane ports had both Sustainability and Environmental reports, while the latter also held an ISO14001 Certification, thus acquiring a High level of disclosure, by scoring 3 out of 3 factors in the category.

TOTAL	CERTIFICATION & REPORTING	% OF PORTS OUT OF TOTAL
TOTAL OF N	40	56.34%
TOTAL OF L	19	26.76%
TOTAL OF M	11	15.49%
TOTAL OF H	1	1.41%
TOTAL # OF PORTS	71	100%

Table 7.9: Sum of N, L, M, H level of adoption for “Certification and Reporting” category

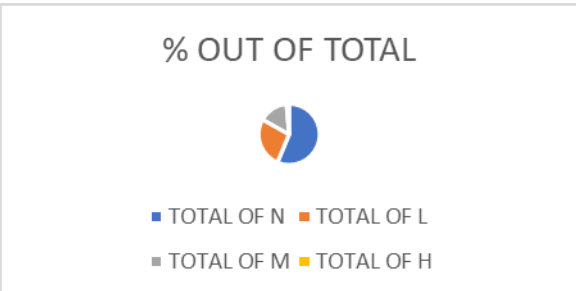

Figure 7.4: Pie chart of the percentage of N, L, M, H out of the total for the 3rd category

It is observed that more than half of the ports neither held an ISO14001 Certification, nor generated any Sustainability or Environmental reports as part of their green and sustainability practices. From the 40 ports that had no level of adoption for the "Certification and Reporting" category, 9 ports were European, 2 ports were Brazilian, while the rest of the 29 ports were Asian. This finding suggests that Asian ports do not prioritise environmental and sustainable reporting and do not hold an ISO14001 Certificate. However, good practices were seen from a few Asian ports, as among the ports that had 2 counts and Medium level of disclosure, there were 3 Asian ports, namely Tanjung Pelepas in Malaysia, Jawaharlal Nehru in India and Khalifa in UAE, that notably had obtained ISO14001 Certification and included in their websites either a Sustainability or Environmental Report.

Most ports require improvement in reporting their green and sustainability related practices, as it has become a necessity for ports to be actively engaged in green and sustainability practices. Also, certain ports that did have reports to reflect their green and sustainability management, did not update or release latest reports on their corporate websites, therefore the current state of the ports' efforts was not be advertised efficiently.

7.4.4 Results for "Energy Sources and Incentives" category

There are in total 3 factors included in the category "Energy Sources and Incentives". Renewable raw materials and renewable energy are the vital pillars for a new energy industrial system to be built. For ports to generate sustainable energy, the core strategy is to look for new cargo flows and find new ways to generate sustainable energy. Solar panels, wind turbines, geothermal, biomass and waste-based energy, are some of the renewable energy sources that ports consider and adopt for their energy transition.

Moreover, to minimise the emissions (NOx, SOx and fine particulates) generated from ships at berth, shore-side power is one of the key decarbonisation strategies for ports to reduce carbon emissions to a minimum level. When ships berth at the quayside by using shore-side power, or otherwise called cold-ironing, they are able to turn off their diesel engines and switch to mains electricity. This is a way of working towards achieving a better air quality both at the port itself, as well as at the port-city interface.

Another strategy adopted by ports, is the reduction in port fees for clean, environmentally friendly vessels. This lower fee incentive aims to generate significant motivation for vessels to become greener and minimise their carbon footprint. Table 7.10 below shows the scores for the factors in the 4^{th} category.

COUNTRY	PORT	ENERGY SOURCES AND INCENTIVES			TOTAL=3	
		RENEW. ENERG.	SHORE-SIDE	FEE INCENTIVES	SUM OF FACTORS	LEVEL OF PORT
BELGIUM	ANTWERP	●	●		2	M
	ZEEBRUGGE	●	●	●	3	H
	GHENT	●	●	●	3	H
GERMANY	BREMERHAVEN	●		●	2	M
	HAMBURG	●	●	●	3	H
	WILHELMSHAVEN		●	●	2	M
ITALY	GENOA	●	●		2	M
	GIOIA TAURO				0	N
	LA SPEZIA	●	●		2	M
SPAIN	ALGECIRAS	●		●	2	M
	BARCELONA			●	1	L
	VALENCIA			●	1	L
TURKEY	AMBARLI				0	N
	MERSIN				0	N
	IZMIR				0	N
NETHERLANDS	AMSTERDAM	●	●		2	M
	ROTTERDAM	●	●	●	3	H
	MOERDIJK				0	N
UK	FELIXSTOWE	●			1	L
	LONDON				0	N
	SOUTHAMPTON	●			1	L
CHINA	NINGBO ZHOUSHAN				0	N
	SHENZHEN				0	N
	GUANGZHOU				0	N
	XIAMEN				0	N
	SHANGHAI				0	N
	QINQDAO				0	N
	TIANJIN				0	N
	DALIAN				0	N
INDONESIA	BELAWAN				0	N
	TANJUNG PERAK/SURABAYA				0	N
	TANJUNG PRIOK				0	N
SINGAPORE	SINGAPORE				0	N
HONG KONG	HONG KONG				0	N
VIETNAM	HO CHI MINH				0	N
	CAI MEP				0	N
TAIWAN	KAOHSIUNG		●	●	2	M
	TAINGHUNG	●	●	●	3	H
	TAIPEI				0	N
PHILLIPINES	MANILA				0	N
	DAVAO				0	N
	BATANGAS				0	N
MALAYSIA	KLANG		●		1	L
	TANJUNG PELEPAS		●	●	2	M
	PENANG				0	N
SOUTH KOREA	BUSAN				0	N
	INCHEON				0	N
	YEOSU				0	N
JAPAN	KOBE				0	N
	TOKYO	●		●	2	M
	YOKOHAMA				0	N
INDIA	CHENNAI				0	N
	JAWAHARLAL NEHRU	●			1	L
	MUNDRA	●			1	L
THAILAND	LAEM CHABANG				0	N
	BANGKOK				0	N
UAE	DUBAI JEBEL ALI	●			1	L
	KHOR FAKKAN				0	N
	KHALIFA				0	N
SAUDI ARABIA	DAMMAM				0	N
	JEDDAH				0	N
	JUBAIL				0	N
BRAZIL	PARANAGUA				0	N
	RIO GRANDE	●			1	L
	SANTOS				0	N
US	LONG BEACH	●	●	●	3	H
	LOS ANGELES	●	●	●	3	H
	NY NJ		●	●	2	M
AUSTRALIA	BRISBANE	●			1	L
	MELBOURNE				0	N
	BOTANY	●		●	2	M
	TOTAL	22	16	17		

Table 7.10: Results for “Energy Sources and Incentives” category

The number of ports that provides fee reduction for clean vessels is 17 or 24% of the ports in the sample. The countries that mostly promote this incentive are the US, Spain and Germany with all 3 ports of each country having fee incentives for clean vessels in their environmental policy. Moreover, 16 ports or 22.5% of the ports, provided shore-side power (cold ironing) for ships at berth. Belgium and the US are leaders, as all 3 ports of each country had shore-power installations. As far as the renewable energy adoption is concerned, 22 ports or 31% of the ports use renewable energy (wind, solar, etc.) in their sites.

TOTAL	ENERGY SOURCES & INCENTIVES	% OF PORTS OUT OF TOTAL
TOTAL OF N	42	59.15%
TOTAL OF L	10	14.08%
TOTAL OF M	12	16.90%
TOTAL OF H	7	9.86%
TOTAL # OF PORTS	71	100%

Table 7.11: Sum of N, L, M, H level of adoption for "Energy Sources and Incentives" category

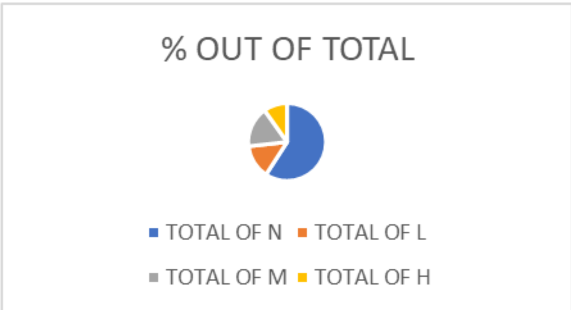

Figure 7.5: Pie chart of the percentage of N, L, M, H out of the total for the 4th category

The results in Table 7.11 indicate that almost 60% of the ports do not report any of the 3 factors in this category, suggesting that there is still a great percentage of ports that do not actively engage in energy transition and do not provide discounts on port charges, thus not emphasising the importance of ships becoming carbon neutral. However, almost 10% largely engaged with these practices, while almost 30% showed a low or medium level of adoption.

Finally, 7 ports scored 3 out of 3 in this group and were considered leaders in this category, namely the ports of Zeebrugge, Ghent, Hamburg, Rotterdam in Europe, Taichung in Taiwan, Long Beach and Los Angeles in the US. These ports are specific examples of the good practices that should set direction for the other ports towards energy transition and carbon emission minimisation.

7.4.5 Results for "Technology and Innovation" category

There are in total 4 factors included in the category "Technology and Innovation". The efforts in digital, innovative or smart strategies can be sought from a port's vision, mission, values statement and goals. Additionally, the presence or absence of these aspects in a port website's Menu Bar can also represent the port's interest in promoting and adopting these aspects in its practices. Moreover, through the adoption of Port Community Systems, data sharing platforms, blockchain applications, etc., ports are accelerating their digitization, working towards innovation and are using these as a lever towards a green and sustainable future for the port industry and the economy as a whole. Table 7.12 below shows the scores for the factors in the 5th category.

COUNTRY	PORT	MENU BAR	VISION/MISSION/VALUES			TOTAL=4	
		DIGITAL-SMART	INNOVATION	P C SYSTEM	BLOCKCHAIN	SUM OF FACTORS	LEVEL OF PORT
BELGIUM	ANTWERP	●	●	●	●	4	H
	ZEEBRUGGE	●	●	●		3	M
	GHENT		●	●		2	M
GERMANY	BREMERHAVEN					0	N
	HAMBURG	●	●	●		3	M
	WILHELMSHAVEN					0	N
ITALY	GENOA		●	●		2	M
	GIOIA TAURO					0	N
	LA SPEZIA		●	●		2	M
SPAIN	ALGECIRAS	●		●		2	M
	BARCELONA		●	●		2	M
	VALENCIA			●		1	L
TURKEY	AMBARLI		●			1	L
	MERSIN		●			1	L
	IZMIR					0	N
NETHERLANDS	AMSTERDAM	●	●	●		3	M
	ROTTERDAM	●	●	●	●	4	H
	MOERDIJK					0	N
UK	FELIXSTOWE			●		1	L
	LONDON					0	N
	SOUTHAMPTON		●			1	L
CHINA	NINGBO ZHOUSHAN		●			1	L
	SHENZHEN					0	N
	GUANGZHOU		●			1	L
	XIAMEN					0	N
	SHANGHAI	●	●			2	M
	QINQDAO		●			1	L
	TIANJIN		●			1	L
	DALIAN					0	N
INDONESIA	BELAWAN		●			1	L
	TANJUNG PERAK/SURABAYA		●			1	L
	TANJUNG PRIOK			●		1	L
SINGAPORE	SINGAPORE	●	●	●		3	M
HONG KONG	HONG KONG					0	N
VIETNAM	HO CHI MINH					0	N
	CAI MEP					0	N
TAIWAN	KAOHSIUNG					0	N
	TAINGHUNG		●			1	L
	TAIPEI					0	N
PHILLIPINES	MANILA		●			1	L
	DAVAO		●			1	L
	BATANGAS		●			1	L
MALAYSIA	KLANG			●		1	L
	TANJUNG PELEPAS		●	●		2	M
	PENANG					0	N
SOUTH KOREA	BUSAN		●			1	L
	INCHEON					0	N
	YEOSU					0	N
JAPAN	KOBE					0	N
	TOKYO					0	N
	YOKOHAMA					0	N
INDIA	CHENNAI		●			1	L
	JAWAHARLAL NEHRU		●	●		2	M
	MUNDRA					0	N
THAILAND	LAEM CHABANG		●			1	L
	BANGKOK		●			1	L
UAE	DUBAI JEBEL ALI					0	N
	KHOR FAKKAN		●			1	L
	KHALIFA	●	●	●		3	M
SAUDI ARABIA	DAMMAM		●			1	L
	JEDDAH		●			1	L
	JUBAIL		●			1	L
BRAZIL	PARANAGUA					0	N
	RIO GRANDE			●		1	L
	SANTOS			●		1	L
US	LONG BEACH		●			1	L
	LOS ANGELES			●		1	L
	NY NJ		●			1	L
AUSTRALIA	BRISBANE		●			1	L
	MELBOURNE		●			1	L
	BOTANY					0	N
	TOTAL	9	39	21	2		

Table 7.12: Results for “Technology and Innovation” category

As far as the digital-smart-innovative matters are concerned, findings suggest that more than half of the ports report smart, innovation, and digital matters in their mission/vision/values statement. However, only a small proportion of the ports analysed include such topics in their Menu Bars, as only 9 ports have incorporated a digital-smart section. Moreover, 21 ports or 30% of the ports have reported to adopt a Port Community System and only 2 ports, namely Rotterdam port and the port of Antwerp mention blockchain applications technology as part of their digital strategy.

Results reveal that European ports are dominant in smart/digital/innovation disclosure in their corporate websites, while Asian ports show a poor scoring. The sum of Asian ports that had no reference to technology and innovation matters was 16, while on the other hand only 6 European ports did not mention any technology and innovation factor in their websites. The majority of Asian ports (20 ports) had a Low level of adoption in this category's factors.

TOTAL	TECHNOLOGY & INNOVATION	% OF PORTS OUT OF TOTAL
TOTAL OF N	24	33.80%
TOTAL OF L	32	45.07%
TOTAL OF M	13	18.31%
TOTAL OF H	2	2.82%
TOTAL # OF PORTS	71	100%

Table 7.13: Sum of N, L, M, H level of adoption for "Technology and Innovation" category

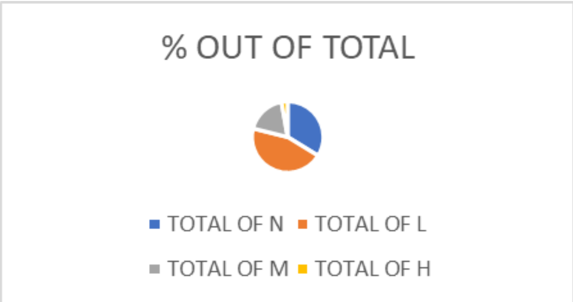

Figure 7.6: Pie chart of the percentage of N, L, M, H out of the total for the 5th category

It is observed that 32 ports have a Low level of technology and innovation adoption, scoring only 1 factor out of the 3 included in the category. Out of these, a great proportion were Asian ports (20 ports), indicating that Asian countries report less technology initiatives in their websites. This trend can be explained either from the fact that Asian websites are not as organised and well-displayed as other countries' websites, or from the observation that Chinese transport sector and ports place priority on efficiency, capacity and throughput (Lam and Li, 2019; Li et al. 2018). Findings also suggest that 2 European ports, namely the port of Rotterdam and the port of Antwerp scored of 4 out of 4, which indicates they are the leading ports in the technology and innovation category.

The examination of the results in this category indicates that the majority of ports are not yet disclosing substantial information regarding their innovation and technology strategy, nor are mentioning them in their strategy statement. This latter fact suggests that there are still a significant number of ports not engaging in technology and innovation development.

7.5 Interpreting Results and Generating Smart Scores

The main question to be answered through this phase is to "what extent, if any, do the world's major ports participate in smart, green and sustainability related port initiatives". Table 7.14 is a summary table of the count of ports for each category for each of the N, L, M, H levels of adoption.

TOTAL	**ENV, SUST. & COMM**	% OF PORTS OUT OF TOTAL	**MONITOR.**	% OUT OF TOTAL	**CERTIF. & REPORT.**	% OUT OF TOTAL	**ENERGY SOURCES & INCENT.**	% OUT OF TOTAL	**TECHN. & INNOV.**	% OUT OF TOTAL
TOTAL OF N	12	16.90	45	63.38	40	56.34	42	59.15	24	33.80
TOTAL OF L	23	32.39	5	7.04	19	26.76	10	14.08	32	45.07
TOTAL OF M	27	38.03	20	28.17	11	15.49	12	16.90	13	18.31
TOTAL OF H	9	12.68	1	1.41	1	1.41	7	9.86	2	2.82
TOTAL # OF PORTS	71	100	71	100	71	100	71	100	71	100

Table 7.14: Summary table of count of ports with N, L, M, H for each category and percentage of ports out of total

The results indicate that ports show a higher level of consideration for the 1st category, "Environment, Sustainability and Community". The sum of M and H levels in this category is 51% and demonstrates that ports are mostly reporting green and sustainable initiatives in their mission/ vison/ values statement and Menu Bars compared to technology and innovation initiatives, as the 5th category's sum of M and H levels is as low as 21%.

Moreover, 21 ports or 30% of the ports have Medium or High level in monitoring practices, showing a moderate interest in achieving a green port status by minimising their environmental impact in the long-term. Among the 71 ports, 31 of them or 44% have included a Sustainability or Environmental report or to have obtained an ISO14001Certification. This means that almost half of the ports are showing to the public that they are actively and with proof committed to green and sustainable development and adoption in their activities.

Finally, findings in the 4^{th} category, “Renewable sources and incentives”, show that 42 ports or 59% of the ports do not mention any renewable energy adoption and do not use as an incentive the fee reductions for clean vessels. The lack of popularity in the factors within this category reveal an insufficient effort in energy transition from ports.

Figure 7.7 shows a bar chart visualising the results presented in Table 7.14.

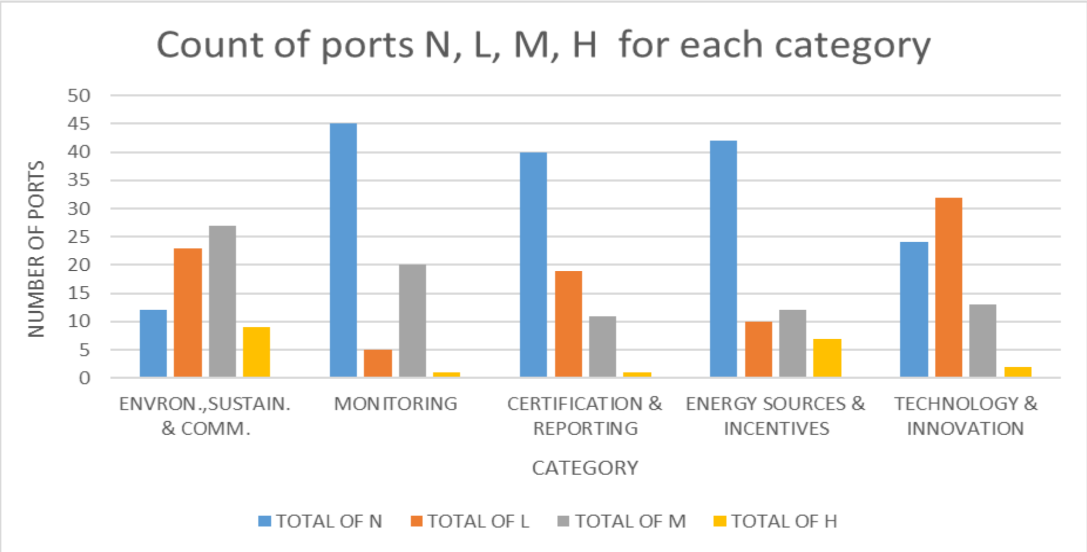

Figure 7.7: Bar chart for count of ports of N, L, M, H for each category

Next, the smart score of each port in the sample was elaborated by finding the horizontal sum of factors for each port and then dividing it by 20 (the total number of factors). Table 7.15 below presents the smart score of each port, while Figure 7.8 shows a bar chart with the scores for each port, grouped by geographical region.

Ranking	PORT	SMART SCORE
1	ANTWERP	0,75
2	AMSTERDAM	0,7
3	ROTTERDAM	0,7
4	LOS ANGELES	0,7
5	GENOA	0,65
6	LONG BEACH	0,65
7	VALENCIA	0,6
8	TANJUNG PELEPAS	0,6
9	KHALIFA	0,55
10	BRISBANE	0,55
11	LA SPEZIA	0,5
12	ALGECIRAS	0,5
13	BARCELONA	0,5
14	JAWAHARLAL NEHRU	0,5
15	BOTANY	0,5
16	ZEEBRUGGE	0,45
17	MOERDIJK	0,45
18	RIO GRANDE	0,45
19	NY NJ	0,45
20	GHENT	0,4
21	HAMBURG	0,4
22	WILHELMSHAVEN	0,4
23	TAINGHUNG	0,4
24	MELBOURNE	0,4
25	FELIXSTOWE	0,35
26	SHANGHAI	0,35
27	KLANG	0,35
28	MUNDRA	0,35
29	DUBAI JEBEL ALI	0,35
30	PARANAGUA	0,35
31	SINGAPORE	0,3
32	CAI MEP	0,3
33	LAEM CHABANG	0,3
34	BANGKOK	0,3
35	SOUTHAMPTON	0,25
36	KAOHSIUNG	0,25
37	DAVAO	0,25
38	KHOR FAKKAN	0,25
39	BREMERHAVEN	0,2
40	AMBARLI	0,2
41	MERSIN	0,2
42	MANILA	0,2
43	BATANGAS	0,2
44	BUSAN	0,2
45	QINQDAO	0,15
46	TIANJIN	0,15
47	TANJUNG PERAK	0,15
48	YEOSU	0,15
49	TOKYO	0,15
50	CHENNAI	0,15
51	DAMMAM	0,15
52	JEDDAH	0,15
53	JUBAIL	0,15
54	NINGBO ZHOUSHAN	0,1
55	GUANGZHOU	0,1
56	BELAWAN	0,1
57	TANJUNG PRIOK	0,1
58	INCHEON	0,1
59	YOKOHAMA	0,1
60	LONDON	0,05
61	HO CHI MINH	0,05
62	PENANG	0,05
63	SANTOS	0,05
64	GIOIA TAURO	0
65	IZMIR	0
66	SHENZHEN	0
67	XIAMEN	0
68	DALIAN	0
69	HONG KONG	0
70	TAIPEI	0
71	KOBE	0

Table 7.15: Smart score of ports

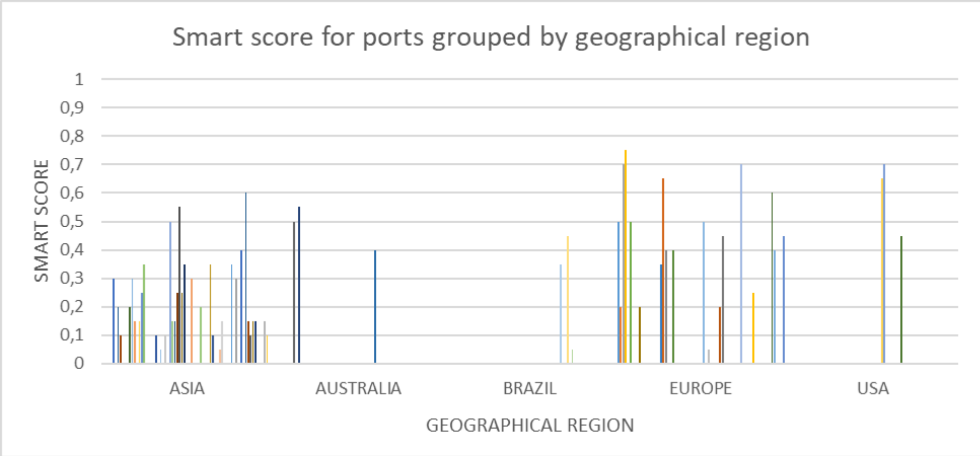

Figure 7.8: Bar chart of smart score for ports grouped by geographical region

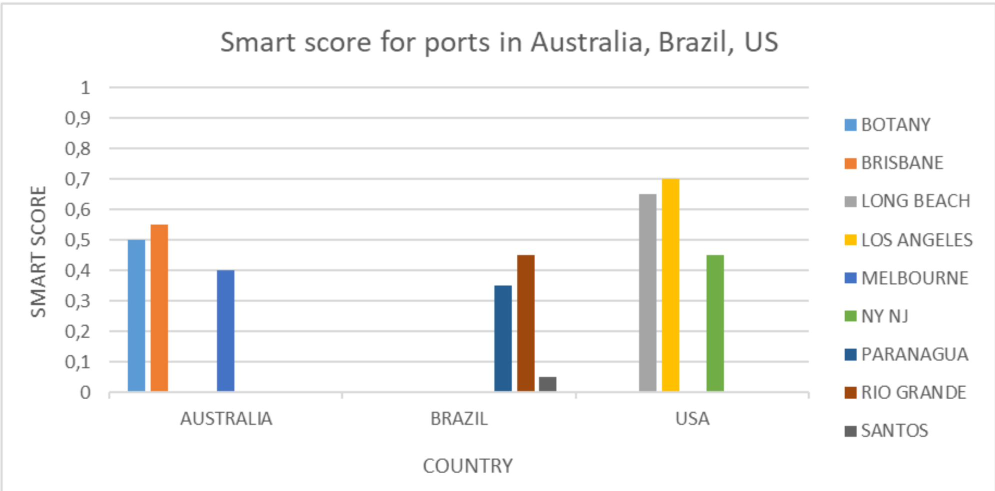

Figure 7.9: Bar chart for smart score of ports in Australia, Brazil and the US

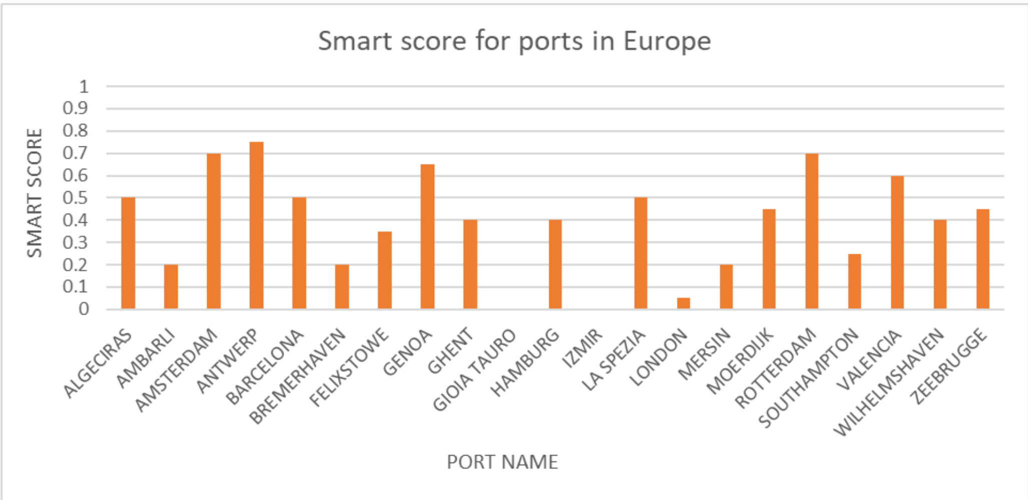

Figure 7.10: Bar chart of smart score for ports in Europe

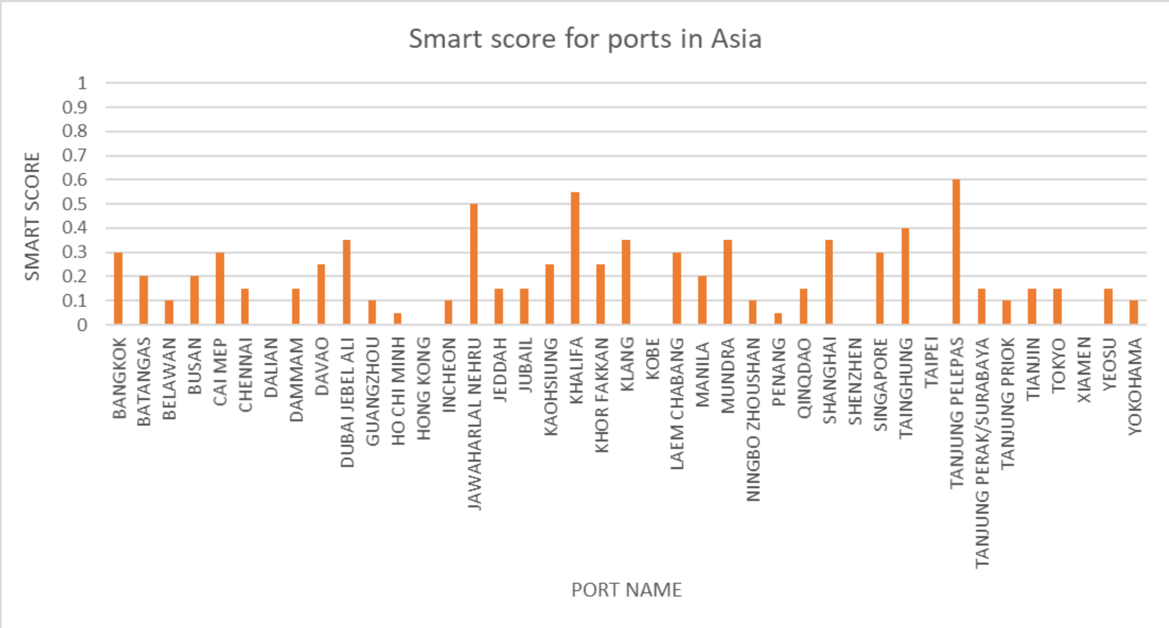

Figure 7.11: Bar chart of smart score for ports in Asia

The author has finally compiled all results in Table 7.16, which represents an overall table with all 5 categories and corresponding N, L, M, H levels and smart score for each port in the sample. Ports that scored over 0.5 are coloured in green, similarly to ports that scored High level of adoption in any of the 5 categories.

WORLD REGION	COUNTRY	PORT NAME	ENVIRON., SUSTAINABILITY & COMMUNITY	MONITORING	CERTIFICATION & REPORTING	ENERGY SOURCES & INCENTIVES	TECHNOLOGY & INNOVATION	SMART SCORE
EUROPE	BELGIUM	ANTWERP	H	M	L	M	H	0,75
		ZEEBRUGGE	M	N	N	H	M	0,45
		GHENT	M	N	N	H	M	0,4
EUROPE	GERMANY	BREMERHAVEN	L	N	N	M	N	0,2
		HAMBURG	L	N	N	H	M	0,4
		WILHELMSHAVEN	M	L	M	M	N	0,4
EUROPE	ITALY	GENOA	M	H	L	M	M	0,65
		GIOIA TAURO	N	N	N	N	N	0
		LA SPEZIA	M	M	N	M	M	0,5
EUROPE	SPAIN	ALGECIRAS	M	N	M	M	M	0,5
		BARCELONA	M	L	M	L	M	0,5
		VALENCIA	H	M	M	L	L	0,6
EUROPE	TURKEY	AMBARLI	M	N	N	N	L	0,2
		MERSIN	L	N	L	N	L	0,2
		IZMIR	N	N	N	N	N	0
EUROPE	NETHERLANDS	AMSTERDAM	H	M	L	M	M	0,7
		ROTTERDAM	H	N	L	H	H	0,7
		MOERDIJK	M	M	M	N	N	0,45
EUROPE	UK	FELIXSTOWE	L	L	M	L	L	0,35
		LONDON	N	N	L	N	N	0,05
		SOUTHAMPTON	L	L	N	L	L	0,25
ASIA	CHINA	NINGBO ZHOUSHAN	L	N	N	N	L	0,1
		SHENZHEN	N	N	N	N	N	0
		GUANGZHOU	L	N	N	N	L	0,1
		XIAMEN	N	N	N	N	N	0
		SHANGHAI	M	N	L	N	M	0,35
		QINQDAO	L	N	N	N	L	0,15
		TIANJIN	L	N	N	N	L	0,15
		DALIAN	N	N	N	N	N	0
ASIA	INDONESIA	BELAWAN	L	N	N	N	L	0,1
		TANJUNG PERAK	L	N	N	N	L	0,15
		TANJUNG PRIOK	L	N	N	N	L	0,1
ASIA	SINGAPORE	SINGAPORE	L	N	L	N	M	0,3
ASIA	HONG KONG	HONG KONG	N	N	N	N	N	0
ASIA	VIETNAM	HO CHI MINH	L	N	N	N	N	0,05
		CAI MEP	H	N	L	N	N	0,3
ASIA	TAIWAN	KAOHSIUNG	N	M	L	M	N	0,25
		TAINGHUNG	N	M	L	H	L	0,4
		TAIPEI	N	N	N	N	N	0
ASIA	PHILLIPINES	MANILA	M	N	N	N	L	0,2
		DAVAO	M	N	L	N	L	0,25
		BATANGAS	M	N	N	N	L	0,2
ASIA	MALAYSIA	KLANG	M	M	N	L	L	0,35
		TANJUNG PELEPAS	M	M	M	M	M	0,6
		PENANG	L	N	N	N	N	0,05
ASIA	SOUTH KOREA	BUSAN	L	N	L	N	L	0,2
		INCHEON	L	N	N	N	N	0,1
		YEOSU	M	N	N	N	N	0,15
ASIA	JAPAN	KOBE	N	N	N	N	N	0
		TOKYO	L	N	N	M	N	0,15
		YOKOHAMA	L	N	N	N	N	0,1
ASIA	INDIA	CHENNAI	L	N	N	N	L	0,15
		JAWAHARLAL NEHRU	M	M	M	L	M	0,5
		MUNDRA	H	N	L	L	N	0,35
ASIA	THAILAND	LAEM CHABANG	M	M	N	N	L	0,3
		BANGKOK	M	M	N	N	L	0,3
ASIA	UAE	DUBAI JEBEL ALI	M	M	N	L	N	0,35
		KHOR FAKKAN	M	N	L	N	L	0,25
		KHALIFA	M	M	M	N	M	0,55
ASIA	SAUDI ARABIA	DAMMAM	L	N	N	N	L	0,15
		JEDDAH	L	N	N	N	L	0,15
		JUBAIL	L	N	N	N	L	0,15
BRAZIL	BRAZIL	PARANAGUA	M	M	N	N	N	0,35
		RIO GRANDE	M	M	L	L	L	0,45
		SANTOS	N	N	N	N	L	0,05
US	US	LONG BEACH	H	M	L	H	L	0,65
		LOS ANGELES	H	M	M	H	L	0,7
		NY NJ	M	L	L	M	L	0,45
AUSTRALIA	AUSTRALIA	BRISBANE	M	M	H	L	L	0,55
		MELBOURNE	H	N	M	N	L	0,4
		BOTANY	M	M	L	M	N	0,5

Table 7.16: Overall Table with results from the Website Content Analysis

Ports that scored over 0.5 are coloured in green, similarly to ports that scored High level of adoption in any of the 5 categories.

From the analysis of the 71 ports located across 5 world regions, namely Europe, Asia, Brazil, US and Australia, there is a clear predominance in higher smart scores for European and US ports, with Asian ports scoring lower in their smart status. Notably, the first Asian port is found on the 8th place of the smart score table. It is also found that Australian ports score high in their smart status as they are listed on the 10th, 15th, and 24th place. The ports that scored over 0.5 are 15 and more than half of them are situated in Europe. The rest of the ports scoring over 0.5 are the ports of Brisbane and Botany in Australia, the ports of Los Angeles and Long Beach in the US, while only 3 of the 15 ports scoring over 0.5 are Asian, namely the ports of Tanjung Pelepas in Malaysia, Khalifa port in UAE and Jawaharlal Nehru port in India.

The smartest port in the sample is Antwerp, scoring 0.75, while next are the ports of Amsterdam, Rotterdam and Los Angeles scoring 0,7. On the other hand, the least smart ports are mostly situated in Asia, as from the 18 ports that scored under 0.1, 14 of them are situated in Asia. Another important result is that from the 8 ports in the sample located in China, 5 of them scored under 0.1 and belong to the least smart ports in the sample.

The average smart score for the ports in the sample is 0.3, with 34 ports scoring over 0.3 in their smart score. From the 34 ports that scored over 0.3, 14 are situated in Europe. Moreover, all 3 Australian ports scored over 0.3, all 3 US ports scored over 0.3, while 12 ports were Asian. Finally, the Brazilian port of Rio Grande scored 0.45 and was among the 34 ports that scored higher than the average score. Moreover, analysis showed that the median smart score was 0.25 and was achieved by 4 ports, namely the ports of Southampton in UK, Kaohsiung in Taiwan, Davao in the Philippines and Khor Fakkan in UAE.

The smart score of ports indicates that none of the ports have gained a 100% or 1 score (Table 7.13). It shows that only 4 ports scored over 70% or 0.7, thus offering a relatively high smart service to port clients, and 11 ports scored more than 50% or over 0.5. Majority of the ports in the sample have obtained less than 0.5 score.

In terms of level of adoption in the 5 categories, it is found that the US ports of Long Beach and Los Angeles are the most active in the 1st and 4th category as they have a High level of adoption in both categories. Similarly, the port of Antwerp scores a High level in 2 categories, in the 1st and the 5th categories. Moreover, the port of Rotterdam is leader as it scores High in 3 categories, namely in the 1st, 4th and 5th categories. The rest of the ports that have a High level in either of the 5 categories (only in one category out of the five categories) are the ports of Zeebrugge, Ghent, Amsterdam, Hamburg, Genoa, Valencia, Brisbane and Melbourne in Australia, Cai Mep, Taichung and Mundra. The rest of the ports scored either Medium, Low or No level in all five categories, with no High level in any category.

Based on the data presented in Table 7.16, it is observed that more than half of the 71 ports are engaged actively in green and sustainable engagement. However, ports focus more on green and sustainable and less on technology and innovation marketing. Overall, results show that smart, green and sustainability related efforts vary from country to country. The geographical diversity of the countries used in the sample shows that there is also a heterogeneity in their practices according to the disclosure stated in their corporate websites.

Finally, the author performed a *distribution analysis for the smart scores* obtained from the Website Content Analysis. A histogram is a graphical representation of data points grouped into user-specific ranges. The graph condenses the data series into a visual representation which is easily interpreted as the data points are grouped into logical ranges or bins. The histogram below represents the distribution of observed smart scores for the 71 ports in the sample.

Figure 7.12 represents a relative frequency histogram for the scores obtained from the website content analysis. A relative frequency histogram is similar to a frequency histogram, with the difference that on the vertical axis it lists percentages/proportion of values that fall into that bin, rather than counts. In the frequency distribution the counts are referring to how many ports have a certain smart score (how often something happens), while the relative frequency distribution shows the percentages of ports scoring a particular smart score.

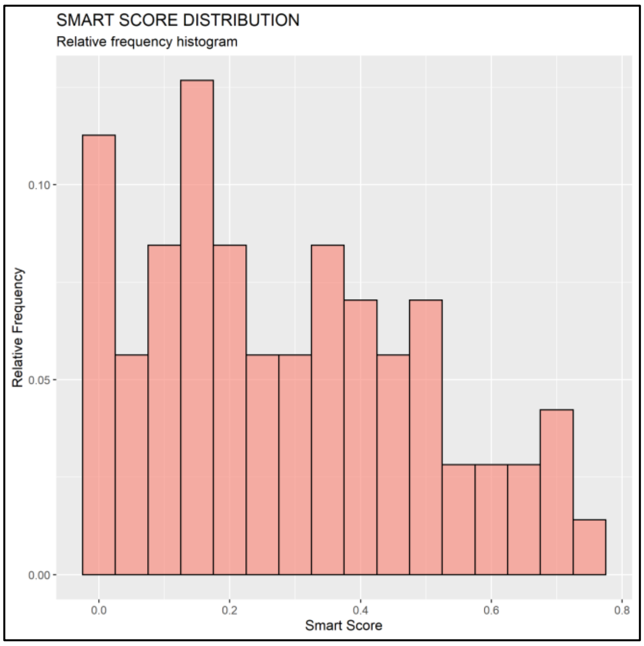

Figure 7.12: Relative frequency histogram for smart scores

The relative frequency histogram below indicates that the relative frequency of the smart scores close to 0.2 is relatively high and therefore the most common in the sample, while high scores of over 0.5 are less common.

The findings demonstrate that ports need to improve their efforts towards becoming smart, as the share of ports focusing on their smart agenda is low. Therefore, ports that focus on their efforts to become smart can set a good example to other ports which should be encouraged to further engage in becoming smart and green. Ports that are increasingly taking steps to improve their smart and green agendas can lead the way for other ports that still have a long road ahead to become smart.

7.6 Correlation Analysis for smart scores and CPPI 2020 scores

In this Section the author explores the relationship between the smart scores obtained from the Website Content Analysis and the CPPI 2020 scores (presented in Chapter 6), taking the two approaches (i.e. statistical and administrative) separately. Only 6 ports were missing from the dataset of the CPPI 2020, and therefore the author performed the correlation analysis for the 65 ports that were included in both samples. This further analysis was deemed necessary in order to determine *whether any relationship exists between the two variables* (smart score and CPPI scores) and to identify *whether ports with high performance based on the CPPI are also showing a high smart score, and vice versa*. In Table 7.17 the author compiled the data from Chapter 6 and Chapter 7 and generated an overall Table including all scores.

COUNTRY	MEDIAN TIME IN PORT 2018 (days)	PORT NAME	AUTOM.	ENV., SUST. & COMM	MONITOR.	CERT. & REP.	EN. SOUR. & INCENT.	TECH. & INNOV.	SMART SCORE	CPPI 2020 STATISTICAL APPROACH	CPPI 2020 ADMINISTRATIVE APPROACH
BELGIUM	1.02	ANTWERP	Semi	H	M	L	M	H	0,75	-1.011	31
		ZEEBRUGGE	No	M	N	N	H	M	0,45	-0.988	-6
		GHENT	No	M	N	N	H	M	0,4	Not in CPPI	Not in CPPI
GERMANY	0.79	BREMERHAVEN	No	L	N	N	M	N	0,2	-2.265	24
		HAMBURG	Fully/Semi	L	N	N	H	M	0,4	1.176	0
		WILHELMSHAVEN	No	M	L	M	M	N	0,4	-0.598	39
ITALY	0.82	GENOA	No	M	H	L	M	M	0,65	2.420	-74
		GIOIA TAURO	No	N	N	N	N	N	0	-0.344	-4
		LA SPEZIA	No	M	M	N	M	M	0,5	5.548	-24
SPAIN	0.66	ALGECIRAS	Semi	M	N	M	M	M	0,5	-3.597	53
		BARCELONA	Semi	M	L	M	L	M	0,5	-1.224	42
		VALENCIA	No	H	M	M	L	L	0,6	1.211	-34
TURKEY	0.63	AMBARLI	No	M	N	N	N	L	0,2	-1.783	32
		MERSIN	No	L	N	L	N	L	0,2	0.275	25
		IZMIR	No	N	N	N	N	N	0	1.136	-18
NETHERLANDS	0.78	AMSTERDAM	No	H	M	L	M	M	0,7	Not in CPPI	Not in CPPI
		ROTTERDAM	Fully	H	N	L	H	H	0,7	-0.611	22
		MOERDIJK	No	M	M	M	N	N	0,45	Not in CPPI	Not in CPPI
UK	0.73	FELIXSTOWE	No	L	L	M	L	L	0,35	2.006	-55
		LONDON	Semi	N	N	L	N	N	0,05	-1.117	1
		SOUTHAMPTON	No	L	L	N	L	L	0,25	1.404	-45
CHINA	0.62	NINGBO ZHOUSHAN	No	L	N	N	N	L	0,1	-2.963	88
		SHENZHEN	No	N	N	N	N	N	0	Not in CPPI	Not in CPPI
		GUANGZHOU	No	L	N	N	N	L	0,1	-5.162	92
		XIAMEN	Fully	N	N	N	N	N	0	-1.541	58
		SHANGHAI	Fully	M	N	L	N	M	0,35	-1.532	41
		QINQDAO	Fully	L	N	N	N	L	0,15	-3.860	102
		TIANJIN	Fully	L	N	N	N	L	0,15	0.310	64
		DALIAN	No	N	N	N	N	N	0	-2.506	66
INDONESIA	1.09	BELAWAN	No	L	N	N	N	L	0,1	0.104	-2
		TANJUNG PERAK	Semi	L	N	N	N	L	0,15	-0.269	3
		TANJUNG PRIOK	No	L	N	N	N	L	0,1	-1.521	31
SINGAPORE	0.77	SINGAPORE	Semi	L	N	L	N	M	0,3	-3.279	83
HONG KONG	0.54	HONG KONG	No	N	N	N	N	N	0	-4.276	89
VIETNAM	0.97	HO CHI MINH	No	L	N	N	N	N	0,05	-0.375	7
		CAI MEP	No	H	N	L	N	N	0,3	-1.932	68
TAIWAN	0.46	KAOHSIUNG	Semi	N	M	L	M	N	0,25	-4.669	99
		TAINGHUNG	No	N	M	L	H	L	0,4	-0.814	8
		TAIPEI	Semi	N	N	N	N	N	0	-2.681	75
PHILLIPINES	0.87	MANILA	No	M	N	N	N	L	0,2	2.445	-19
		DAVAO	No	M	N	L	N	L	0,25	-0.341	6
		BATANGAS	No	M	N	N	N	L	0,2	-0.663	8
MALAYSIA	0.76	KLANG	No	M	M	N	L	L	0,35	-3.334	78
		TANJUNG PELEPAS	No	M	M	M	M	M	0,6	-3.342	86
		PENANG	No	L	N	N	N	N	0,05	-0.367	-7
SOUTH KOREA	0.6	BUSAN	Semi	L	N	L	N	L	0,2	-1.887	51
		INCHEON	Semi	L	N	N	N	N	0,1	-2.422	51
		YEOSU	No	M	N	N	N	N	0,15	-2.831	48
JAPAN	0.35	KOBE	No	N	N	N	N	N	0	-3.127	39
		TOKYO	Semi	L	N	N	M	N	0,15	-2.418	38
		YOKOHAMA	No	L	N	N	N	N	0,1	-5.995	130
INDIA	0.93	CHENNAI	No	L	N	N	N	L	0,15	Not in CPPI	Not in CPPI
		JAWAHARLAL NEHRU	No	M	M	M	L	M	0,5	-1.786	31
		MUNDRA	No	H	N	L	L	N	0,35	-1.902	43
THAILAND	0.79	LAEM CHABANG	No	M	M	N	N	L	0,3	-1.807	39
		BANGKOK	No	M	M	N	N	L	0,3	1.024	-15
UAE	0.91	DUBAI JEBEL ALI	Semi	M	M	N	L	N	0,35	2.482	33
		KHOR FAKKAN	No	M	N	L	N	L	0,25	Not in CPPI	Not in CPPI
		KHALIFA	Semi	M	M	M	N	M	0,55	-2.795	60
SAUDI ARABIA	0.76	DAMMAM	No	L	N	N	N	L	0,15	-0.737	20
		JEDDAH	No	L	N	N	N	L	0,15	-1.862	46
		JUBAIL	No	L	N	N	N	L	0,15	-2.898	33
BRAZIL	0.81	PARANAGUA	No	M	M	N	N	N	0,35	0.659	16
		RIO GRANDE	No	M	M	L	L	L	0,45	-1.332	42
		SANTOS	No	N	N	N	N	L	0,05	-1.376	28
US	1	LONG BEACH	Fully	H	M	L	H	L	0,65	3.175	-96
		LOS ANGELES	Fully	H	M	M	H	L	0,7	2.889	-82
		NY NJ	Semi	M	L	L	M	L	0,45	-0.969	10
AUSTRALIA	1.2	BRISBANE	Semi	M	M	H	L	L	0,55	0.569	-8
		MELBOURNE	Fully	H	N	M	N	L	0,4	1.676	-40
		BOTANY	Fully/Semi	M	M	L	M	N	0,5	3.907	-63

Table 7.17: Overall Table with results from the Website Content Analysis, the Median Time spent in ports for 2018, Container Port Performance Index 2020 and automation level of ports in the sample

Firstly, a Pearson correlation analysis was conducted between the “smart score” and the “CPPI total score” (statistical approach). Through this analysis the author was able to compare the relationship between the smartness and the performance of the 65 ports included in both samples. The Pearson correlation coefficient (or “R”) measures the strength of the linear relationship between two different variables. The range of the R value is between -1 and 1. An R that is greater than zero signifies a positive relationship, whereas an R value that is less than zero indicates a negative relationship. Moreover, the closer the R is to -1 the stronger the negative linear relationship is and the closer the R is to +1 the stronger the positive linear relationship is indicated.

The scatter plot (or scatter diagram) in Figure 7.13 shows the relationship between the two variables **(“smart score” and “CPPI statistical approach”).** In the analysis performed the R was equal to 0.39. This value indicates that the linear relationship between the performance total score and the smart score for the ports in the sample can be characterised as “positively moderately correlated”. The positive linear correlation coefficient (R) for the ports in the sample indicates that as one variable increases the other variable increases as well. However, in the case of the CPPI statistical approach, as the CPPI performance score increases (Yokohama port was the highest performing port and had a total score of -5.995, while port Botany was the lowest performing port and had a total score of 3.907) this indicates that the performance drops. Therefore the higher the CPPI performance score the lower the performance. Therefore, as the smart score increases the CPPI performance score decreases. More specifically, the results show that ports with a high smart score tend to have a high total score in the CPPI statistical approach, which means a low performance level, and thus, although the R value indicates a “moderate positive correlation” between the two variables, the relationship is actually negatively correlated.

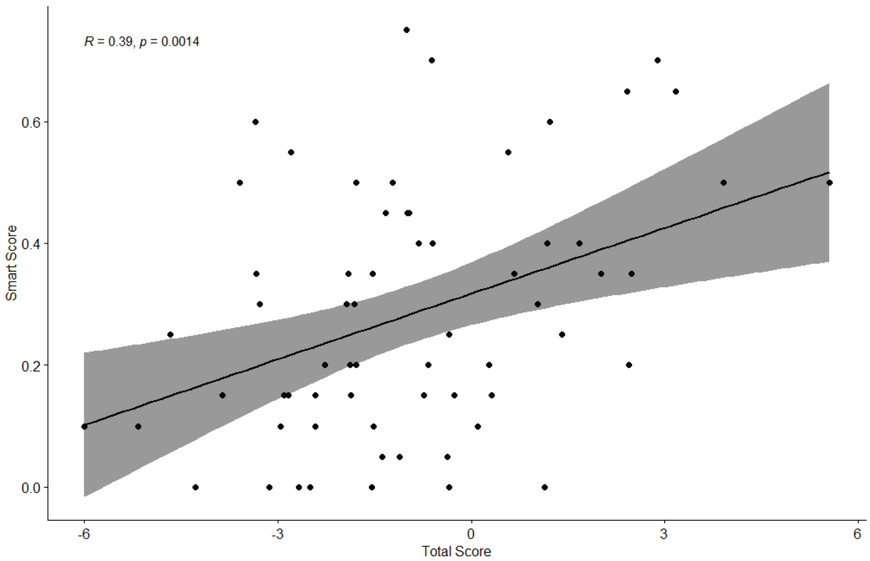

Figure 7.13: Scatterplot for correlation analysis between smart score and CPPI total score (statistical approach)

The "x variable" is moderately correlated with the "y variable" with correlation coefficient equal to 0.388. The statistical test checks the Null hypothesis that $R = 0$ (no correlation between two variables) versus the Alternative hypothesis that $R > 0$ or $R < 0$ (which means R is away from zero).

This correlation is statistically significant, as the p-value = 0.001378 < 0.01, which is less than the significance level a = 0.01. If p-value is < than the significance level alpha, which in this case can be set to 0.01, the conclusion is that there is enough evidence to reject the Null hypothesis, which means there is enough evidence from the data to conclude that the Pearson correlation is not equal to 0.

In other words, the productive ports in the sample, namely those that score low in the CPPI (statistical approach), which in this case means that they are highly productive, are not found to be scoring high in their smart score. Consequently, this analysis finds that ports which aim to be productive focus more on improving their performance, rather than focusing on efforts to become smart.

Next, the author performed a Pearson correlation analysis between the **“smart score”** and the **“CPPI administrative approach”**. The scatter plot (or scatter diagram) in Figure 7.14 shows the relationship between the two variables. In the analysis performed for the ports in the sample the R was equal to -0.38. This value indicates that the linear relationship between the smart score and the CPPI performance score can be characterised as “negatively moderately correlated”.

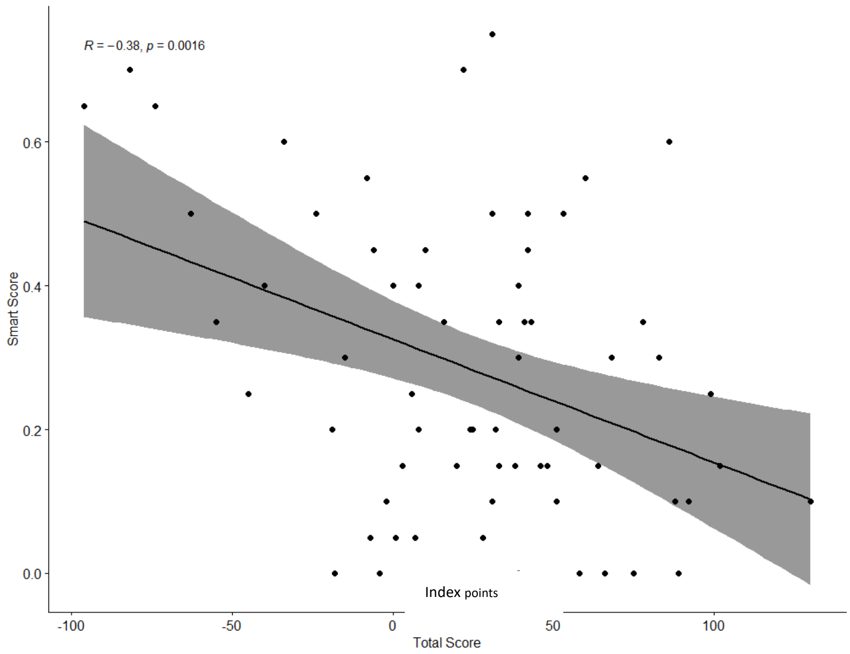

Figure 7.14: Scatterplot for correlation analysis between smart score and CPPI index points (administrative approach)

The negative linear correlation coefficient (R) found for the ports in the sample indicates that as one variable increases the other variable decreases. More specifically, as the smart score increases the performance of the ports decreases, and vice versa. The findings show that there is a negative relationship among the two examined variables and thus the conclusion is that the more productive a port is the less smart focus it shows.

The "x variable" is moderately correlated with the "y variable" with correlation coefficient (R) equal to -0.38. This correlation is statistical significant, as p-value = 0.001561 < 0.01, which less than the significance level a = 0.01. Therefore, the conclusion can be withdrawn that there is enough evidence to reject the Null hypothesis, which means there is enough evidence from the data to conclude that Pearson correlation is not equal to 0.

Consequently, this analysis is in line with the results of the correlation analysis performed for the CPPI statistical approach, and finds that ports of greater productivity level focus more on improving their performance, rather than focusing on efforts to become smart.

7.7 Conclusion

This phase of the research used Website Content Analysis to identify the extent of adoption of the world’s major ports regarding the disclosure of information in their corporate websites focusing on their smart, green and sustainability related practices and efforts. Overall, findings reveal that ports located in Europe, US and Australia tended to have higher levels of smart, green and sustainability related communication compared to Asian ports, in terms of disclosure extent in their corporate websites. The evidence from this analysis suggests that online communication of smart strategies is relatively low, regardless of the advent of the Fourth Industrial Revolution and the major interest that is reported nowadays towards smart port development. It is recommended that the top management of ports should commit to adopt the four fundamental aspects that form the Smart Port of the future in their website marketing efforts and thus reflect their practices.

Finally, the correlation analysis conducted between "smart score" and the "CPPI 2020 scores", were in line with the conclusion drawn also on Chapter 6; that automation does not also imply increased performance, contrariwise, it implies a decreased performance as the median time spent in port (days) of automated ports was high. Similarly, in the final Section of Chapter 7, the results indicated that as the smart score increases the performance of ports drops, as ports with lower scores (in the statistical approach this implies high performance) and higher index points (in the administrative approach this implies high performance) show a low smart score. In conclusion, ports in the sample that put high effort on environmental, sustainability, and smart priorities, (considering from the information outlined in their websites) appear to demonstrate lower performance, and vice versa.

Chapter 8. UK Case Study

8.1 Introduction

Having analysed the extent to which ports around the world adopt the smart, green, and sustainability related practices, this Chapter focuses on the way in which UK ports respond to the need for development of smart, green and sustainable ports. It analyses the current state of UK ports, outlines the smart score of the major UK ports, and explores how they plan to adapt to the changing operational landscape in the port sector. Based on twelve semi-structured in-depth interviews with key industry stakeholders, and using Thematic Analysis for the qualitative analysis of the data collected from the interviews, the author in this Chapter addresses the fourth and fifth research questions, related to the net benefits generated from the application of technological advancements in port operations. This Chapter also investigates how different external factors affect the adoption of technological advancements and the maximisation of the potential gains for port operators and the local economy.

Section 8.2 describes the UK port sector, while Section 8.3 discusses the smart score of the major UK ports. Next, Section 8.4 presents the data collection process adopted to explore deeper the practices adopted currently in UK ports. Section 8.5 analyses the findings of the Thematic Analysis and finally, Section 8.6 discusses the conclusions of this Chapter.

8.2 The UK port sector

The UK is considered one of the world's dominant maritime nations (Germond, 2015). Being an island nation, the UK's maritime sector is a pivotal part and fundamental enabler of its economy, as 95% of goods are moved by ship and through UK ports (Maritime UK, 2019). The macroeconomic contribution of the maritime sector to the UK through employment, turnover, Gross Value Added (GVA), and through compensation of employees is very substantial. It is estimated that the sector in 2017 supported 220,100 jobs across the UK, over £47bn in business turnover and £17bn in GVA (Maritime UK, 2019).

During the past 25 years, UK ports have transitioned from being largely state-owned enterprises to adopting the model of privatisation of terminal and port operations, where the port's regular functions are shifted to private enterprise and a large-scale transfer of physical assets is noticed (Wilmshurst, 2021). In general, there are three main models of port ownership in the UK, namely private, municipal and trust. More specifically, the majority of the UK's biggest ports, handling 69% of the total tonnage, are privately owned and operated (Monios, 2017). From all ports in the UK, 161 report commercial traffic, while all others deal with fishing craft and leisure (Monios, 2017). Almost 98% of the commercial traffic in the UK is handled by 53 ports classed as 'major' and the remainder 2% is handled by 108 'minor' ports (Monios, 2017). On the other hand, when a port is operated by a trust, rather than reporting to its shareholders, all its profits are reinvested in the port itself. Trust ports are independent statutory bodies, governed by their own statues and controlled by an independent local board. However, only 20 from an overall of more than 100 trust ports have an annual turnover exceeding £1m (Monios, 2017). Finally, municipal ports are operated and owned by local authorities and mainly focus on leisure craft, with only a few handling some commercial traffic (Monios, 2017).

Moreover, regardless of their size, ports are major sources of employment within their port-city areas, and through all their activities they contribute to local economies in many ways (British Ports Association, 2020). Therefore, the UK port sector's aim is to work with the Government to support economic development in port-city communities, to create the conditions for further private investment by ports, to drive growth and foster collaboration (Maritime UK, 2019). More specifically, municipal and trust ports governance structures are specifically designed to reflect the needs of local communities and local markets (British Ports Association, 2020).

As was mentioned above, the UK is one of the world's dominant maritime nations (Germond, 2015). However, leading maritime nations only preserve their position because they plan and adapt for the future (Department for Transport, 2019). Since the world faces a fourth industrial revolution, as was previously discussed in Chapter 2, the rapid development of technology leads to reconceptualising how individuals work and live. Similarly, the UK port sector is also facing arduous challenges, from the responsibility to maintain a healthy mixture of public and private markets, to the emergence of new digital technologies, and from many unforeseen hazards to the resilience of the UK ports system (Shaw et al., 2019). It is thus working towards growing with determination and strength, to be able to meet the current and future challenges.

Currently, the key national priorities for the UK port sector, vital to ensure its global position and competitiveness, are focused on five main areas; namely environment, innovation, regional growth, people and competitiveness (Maritime UK, 2019). Based on these priorities, and recognising the critical role of the maritime sector to its economy, the UK

Government has launched in 2019 its ambitious **Maritime 2050 strategy**. Maritime 2050 is the UK government's long-term national strategy for the sector, where industry is committed to collaborate with government to drive towards a golden maritime future. Maritime 2050 has its focus on seven themes; namely the UK's competitive advantage, infrastructure, environment, technology, people, security, and trade, as these were considered fundamental for the implementation of a national strategy and vision for the future. Each theme consists of recommendations seeking to introduce the government's short, medium, and long-term priorities. Some refer to the government, some are addressed to the UK maritime sector which comprises of social partners, and most can be only achieved through mutual endeavour. Thus, it is crucial for the government and the industry to work in a continuous partnership towards achieving the vision set out in Maritime 2050.

For the purposes of this research, Maritime 2050 was used as the basis for the UK case study interviews and the Participant Observation study. The vision set in the Report was outlined by the author when initiating the discussion with the interviewees, as the current status of UK ports and the plans to reach the goals set in Maritime 2050 were the main themes explored.

Developing green and smart ports are at the heart of the government's vision for the UK maritime sector, as outlined in Maritime 2050, and therefore UK ports need to minimise their impact upon the environment and adopt smart strategies and technologies to become more efficient, green and digitilised. All these actions, strategies and technologies were explored through the 12 semi-structured in-depth interviews reported in this Chapter.

8.3 Smart Score of major UK ports

The author in this Section explored the smart score of the major UK ports (national level) and compared these against the 71 ports analysed in Chapter 7 (global level). The top 10 UK ports by TEU throughput in 2018, as outlined in Tables 8.1 and 8.2 below, are the Port of Felixstowe, Port of Southampton, Port of London, Port of Liverpool, and Port of Tees and Hartlepool, Port of Grimsby and Immingham, Port of Hull, Forth Port, Port of Belfast and Medway Port.

Department for Transport Statistics
Port Freight Statistics
Table PORT0303
UK major port freight traffic by top 30 UK ports for each cargo type (year filter)

Cargo Group	Lo-Lo
Cargo Category	All Lo-Lo
Metric	Units
Year	2018
Sort values by...	Total

Thousand Units

		2018				2017	
Rank	Port	Inwards	Outwards	Total	Percent [4]	Total	Percent
1	Felixstowe	1,116	1,099	2,215	37.2%	2,433	41.1%
2	Southampton	606	554	1,160	19.5%	1,169	19.7%
3	London	469	500	969	16.3%	801	13.5%
4	Liverpool	236	235	471	7.9%	433	7.3%
5	Tees & Hartlepool	119	117	235	3.9%	203	3.4%
6	Grimsby & Immingham	95	90	185	3.1%	199	3.4%
7	Hull	87	80	167	2.8%	147	2.5%
8	Forth	76	70	146	2.5%	138	2.3%
9	Belfast	65	63	128	2.1%	125	2.1%
10	Medway	43	27	71	1.2%	52	0.9%
11	Bristol	32	33	65	1.1%	58	1.0%
12	Clyde	29	27	56	0.9%	53	0.9%
13	Tyne	15	17	33	0.5%	27	0.5%
14	Portsmouth	15	16	30	0.5%	40	0.7%
15	Dover	7	6	13	0.2%	3	0.1%
16	Warrenpoint	6	6	12	0.2%	15	0.3%
17	Aberdeen	1	1	1	0.0%	17	0.3%
18	Cardiff	~	~	~	0.0%	2	0.0%
19	Harwich	~	~	~	0.0%	~	0.0%

Table 8.1: UK major port traffic by top 30 UK ports for the Lo-Lo category (metric: units)

Source: Department for Transport Statistics

Department for Transport Statistics
Port Freight Statistics
Table PORT0303
UK major port freight traffic by top 30 UK ports for each cargo type (year filter)

Cargo Group	Lo-Lo
Cargo Category	All Lo-Lo
Metric	Tonnage
Year	2018
Sort values by...	Total

Thousand Tonnes

		2018				2017	
Rank	Port	Inwards	Outwards	Total	Percent [4]	Total	Percent
1	Felixstowe	14,387	10,133	24,521	35.8%	25,346	39.6%
2	London	9,200	4,431	13,630	19.9%	10,448	16.3%
3	Southampton	5,295	4,037	9,332	13.6%	9,560	14.9%
4	Liverpool	3,865	1,931	5,796	8.5%	5,424	8.5%
5	Tees & Hartlepool	2,108	701	2,808	4.1%	2,160	3.4%
6	Forth	904	1,485	2,389	3.5%	2,208	3.4%
7	Grimsby & Immingham	1,832	289	2,121	3.1%	2,281	3.6%
8	Hull	1,535	478	2,013	2.9%	1,773	2.8%
9	Belfast	960	768	1,728	2.5%	1,694	2.6%
10	Medway	1,325	53	1,378	2.0%	661	1.0%
11	Bristol	657	309	966	1.4%	807	1.3%
12	Clyde	129	513	641	0.9%	599	0.9%
13	Tyne	212	250	462	0.7%	399	0.6%
14	Portsmouth	279	17	296	0.4%	305	0.5%
15	Warrenpoint	62	134	196	0.3%	221	0.3%
16	Dover	91	72	163	0.2%	3	0.0%
17	Aberdeen	4	9	14	0.0%	81	0.1%
18	Cardiff	1	0	1	0.0%	21	0.0%
19	Harwich	0	~	~	0.0%	5	0.0%

Table 8.2: UK major port traffic by top 30 UK ports for the Lo-Lo category (metric: tonnage)

Source: Department for Transport Statistics

Table 8.3 outlines the factors and categories that were used in the Website Content Analysis in Chapter 7 to identify the smart scores of the 71 ports around the world.

Category	Environment, Sustainability and Community						Monitoring				Certification and Reporting			Energy Sources and Incentives			Technology and Innovation				Smart Score
Factors	Environment in Menu Bar	Environmental in mission/ vision/values	Sustainability in Menu Bar	Sustainability in mission/vision/ values	Community/social/ society in Menu Bar	Community/social vision/mission/ values	Air monitoring	Water monitoring	Noise monitoring	Energy monitoring	Online Standalone Environmental Report	Environmental ISO 14001 Certification	Online Standalone Sustainability Report	Renewable Energy Sources	Shore-side power supply – cold ironing	Fee incentives for clean vessels	Digital/smart/ innovation in Menu Bar	Digital/smart /innovation mission/vision /values	Port Community System	Blockchain	
Felixstowe					•	•	•				•	•		•					•		0.35
London												•									0.05
Southampton		•	•				•					•		•				•			0.25
Liverpool	•		•	•	•	•	•					•									0.35
Tees & Hartlepool					•							•									0.1
Forth	•	•			•	•						•									0.25
Grimsby &Immingam		•	•	•	•	•	•	•				•									0.4
Hull		•	•	•	•	•	•	•				•		•							0.45
Belfast	•	•		•	•	•	•					•		•				•			0.45
Medway	•		•	•	•	•	•					•									0.35

Table 8.3: Overall Table with results from Website Content Analysis of UK major ports

Based on Table 8.3, results show that overall UK major ports present high levels of green and sustainable communication in their mission/vision/values, and the majority also include either Sustainability or Environment in their Menu bars. Moreover, results reveal that on the when considering the UK (national level) most UK ports have an active approach towards community engagements, as 8 out of the 10 major UK ports analysed are outlining their corporate social responsibility in their websites and are highlighting the importance of being community-oriented as ports.

As far as “Monitoring” is concerned, 70% of the ports report that they monitor their air quality, however only two monitor their water consumption and none report to monitor noise pollution and energy consumption.

It is also observed, that only one port has a standalone Environmental Report, namely the Port of Felixstowe and none of the ports report annually on their Sustainability progress. Notably, all major UK ports have obtained the ISO14001 Certification, as they have developed their own EMS that complies with the specified requirements outlined by ISO.

Additionally, renewable energy sources are becoming more and more popular within ports during the past few years, and based on the results almost half of the UK major ports have started to install renewable energy sources within their land. However, the “Energy sources and incentives” category as a whole has a low level of adoption among UK ports.

Interestingly, the presence of the factors included in the “Technology and Innovation” category is significantly low, as only two ports mention digitilisation and smart strategy in their missions/vision/values, while only ones states that it has adopted a Port Community System in its operations.

In conclusion, the average smart score of UK major ports is 0.3, which is identical to the average smart score of the 71 ports analysed within Chapter 7. The smartest ports among UK major ports is Hull, Belfast and Medway.

8.4 Data Collection

Since this study explores the current state of UK ports, the wider benefits or impacts generated from the adoption of new technologies in the UK port sector, the benefits and barriers to adoption of the application of technological advancements in port operations, the future plans and policies adopted for UK ports to become smarter, greener and sustainable, it was deemed necessary to include interviews in the methodological design, to get a precise interpretation of all the above (Saunders, 2019). The author therefore conducted 12 in-depth semi-structured interviews with relevant key industry stakeholders, to explore deeper the UK ports' case.

To collect the necessary data, the researcher conducted in-depth semi-structured interviews with key industry stakeholders. The use of semi-structured and in-depth interviews may lead the discussion into areas that the researcher had not previously considered and uncover aspects that may have not been revealed through other data collection methods (Saunders, 2019). This is because interviewees may use ideas or words in a specific way, thus adding significance and depth to the data leading to a detailed and rich set of data (Saunders, 2019). Moreover, semi-structured in-depth interviews provide the chance to investigate further a response when the interviewer wants from the interviewee to build on, explain further on their previous answers (Saunders, 2019).

The author, to gain in-depth information from the selected stakeholders, created an effective and thorough *interview protocol*. The identification of the subject areas and the preparation of the interview questions enabled the author to structure the flow of the interview. The interviews were audio recorded, always with the interviewee's consent, and were then transcribed, this being the standard procedure in qualitative research (Auerbach and Silverstein, 2003). Figure 8.1 presents the interview questionnaire used by the author for the twelve in-depth semi-structured interviews. The author selected to use semi-structured interviews, using the questionnaire only as a general interview guideline, without following strictly the order of questions. This encouraged respondents to answer the questions in their own words and led the discussion into areas not previously considered.

Interview Agenda

Newcastle University

Marine, Offshore and Subsea Technology Group
School of Engineering

Research Focus: Port operation, efficiency and technological advancements: analysis of local costs and benefits.

Interviewer: Eleni Bougioukou, PhD student (E.Bougioukou1@newcastle.ac.uk).
Research Supervisory Committee:Professor John Mangan (Newcastle), Dr Paul Stott (Newcastle) and Dr Alessio Tei (Genoa).

The following are some points I would like to explore during our discussion:

1. How are port technologies evolving (what are the current / likely future technologies of interest)?
2. Are ports planning sufficiently for new technologies?
3. What impact will these technological changes have on skills, jobs and training?
4. Data: what is/can be collected, and what value can be leveraged from this data?
5. What are the net benefits (economic, social, environmental, safety) to the hinterland and how can they be measured?
6. Barriers/incentives to developing smart ports:
   - Ownership?
   - Unionisation?
   - Location?
   - Government?
   - Client base?
   - Costs?
   - Skills/ capabilities?
7. What tools can we use to evaluate smart ports?
8. Can we rank ports according to their "smartness"?
9. Are there other stakeholders whom you would recommend that we contact in relation to this research?

Figure 8.1: Interview Questionnaire

The interviewees were selected on the grounds of in-depth knowledge in port operations and technological advancements in the UK port sector. The author employed the technique of the "key informant" which collects information through a selected limited number of interviewees-respondents (Sihyun Kim and BongGyu Chiang, 2014; Cousins et al., 2006; Phillips, 1981). "Key informant interviews" are in-depth interviews of a non-random selected group of experts who essentially consist of an expert source of information and are most knowledgeable of an issue or organisation (Lavrakas, 2008; Marshall, 1996). The organisation, job position, involvement level, working experience were used as selection criteria of the interviewees.

Additionally, the “snowball sampling method” or otherwise stated “chain-referral sampling” was adopted by the author to collect the required data. This is a popular non-probability sampling technique, which relies on the provision of referrals from initial respondents to other ‘subjects’ believed to acquire the characteristics/knowledge of interest to the researcher (Johnson, 2014). The disadvantages of this method include the non-random selection procedures, confidentiality concerns, reliance on the informants’ subjective judgement, correlations between selection probabilities and network size, while the advantages include the efficiency and the zero cost (Johnson, 2014).

Respondents were approached via e-mail and those who accepted the interview request were interviewed in person or via video call. After the careful selection of candidates, twelve interviews with industry stakeholders were conducted in 2020 and 2021, ranging between 45 and 60 minutes on average. The first three interviews were conducted in person, while the other 9 online via video call, due to the COVID19 restrictions. The overall interview objective was for the respondents to describe the current status of UK ports, which are the current technologies of interest in the UK port sector, how new technologies have affected the port sector’s efficiency, the impact of new technologies in jobs and required skillsets, what net benefits are generated for the hinterland, and how external factors affect the maximisation of the potential gains for port operators and the local economy. Finally, the interviewees were asked whether ranking ports according to their ‘smartness’ would be possible in the future and what tools could be used for this process.

To ensure the validity of the results and to get highly valuable insights, the twelve interviews comprised two groups of stakeholders with six within each group, spanning external stakeholders (e.g. government bodies, consultants) and internal stakeholders (e.g. port stakeholders). The interviewees were selected among experts in various senior positions of the port industry and included Operations and IT department directors, Managers, Chief Executives, port-representatives and Senior Consultancy Analysts. Due to confidentiality reasons neither company nor interviewee names are provided in this written dissertation, but have been made known to the student’s supervisory panel. .

As mentioned above, each of the two groups of stakeholders comprised 6 interviewees. Within the internal stakeholders group, the author selected 6 interviewees working in the top 5 UK ports by TEU throughput in 2018, as outlined in Tables 8.1 and 8.2 presented in Section 8.3; namely the Port of Felixstowe, Port of Southampton, Port of London, Port of Liverpool, and Port of Tees and Hartlepool. The 6th port selected was the Port of Tyne, due to the fact that it hosts the UK's first and only 2050 Maritime Innovation Hub, aligned to the Maritime 2050 strategy.

Moreover, for the selection of the 6 interviewees belonging to the second group of external stakeholders, the author used the snowball sampling method, as was described above. Table 8.4 presents the full list of the 12 interviewees.

Company	**Classification**	**Position**	**Respondent Ref.**
1) Port	Internal Stakeholder	Port Captain	R1
2) Port	Internal Stakeholder	Yard & Gate Superintendent	R2
3) Port	Internal Stakeholder	Head of Technology and Development	R3
4) Port	Internal Stakeholder	Chief Technology Officer	R4
5) Port	Internal Stakeholder	UK Chief Operating Officer	R5
6) Port	Internal Stakeholder	Commercial Manager, Logistics	R6
7) Government Body	External Stakeholder	Maritime Technology expert in DfT Maritime Directorate	R7
8) Consultancy company	External Stakeholder	Director, Port Operations & Technology for Smart Ports	R8
9) Consultancy company	External Stakeholder	Senior Analyst, Ports & Terminals	R9
10) Consultancy company	External Stakeholder	Port Representative UK & Ireland	R10
11) Innovation Business	External Stakeholder	Principal Technologist	R11
12) Port Association	External Stakeholder	Chief Executive	R12

Table 8.4: Overview of Interview Participants

8.5 Data Analysis

The data analysis was conducted upon completion of the last interview through thematic analysis and using NVIVO software (since 2020 NVIVO have changed the way they version their software and no longer refer to NVIVO using a number, therefore no version number is used in the author's description) in combination with manual techniques (Braun and Clarke, 2006). Initially, the author developed a manual coding system on printed transcripts, using a variety of post-it notes, highlighters and pens of different colours to assign codes and themes into the data. Manual coding therefore requires the researcher to read thoroughly through the data and manually develop and assign codes and themes to the available text. Although manual coding is very time-consuming, it was deemed necessary to combine this process with the electronic coding (using NVIVO software), as this allowed the author to code for as many interesting themes as possible and helped streamline the overall analysis process (Basit, 2003). The NVIVO software was used as a tool for further data management and analysis, as it can give a deeper understanding and refinement of the available data.

First, the author transcribed all interviews and generated transcripts that were used for the thematic analysis of the data. The interview transcripts were printed and read several times and the second step was to produce initial codes from the available dataset. The coding phase started with a manual coding process; highlighters and post-it notes were used to identify the interesting ideas and statements in the printed transcripts and were assigned specific codes. After the completion of the coding phase, the author identified the themes occurring across the dataset. Next, and following the manual coding process, the NVIVO software was employed to further identify codes within the data. The total of the identified codes were matched with data extracts demonstrating that code, leading to a collation of extracts within each code. The NVIVO software helped this process to be much easier than if only the manual process would have been employed. Appendix D moreover represents an exemplary extract of the coding surface in NVIVO.

Once all data was analysed, coded and collated, the author refocused the analysis at the broader level of themes. During this step, the identified codes were sorted into potential themes and the coded extracts were collated within the identified themes (Braun and Clarke, 2006). The overarching themes were then reviewed and refined, to ensure they were in line with the dataset and the coded extracts. Finally, the report was generated, where the author wrote a detailed analysis for each individual theme which are presented below in Section 8.6.

8.6 Results – Identified Themes

Given the above description, and through the thematic analysis the author identified codes, which were subsequently converted into ten themes. The overarching themes that were identified within the dataset are outlined in Table 8.5.

❖ **Port industry features**
❖ **Technological advancements in UK ports**
❖ **Planning for new technologies**
❖ **Change in required skillset**
❖ **Impact on number of jobs**
❖ **Data collection challenge, value and integration**
❖ **Net benefits generated from technological advancements**
❖ **Barriers to development of smart ports**
❖ **Incentives to development of smart ports**
❖ **Ranking of smart ports**

Table 8.5: Identified themes from analysis

8.6.1 Port industry features

The results identified a recurrent theme in the interviews; that the port industry is many years behind in terms of automation and intelligence compared to other industries, as for example the manufacturing or automotive industries. All stakeholders interviewed mentioned that the port industry is "*conservative* and *resistant to change*", as ports usually adopt a technology only when it is already proven and are hesitant to implement new technologies first. Ports were therefore characterised as *"slow adopters"*. More specifically, interviewees highlighted that:

> “Ports are adapting today a lot of what other industries have adopted probably 15-20 years ago and are very much behind the times compared to the process, manufacturing or automotive industries.” (Respondent R3, 2021)

> “I think it's due to the culture of the port industry, as it is a very conservative industry and with a lot of resistance to change.” (Respondent R11, 2020)

> “I think there is a lot of cultural nervousness about adopting new technologies, and so a lot of people in the port sector are looking to learn from someone else [another industry or another port] rather than try and be the first mover. They are very worried about being the first mover, so they prefer to be third or fourth so they can learn from other people’s lessons and hopefully have an easier adoption process, rather than proactively adopting first a new technology or process”. (Respondent R7, 2020)

When analysing the reasons behind this resistance to change, one respondent highlighted that taking away the inefficiencies is surprisingly not actually convenient to some stakeholders:

> “So it's thinking about the reasons why our [UK] ports are collectively resistant to change. It's not because they think it's a bad idea, it's partly because there are so many stakeholders in the industry that have different interests. So think about the freight forwarders and the cargo agents and truckers and all these stakeholders involved, they are happy with keeping this status quo of old-fashionism of old and poor systems. So if you add something new that disrupts this or changes it, some people lose, some people win. Therefore, if you take away these inefficiencies it is not convenient to them, as the inefficiencies are where these people get paid from and by removing them they might lose their job”. (Respondent R8, 2020)

However, as one interviewee suggested, the *aggressiveness* of the port sector nowadays into applying new technologies shows great dynamics that is not similar to any other industry. Thus, although slow adopters, ports are currently aggressive when it comes to the adoption of new technologies:

> "…But that said, their [ports'] aggressiveness into using that technology and applying it is very strong, due to having a lot of other dynamics which the automotive or chemical processing industries do not have, like for example the impact of weather, more humans involved into the operations, and so automation has to play a bigger part". (Respondent R3, 2021)

It has become also apparent that the maritime industry as a whole is perceived as very traditional and old-fashioned and is not attractive to younger workforce, this causing a lack of the required skillset, which will be described in the next sections:

> "Maritime as an industry is not seen as very attractive to young engineers and data scientists so there is more to be done in this field". (Respondent R11, 2020)

> "But unfortunately, as an industry [ports], we do not communicate that [the fact that the port industry is changing and aims to become more digitalised] to young people. So therefore, they are not entering the sector." (Respondent R10, 2020)

With regard to what can be done to change this situation, one of the respondents highlighted that bringing into the industry people coming from different industries can be a key factor to enable the culture change that is required to occur in the port industry:

> "… when I talk to people in ports who come from different industries [have a background in other industries] they can actually see the problems and they can see the value of new technologies compared to when I talk to people who have been in this [port] industry for a very long time. It's difficult for them to see the value. A leadership that is coming from a different industry can bring into the port industry leaders that are actually very supportive of applying new technologies and trying new things". (Respondent R11, 2020)

The author created a **'word cloud'** for the "port industry features" theme in order to create a visual interpretation of word frequency and to identify the focus of the written material, thus giving an insight into the most prominent words mentioned in the extracts within this theme. Within a 'word cloud' the more frequently a term appears within the text being analysed, the larger the word appears in the figure generated, and word clouds are increasingly being employed as a simple tool to identify the focus of written material (Atenstaedt, 2012). Figure 8.2 visualises the word frequency in the text as a weighted list.

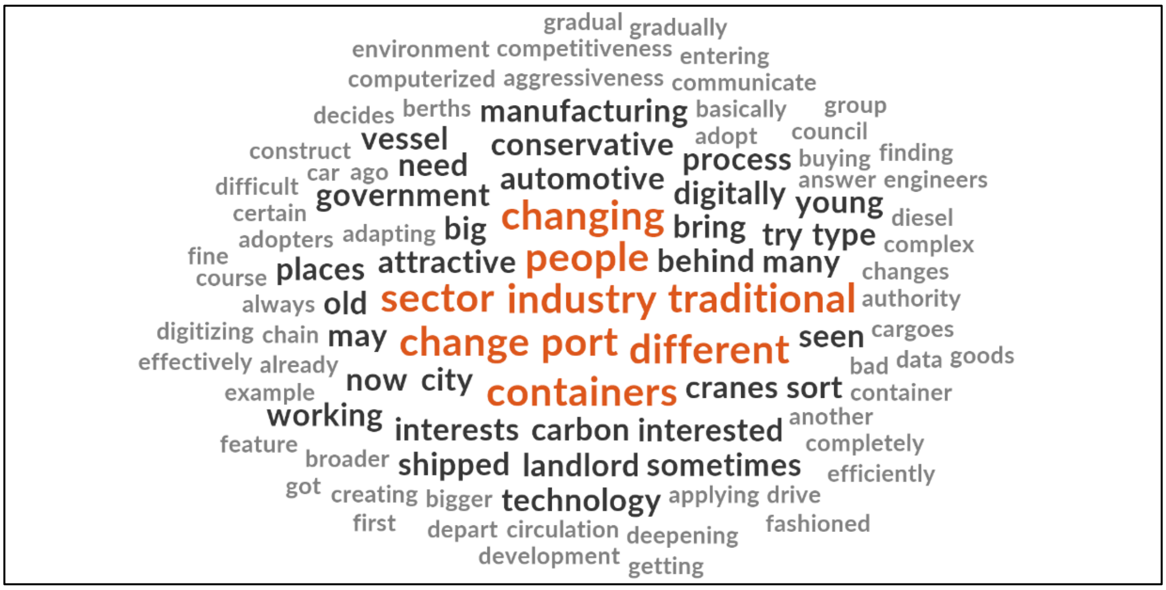

Figure 8.2: Word Cloud generated for the “port industry features” theme

Figure 8.2 illustrates the main words used by respondents when referring to the “port industry features” theme. It can be seen that three of the most prominent words highlighted are ‘traditional’ and ‘changing’ and ‘different’. This finding does conform to the outcomes described above, as respondents characterised the port industry as very ‘traditional’ and ‘conservative’, but have highlighted that this is ‘changing’ in recent years and ‘young people’ should be made aware of this change, in order to become attracted to the port industry and stop perceiving it as ‘old-fashioned’.

8.6.2 Technological advancements in UK ports

It has become apparent that to keep up with the competitiveness among ports, the only solution is **automation**. As vessels become wider, bigger and are carrying more volume, the challenge for ports is to serve them as quickly, efficiently and effectively as possible so that the vessel can depart on time to get to the next port of call, hence avoiding bottlenecks by maintaining the heartbeat of the vessel circulation:

> “…the only way for ports to achieve the current requirements is by introducing automation into their operations. The automation should start with the quay

crane [ship-to-shore crane], with technologies that involve smart scanning of the vessels and making the cranes more intelligent to aid the crane drivers' ability and to operate the cranes faster and more efficiently." (Respondent R3, 2021)

Mainly mentioned was also the fact that automation does not imply the elimination of the human element, but is just a change in the type of job that the operator performs:

"By automation I don't mean eliminating the human element, but instead of the crane driver driving the crane and being on the crane itself, he is in a control room and is operating the crane remotely, this enhancing also the safety side of the job, apart from the potential productivity improvements" (Respondent R4, 2021)

The benefits arising from automation are therefore twofold; on one hand lies the health and safety aspect, and on the other the productivity aspect. This however is controversial, as one respondent highlighted that automation does not necessarily imply higher productivity and performance, this being in line also with the conclusions derived in Chapters 4 and 5, where the author concluded that automated and smart ports tend to have lower performance scores compared to the non-automated and less smart ones:

"And to start with, the productivity at London Gateway [port] was significantly worse compared Southampton [port], because there was a big learning curve of using the automated technology. That gap has closed over time, but Southampton's [traditional terminal] productivity is still higher compared to London Gateway's [automated terminal]." (Respondent R5, 2021)

It was hence found, that most respondents regarded automation as the primary technology of interest currently for UK ports, which will take away the inefficiencies that still exist, thus eliminating bottlenecks in the ports' operation. The author elaborated Table 8.6 using the data generated from 'text search queries' in NVIVO. More specifically, Table 8.6 illustrates in detail the responses of each Interviewee around the theme of 'technological advancements in UK ports', and a 'square symbol' is used in the table to capture the respondents that mentioned this specific technology (i.e. automation). Thus, the word 'automation' was used as the key word for the 'text search query' in the interviewees' description of the current landscape in UK ports when it comes to technological advancements.

Code system	R1	R2	R3	R4	R5	R6	R7	R8	R9	R10	R11	R12
• New Technologies ○ **Automation**	■	■	■	■		■		■		■	■	■

Table 8.6: Automation mentioned as key technology currently in the port sector

Another technology reported by respondents, which brings the capabilities of other port technologies forward, was around the **5G network** adoption in ports. Some of the respondents highlighted the benefits brought by the adoption of 5G networks in ports:

> "…although having been fortunate and having had great fibre networks that were generating a good connectivity responding to the needs of our port so far, in some applications, you need that further remoteness and you can only get that by a 5G network connection " (Respondent R3, 2021)

> "I think the other thing that a lot of people talk about, and is likely to have a big impact, is on the hardware side is around what more can be done with 5G networks in a port environment. I think that will make a big difference and will allow people to do clever processes and modelling of what they're doing with their assets and how they can use the most effectively." (Respondent R7, 2020)

The findings revealed that the adoption of a 5G network is an enabler to other projects, as it provides the base connectivity upon which other innovative technology can be built:

> "…and 5G brings different benefits to different ports, depending on the kind of their use cases. Many are thinking for example about how they can make their operations more sustainable, from the environment side of things". (Respondent R11, 2020)

Therefore, the adoption of a 5G network brings faster speeds, greater capacity and lower latency, which can help towards the use of:

- Autonomous land and water vehicles used by the port
- Remote-controlled quayside plant and machinery

- Remote pilotage of port vessels (pilot boats, tugs)
- IoT sensors to collect real time productivity data from operations
- Track and track of plant, vehicles, cargo and personnel
- Enabler of virtual reality (VR) and augmented reality (AR) applications
- Environmental monitoring
- Health and Safety monitoring and alerting

The author elaborated Table 8.7 using the data generated from 'text search queries' in NVIVO, and includes the respondents that mentioned 5G network adoption as one of the technologies of interest currently in the UK port sector.

Code system	R1	R2	R3	R4	R5	R6	R7	R8	R9	R10	R11	R12
• New Technologies ○ **5G network**			■				■		■		■	

Table 8.7: 5G network adoption as technology of interest in the UK port sector

The technologies and strategies of interest currently in the UK port sector mentioned by respondents were further enriched by **digitilisation**. The need for the port sector to become more digitalised, moving away from paper-based transactions and manual processes, and adopting smarter strategies and software that will give them greater intelligence and capability to reduce inefficiencies, can only be achieved through the adoption of digitilisation:

> "So, a lot has been focused on removing paper based transactions and streamlining processes and using current technology. … But we have seen big steps, as UK ports have been gradually moving away from paper based transactions. So we started off with optical character recognition at the gate, as digital photos was a major game changer where you're able to do condition inspections digitally rather than manually." (Respondent R9, 2020)

> "Vehicle booking systems have been really good for container terminals, maybe less good for hauliers, but it helps with the peak times generating benefits and in turn time efficiencies within the overall supply chain". (Respondent R9, 2020)

Therefore, the majority of professionals interviewed regarded digitilisation as another pivotal aspect. Overall, digitilisation can be holistically defined as the deployment of digital technologies to transform business processes and practices and to generate new sources of revenue. Additionally, moving away from paper based transactions through the digitisation of processes is also changing in a positive direction the future of ports. Digitisation is transcribing data into a digital form that can followingly be directly processed by a computer. It thus provides the possibility to make better use of existing assets, rather than necessarily having some new equipment brought into the operation of a port, enabling ports to manage their assets more effectively.

> "I think a lot of the changes that we expect to see are mostly around the kind of digitisation point and making better use of existing assets, rather than necessarily having some brand new thing come in that changes the way that ports operate." (Respondent R7, 2020)

Code system	R1	R2	R3	R4	R5	R6	R7	R8	R9	R10	R11	R12
• New Technologies ○ **Digitilisation**				■	■		■	■	■	■	■	■

Table 8.8: Digitilisation mentioned by respondents

Furthermore, there was a particular mention by respondents that the value of **Artificial Intelligence (AI)** in port environments can be enormous. AI can be defined as a technology that is concentrated on making machines work intelligently, similar to how human minds work. Hence, the use of AI in port operations through the simulation of human intelligence, can be hugely transformational in terms of making decisions and enabling problem solving. One way in which AI can improve operations is by generating a decision-making support system through a predictive model of behaviour, through the use of historical data, digital images, etc.:

> "So people have tried to use artificial intelligence for example to predict more accurately when ships are going to arrive". (Respondent R5, 2021)

"…we utilise data for moving into forecasting and predictive analytics through the use of artificial intelligence. So I think there is a fantastic opportunity for that at the moment through the intelligent use of data, as historically when the crane was operating on the quay with no system it generated zero data (apart from the manual Excel sheets), however now that everything can be completely automated a massive amount of information is generated". (Respondent R4, 2021)

"For example, some ports in the US use patterns of data collections to forecast when imports will be delivered in their port. So based on historical performance, we can learn from the patterns and can predict when the containers will be delivered, being therefore one step forward in knowing when the truck will need to arrive to pick up the container. Usually it is a pattern that dictates when the cargo is delivered, based on where it comes from, etc. so when you start collecting this information systematically and a pattern start to be built, then you can start to forecast when the cargo might arrive, predict when it might be picked up, etc. by looking at the models generated. This will save you unproductive crane moves as you will save time, cost and carbon emissions by minimising the unnecessary movement of containers." (Respondent R8, 2020)

These observations showed that the current operational challenge of handling an increased amount of cargo and traffic in an efficient, safe and green way can be solved through the use of AI in port operations, as it can enable the optimisation of employee working hours, make port operations more productive and cut human error, therefore improving the overall supply chain and generating significant cost savings.

Code system	R1	R2	R3	R4	R5	R6	R7	R8	R9	R10	R11	R12
• New Technologies ○ **Artificial Intelligence (AI)**		■	■	■	■			■			■	

Table 8.9: Artificial Intelligence (AI) mentioned by respondents

Two of the respondents mentioned Machine Learning (ML) as another technology, and branch of AI, that can transform port operations, which is currently considered by ports in the UK. Since AI uses deep learning techniques to analyse more efficiently data compared to human brain, this process is called Machine Learning and can be characterised as the ‘engine’ of AI. During this process the computer develops rules, through the use of the raw data that has been fed into it:

> “…but I believe this is the way forward now as far as the evolution of the technology is concerned, as this is an ever evolving field, reaping the benefits of data accumulation and of course machine learning, so I would say that these are the areas of focus for the future.” (Respondent R2, 2021)

> “People are working on it [data leverage] with some companies who are looking at different ways to be able and process it and do more machine learning, and there are definitely applications that have been developed in that field.” (Respondent R8, 2020)

Another promising and upcoming technology in the UK port sector highlighted by interviewees, was the **digital twin** technology and its capabilities and use cases in the sector. In short, a digital twin encompasses the process of creating a highly realistic, interactive and visually accurate digital model of the port and its surroundings that has the capability to update in real-time all port activities through the use of sensors on site that collect all types of data.

> “The port can be mapped digitally through a digital twin, which can be used as a planning and maintenance tool. We can install cameras, sensors, e-noses that can take readings on smell and odours, and all this can be mapped into the system so we can use this information to improve how we are operating the port. For example, we can create a sensor and program the digital twin to aid in keeping distance between moving vehicles or overhead loads, and so, if something came close to you in a warehouse it would activate an alarm, thus keep people and machines safe. … So, I think data can be used for lots of different things, but particularly for planning cargo movements, better use of facilities and better use of resources.” (Respondent R10, 2020)

> “I think we'll see more and more people try and operate versions of a digital twin and whether that is a kind of full digital twin or actually a kind of half version of that, where they get some of the benefits and they use it to model certain things without a full model of the port, I think that's probably a bit far away still, especially in the UK”. (Respondent R7, 2020)

> "But it's interesting when you move into the buzzword of digital twin, that is kind of an interesting way of how you can use data to model what is the most efficient way to move machines around the container terminal for example. Some interesting applications can be to learn how to do different patterns and then you let the digital twin make decisions." (Respondent R8, 2020)

In digital twinning, the concepts of Augmented Reality (AR) and Virtual Reality (VR) participate in a manner as well. On one hand, AR is the artificial environment that can be created through the aggregation of computer generated and real-world data, while VR is the technique through which a person can experience the presence in an environment created by a computer, by wearing gloves, headsets and other type of equipment, while also having the chance to interact with it. In a nutshell, it was observed that the use of digital twins will enable ports to model their operations efficiently and help operators manage their assets more effectively, safely and in an environmentally friendly way. These observations were further substantiated by a respondent which underlined the benefits of '*virtual training'*, which can be a use case generated by the digital twin of a port, using VR by new operatives:

> "…but we are seeing that traditional things, like crane drivers' training for example, is now replaced by virtual training. So at the port of Tilbury they have got simulators to train their crane drivers. Traditionally, the way you train a driver is actually on the machine [crane] itself. So training through a simulator is a much better and more an efficient way to do it, because it costs less, as you are not using fuel when you have a training facility, and most importantly there is no risk for the trainee nor danger for destroying the machine, neither waste of the operational time of the crane." (Respondent R12, 2020)

Code system	R1	R2	R3	R4	R5	R6	R7	R8	R9	R10	R11	R12
• New Technologies ○ **Digital Twin**							■	■		■		

Table 8.10: Digital Twin mentioned by respondents

Additionally, the clear **decarbonisation** target set in Maritime 2050 is a major driver for UK ports to adopt green technologies, renewable energy sources and electrification of equipment. Ports are currently exploring their options to decarbonise their operations also due to the pivotal change in their customers' requirements. Hence, one of the reasons behind the emergence for the adoption of green technologies in the UK port sector is that the ports' customers are now requiring their products to be environmentally shipped and handled throughout the whole supply chain, and as a consequence, since the ports are an integral part of the supply chain, their equipment needs to adapt to this new requirement:

> "The other technology of interest to us is anything that reduces our emissions. So we use straddle carriers that are electric or hybrid, and therefore they use less fuel and generate less emissions." (Respondent R5, 2021)

> "They [customers] want their products to be associated with an environmentally friendly supply chain. So sourced ethically, shipped environmentally, and this is all about taking carbon out of the supply chain." (Respondent R10, 2020)

When asked about the actual pace in the adoption of environmental technologies and green strategies from UK ports, some respondents indicated that although the emergent need for adopting green technologies is widely recognised by UK ports, the requirement for the government to financially support and fund ports is substantial, and has not been yet realised. Albeit the target dates for the UK maritime industry to be net zero has been set to 2050, according to the UK Government's Maritime 2050 strategy, the Government has not shown the pivotal support that the players in the industry are expecting. Therefore, port stakeholders do not see the changes happening as fast as is required to achieve this goal, but are seeing just a gradual slow development.

> "But I think the answer [in how fast is the UK port sector actually adopting green technologies] is probably quite gradually. I think there may be rapid changes in certain things like computerized systems and management things, but in terms of big heavy infrastructure and from the sort of traditional port process transformation, I see that as being a quite gradual development." (Respondent R12, 2020)

One respondent expressed the view that unless the government invests a lot of money into ports or if regulation makes certain technologies mandatory, only then will the UK sector respond rapidly:

> "Unless we get a load of money from the government, which as you know is a market lead industry, and it's very unlikely I think. …Or if we get regulation. So if government decides that, for example, carbon intensive or diesel powered cranes, or whatever it may be, need to be completely prevented from working because they are bad for the environment and generate new regulations, then of course you would see the sector respond rapidly." (Respondent R12, 2020)

In terms of quick improvements that can have an immediate benefit to ports, while also having the advantage of being delivered quickly after the project begins, are:

- The replacement of small diesel vehicles within the operation of the port with electric equivalents, supported by EV charging point across the port estates;
- The strategic decision that ports can take to replace the outdoor and indoor lighting in the port with low energy LED lights, managed by a central management application and giving also the ability to dim them down when operations are not happening. This action can significantly reduce energy consumption within the port;

> "All the lights in the port are LED, and we can also dim them down as well, so we can smart control them through the system" (Respondent R3, 2021)

> "…we have changed a lot of our small vans, as most of our small vans in our group are now electric." (Respondent R3, 2021)

In terms of bigger investments, that require detailed feasibility studies, high costs, and can take longer to implement and install include:

- Shore power installations (cold ironing), that can provide power to ships while berthed. In this way ships are able to switch off their engines and therefore emissions are minimised:

  "…I think that one of the green technologies that UK ports are looking into is the provision of power to ships. This means that you can plug ship into an onshore power source, and therefore ships they turn off their generators." (Respondent R12, 2020)
- Renewable energy installations, such as solar panels, wind turbines, geothermal heat pumps, as ports are considered the gateways to the UK's Energy Transition:

"We are looking into renewable energy generation into the port, as a means of decarbonising the port and the sector". (Respondent R6, 2020)

- Being a multi-fuel port; both using and providing clean fuels, such as for example bunkering LNG, having hydrogen production in the port, as well as utilisation and storage and hence UK ports can help to decarbonise energy generation, transport and the industry.

  "…So you know I think being a multi fuel port is very important for ship owners choice at the moment." (Respondent R10, 2020)

  "I think the biggest one, from a personal point of view, is the environmental element, so moving away from traditional technologies to electrification and hydrogen or other sources, and that is something that our company [port group] has a strong view or drive around, and it is something that we are very keen to move on. Particularly from an environmental point of view and becoming carbon neutral." (Respondent R4, 2021)

- Electrification of existing 'heavy' assets and procurement of electric and hybrid new assets (cranes, reach stackers, etc.)

  "Rather than having a bunch of diesel cranes driving around the terminal, moving to an electric crane which can them also be automated is the solution. So electrification and automation are key". (Respondent R8, 2020)

Collectively, the analysis of the interviews showed that respondents highlighted the current drive of UK ports to decarbonise their operations, although Government financial support or regulation is needed in order to achieve the timeline of Maritime 2050. Overall, environmental commitments are driving UK ports and as businesses they are investing heavily into trying to achieve greener operations.

Code system	R1	R2	R3	R4	R5	R6	R7	R8	R9	R10	R11	R12
• New Technologies ○ **Environmental technologies**	■	■	■	■	■	■	■	■		■		■

Table 8.11: Environmental technologies mentioned by respondents

Finally, the other two technologies of interest for the future of UK ports, highlighted by some interviewees are:

- Firstly, the need for UK ports to start planning their capability to serve autonomous vessels and to be able to accommodate autonomous berthing, through automated mooring systems:

  "And then I think that the final one, which I am less comfortable exactly how it will play out, but it is how UK ports will respond to much greater autonomy levels on vessels, which is a technology that will change the vessel, but it will demand a change from the ports too, and so whether that is setting up ways to handle automated berthing. … I tend to focus my time on work on autonomous vessels and how they can operate in the UK ports." (Respondent R7, 2020)

- Secondly, another interviewee argued that the main challenge faced by ports is the lack of space. Therefore, according to his experience, one of the most pivotal technologies of interest in the port sector is any technology or strategy that allows a more intensive stacking of the containers.

  "So the main challenge in this port is lack of space, so probably the most interesting technologies for us are any technologies that allow us to stack containers more densely, for example through new and intelligent high bay storage systems". (Respondent R5, 2021)

Overall, there was a common sense amongst interviewees, that the UK port sector is changing and the transformation of traditional operations to autonomous and green operations is the current reality in their plans and actions, with the ultimate aim to achieve the Maritime 2050 goals. Table 8.11 below lists all of the technologies mentioned by respondents and captures the combination of answers for each respondent for the theme ‘technological advancements in UK ports’.

Code system	R1	R2	R3	R4	R5	R6	R7	R8	R9	R10	R11	R12
• New Technologies ○ **Automation**	■	■	■	■		■		■		■	■	■
○ **5G network**			■				■		■		■	
○ **Digitilisation**				■	■		■	■	■	■	■	■
○ **Artificial Intelligence (AI)**		■	■	■	■			■			■	
○ **Digital Twin**							■	■		■		
○ **Environmental technologies**	■	■	■	■	■	■	■	■		■		■

Table 8.12: Technologies mentioned by each respondent for the ‘technological advancements in UK ports’ theme

Interestingly, Table 8.12 shows that most respondents highlighted that ‘automation’ and ‘environmental technologies’ are increasingly at the centre of the UK port sector’s policies and concerns.

8.6.3 Planning for new technologies

When asked whether ports are planning sufficiently before a new technology arrives the responses were contradictory. Respondents were asked for example, if when automating the yard or when bringing in a new system, whether enough training is undertaken by operatives beforehand and enough planning is made, in order to avoid problems and a drop in the efficiency of the operations when the technology arrives:

> “…And I can only give you an example from our terminal. When we brought in the new integrated operational platform [advanced container handling equipment, vehicle booking systems, and automated gates – each step of the operational process is automated through one platform] with the new processes specifically designed and developed for our port, we had trained all our control room staff very early on

> to get them to be aware and understand what the process is going to look like." (Respondent R3, 2021)

On the other hand, one port stakeholder representing two of the biggest ports in the UK handling containers (one terminal being semi-automated while the other traditional), mentioned disruptions being caused after the arrival of a new technology in the semi-automated terminal due to lack of knowledge or sufficient beforehand training:

> "And to start with, the productivity at London Gateway [port] was significantly worse compared Southampton [port], because there was a big learning curve of using the automated technology. So it is definitely the case that when you bring in a new technology, you do not always get the same level of productivity immediately." (Respondent R5, 2021)

Another view echoed by one interviewee, is that when you start building a port from 'scratch' it is easier to hire people that already have the knowledge of automated machines and digital applications for example, rather than having to re-train old staff in order for them to be able and use a certain type of new technology brought into the port:

> "…if you own a port and you start from scratch - from zero and built it all the way up, it is easier to create a smart development because you can make it as the given, and you can hire labour that is unaware of anything outside or inside the port community and make them trained and scale. So in our case, we started from scratch, and the development start from zero and the labour that was hired was predominantly outside the port industry with the knowledge already there." (Respondent R2, 2021)

In summary, findings showed that training the workforce in advance of the arrival of a new technology can sometimes prove to be vital and prepare them to be ready to use it in full capacity and with no gaps in their knowledge, whilst other times training cannot happen in advance and a drop in the productivity of the port is sometimes inevitable.

8.6.4 Change in required skillset

The next theme focused on the informants' view on the impact of new technologies on skills needed for the new type of jobs created in the port sector, and what is the current availability of the required skillset compared to the demand from ports. A common view among respondents was that the port workforce will now need a higher skillset than was needed in the old traditional port industry. This is generating a skill shortage which was attributed to the fact that millennials are not interested to join the port sector, as they still regard it as "dangerous", "old-fashioned", "dirty" and "low paid". Consequently, the lack of talent needed in the industry is a major challenge faced by ports nowadays, as the sector is still not very attractive to young people, although it now requires a younger and digitally literate workforce:

> "I think what has happened is ports have realised that young people are not being attracted to the industry, even though there are now some new jobs particularly linked to technology and data science, which is exactly the sort of skills that young people are being educated currently, but of course there is the perception that the port industry is old, male dominated, with irregular and low pay." (Respondent R10, 2020)

> "There is definitely a lack of skills, as the port sector is not particularly attractive to people who are interested in technology, although but there's a lot of quite complicated technology involved in it [port sector] nowadays. It is also probably not that attractive to a lot of women, as there is this kind of perception of being an old fashioned industry, which is not necessarily 100% true today, but definitely it is difficult to attract some of the talent we need." (Respondent R5, 2021)

Another reported reality was the change in the required skillset, as currently some of the jobs that were existing in traditional ports have been replaced by their equivalent 'digital' jobs:

> "So what we see in a fully automated yard, is that where it used to have people driving straddle carriers to move containers around, now you can automate cranes and where used to hire more drivers to drive the machines, now you need to hire more engineers to maintain the cranes or software engineers and people to operate the cranes remotely." (Respondent R2, 2021)

The solution lies within making younger people aware of the new era in the port industry and of how their skills and capabilities can be applied in the port sector, which differs greatly from the traditional port landscape that they still have a perception for:

> "...and therefore some of the major port companies have been doing very active efforts in terms of apprenticeships for example, as a way of getting new talent into the organisation, and they are doing a lot more than they used to in terms of going into schools, colleges and universities. And they are more active because they realise that they need to attract the relevant talent. So it is fair to say in certainly in the UK very much more active than they used to be." (Respondent R10, 2020)

> "… and we are trying address this [change in the required skillset in ports] to kind of age groups. So we're doing some work with Maritime UK on how we can reach out to schools to get people to think about ports, to try and increase the attractiveness of the sector. Currently young people do not realise that there are all these interesting jobs you can do in the maritime sector." (Respondent R7, 2020)

Therefore, the existing skills gap is seen as major problem by most respondents, as the ports industry is still regarded as an old-fashioned traditional industry that is not attractive to the younger workforce, who mainly focus on being employed in more attractive industries. Although the industry is currently facing a major transformation, this is not communicated accurately to the younger workforce and therefore it is harder to acquire the talent required from other industries. Figure 8.3 illustrates this holistic problem that needs to be considered by both the Government and the port industry as a whole. In this regard, the Government representative interviewee noted that the Department for Transport is looking at different ways of attracting young engineers, data scientists and people with IT skills in the maritime sector:

> "Yes, there is absolutely a change of skillset and lack of people in the sector. And this is something that we have been looking at, as we have set up a Maritime Skills Commission, which is looking at the kind of skills picture across the whole sector, and we have been given a specific mandate to look at the skills that are going to be needed with these new technologies coming into the picture, because I think the requirements are absolutely going to change. In this way skill shortages will be addressed and roles will be filled more efficiently." (Respondent R7, 2020)

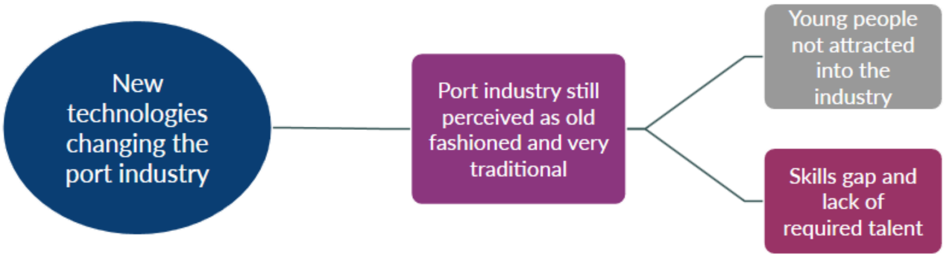

Figure 8.3: Mind map created by the author in NVIVO for new technologies and required skillset

8.6.5 Impact on number of jobs

Opinions differed as to whether new technologies will mean job losses and a decrease in the number of existing jobs in the port sector. Some respondents indicated that automated terminals do not actually decrease the total number of jobs needed, but they just request different types of jobs. The number of staff might be the same, but in semi-automated or fully-automated terminals the number of people involved in driving cranes might be lower, while the number of people working remotely in offices might be higher. Therefore, the majority of respondents suggested that there is a different type of skillset required to cover the new type jobs that are arising in the port industry, this not necessarily meaning a decrease in the overall number of jobs:

> "As for job losses, the respondent expressed the view that they are very likely to happen, as are in most sectors, and that conversations with the labour unions will need to focus on the training and retraining of the existing staff." (Respondent R7, 2020)
>
> "To answer your question about jobs number, what we have seen at the moment, and let's say we can compare our semi-automated terminal to our traditional one side by side, the semi-automated one does not actually save you that many jobs, there are different types of jobs. So you probably see that we have a lot more staff in offices in the semi-automated terminal but less people involved in driving equipment, while in the traditional terminal it is the other way around. So you might have slightly less people in automated terminals, but the main difference is actually a different type of skill set." (Respondent R5, 2021)

As mentioned above, responses differed and some interviewees commented that there will inevitably be job losses and redundancies:

> "Increasing automation does mean reskilling but inevitably you need less people to do the same amount of work. So for example if you look for example at a container of sugar that can carry 40 tons of sugar and is unloaded with only one crane lift. So you need one remote operator to move the crane and maybe another operator at the quay side to receive the container and move it to the stack. If that amount of sugar was individually bagged you would potentially need 10-15 people to lift the same quantity. So there is some natural redundancy in the system. There will always be job losses due to automation." (Respondent R10, 2020)

One respondent interestingly highlighted that although some specific jobs might not be needed any more, overall their replacement has brought costs down and more jobs have been created overall:

> "Certain types of jobs might have disappeared, so for example a man whose job was to climb up a ladder and have a look at the top of every container now has disappeared and lost his job, but the efficiencies created from the other types of jobs that have replaced that one have been increased, and the profitability has brought the total costs down. Therefore, the businesses expanded and therefore there are more jobs overall, they are just different types of jobs." (Respondent R9, 2020)

Another reported problem was around labour unions and their fear for job loss which leads them to be opposed to change:

> "So technology is taking over and some jobs are no longer required, and trade unions are opposing to automation on the grounds of safety, so they will always oppose thus trying to protect their jobs." (Respondent R10, 2020)

It was also reported by some respondents that most ports have to retrain and reskill their operatives in order for them to be able to do multiple jobs, like for example driving tugs and trailers, straddle carriers, reach stackers, customer service staff have moved into a control room, some tug drivers became crane drivers, who in the future might sit in an office and not up a crane, doing a similar role using a computer. Thus, the skills of each person are going to have to adapt to what the operation is at the time and that can only be done with a strong relationship between the unions and the port.

> "People were afraid of losing their jobs and we have had to retrain and reskill a lot of our operatives here to be able to do multiple jobs." (Respondent R3, 2021)

Another reported problem was that there might be a shortage of people having specific skills, as for example into how to handle the very complex Terminal Operating Systems. This might lead to ports having to compete among them to acquire the small number of people that would have the skillset required:

> "Terminal operating systems are so complex and the skillset for them is in a shortage, as not many ports have the specialised people to handle these systems effectively. So you find that because this specific skillset is required now [fast] from ports they are 'pinching' people from other ports." (Respondent R3, 2021)

8.6.6 Data collection challenge, value and integration

The responses on data value were answered unanimously, as all interviewees felt that data collection and its effective analysis and usage is vital to the UK port sector. Respondents were therefore asked to suggest whether data collected by UK ports is exploited sufficiently and what value can be leveraged from this data if analysed accurately and efficiently to get pivotal insights. Respondents highlighted that data is currently collected in huge amounts, but is not understood accurately and the enormous use cases that it can help with are not yet fully interpreted:

> "So a lot of the time the people I speak to are thinking about how they can make best use of the data they have got and how can they how they can actually organise their data in a way that they can get the benefit out of it. I think it is a huge problem in the sector currently that there is a lot of data available, but it is very poorly captured and even more poorly understood." (Respondent R7, 2020)

By making a better use of the data collected by ports and by organising it in ways that would bring benefit to ports, huge benefits can be generated. Most of the ports that are trying to be competitive nowadays, they are all data driven. Data is pivotal as it can be used to plan processes more smartly for example:

> "Technology will help get people to the solution. But actually, the solution is not so much a technological solution, but it is a better data management solution. I think more and more we will start to see digital port management systems that some places are already picking up". (Respondent R7, 2020)

> "Every time you pick up a container and put it down, you get a transaction. So there is loads of interesting data there to optimise your operations by learning and modelling and simulating different ways of working." (Respondent R8, 2020)

> "We are using all that data to see where we can be more efficient, more effective. So you can have the planners effectively plan your yard operations, as you might initially have a lot of unnecessary moves of boxes, and you can then minimise the non productive moves [non-revenue generating] with more effective planning through data analysis. …Same with the quay cranes, you can look at quay crane operators' performance and the time period they are there on the crane and you can identify where the waste time on some of the cycles is, and you do see such a difference between operators. You can then quite easily graph this, show them and educate them accordingly". (Respondent R3, 2021)

To be able to leverage the huge amounts of data that are and can be further collected, ports need to have the right people with the right skillset to use and analyse this data. Ports are therefore now looking into that cutting edge of how they can look at their data and how they can leverage the information collected:

> "You have got to have the right skill set to be able to use and analyse the collected data, because it is very good to collect many terabytes of data per day, but if you are not sure what 'good', 'bad' and 'ugly' data looks like or how you need to align it to make use of it and understand it well, it is completely useless to you." (Respondent R3, 2021)

One other significant observation made by a respondent is that it is key to first understand the problem that an operator is trying to solve and then collect the data needed, while currently ports are often collecting data without knowing what they want to generated out of it. Otherwise, if port operators just collect data without knowing the purpose of collecting it this leads to unused or poorly understood data which is either also not the correct data or is not serving its purpose:

> I think the key thing is to understand the problem that you're trying to solve. That will then derive the decisions that you need to make and the information you need, which will then identify the relevant data that you need to collect. Then you will identify the cyber format needed and the frequency of the specific data collection. You need to start from the problem. Otherwise, as you start collecting data, you think you are doing something important, and actually the data you are collecting is not the right one, nor is serving its purpose, and you do not even know why you collected it and you are basically just wasting time, resources and money to collect something that is of no need." (Respondent R11, 2020)

It appears that there was a common sense amongst interviewees that there is a growing acceptance in the UK port sector that data is not being used effectively at the moment and that there is great leverage that can be taken out of existing data. As a first step people need to understand the data they hold and consider how the data can be collected in a more efficient and effective way. Secondly, it is key for the data to be organised and standardised, so that ports can be able to identify the benefits they can get out of it, and also which data is sensitive and which data is not sensitive and can be shared while complying with relevant requirements (e.g. GDPR, commercial sensitivity, etc.). At the moment people are afraid and hesitant to share any of their data, as they are not fully aware of the commercial sensitivity of each dataset. Some of the data that can be shared can leverage the sector as a whole, as ports will be able to learn from each other, without the danger of sharing commercially sensitive information that might result in a problem for them. It was highlighted that huge opportunities will arise after the negativity of stakeholders in the supply chain to share their data is overcome.

However, as far as data integration and data sharing is concerned, although the leverage that can be taken out of Port Community Systems for example is enormous, the inefficiencies that this would remove are not in the interest of some stakeholders in the supply chain, and this is why many stakeholders are resistant to the adoption of new technologies and to sharing their data with the whole supply chain, as was also described in Section 8.5.1:

> "…But if you have these poor systems and no data sharing is beneficial for some people. If you take away the inefficiency it is not beneficial to them, as it is the inefficiencies where these people get paid from. …So the people who operate the ports may or may not have an interest in really doing it, particularly for port community systems, as these are usually regional or national projects, because they are big and difficult. So it is a hot topic for sure around the world but there is a lot of resistance to do these things." (Respondent R8, 2020)

In addition, when asked whether UK ports are planning to start making actual use of their data and getting the most value out of it, one respondent suggested it depends on each port:

> "It depends on who you talk to, so if you go to big ports for example, they understand their technology well and also the value of their data. And it is not just about data collected in the port, it is actually about data across the value chain, they are interested in ships' data, in traffic real traffic data, etc. Because they know they need that data to be able to increase the efficiency in their operation. …They need to first understand what they will get in return from their data in order to be willing to pay for collecting it". (Respondent R11, 2020)

8.6.7 Net benefits generated from technological advancements

The findings also revealed significant benefits generated for the hinterland from the adoption of technological advancements in port operations. When asked about the net benefits, the **creation of jobs** was one of the most unanimous factors stated by respondents. It was argued that every direct job creates three or four indirect jobs in the hinterland. These jobs are also well paid, which in turn means that people are spending more in the local economy, which is also a big positive outcome of the new jobs created in a port through the adoption of technological advancements:

> The big benefit for the area is in terms of jobs, as if you include permanent port employers, subcontractors, haulage companies, rail operators and so on, all these jobs rely on the container terminal. Generally, it is acknowledged that for every one direct job there are probably three or four indirect jobs related to the container terminal." (Respondent R5, 2021)

> “These jobs are also quite well paid jobs and good quality jobs, with this bringing further benefits to the area, as obviously, those people have been spending money in in the local economy.” (Respondent R5, 2021)

In all cases, a second major benefit reported by respondents, was the **safety** aspect generated from the adoption of technological advancements in port operations. The reduced human interaction with machinery eliminates significantly the injuries, while respondents reported massive safety enhancements with the use automation, during the past few years the decline in the number of injuries is significant:

> “Safety is always is my highest priority, so yes new technologies bring safety. Massive safety enhancements.” (Respondent R3, 2021)

> “So over the last 15 years with the introduction of new technologies there has been a big decline in the number of injuries.” (Respondent R5, 2021)

> “I think the safety benefits are really important, because they cannot be underplayed. I have seen some people developing solutions of how this kind of thing can get better, even just through better analysis of how safety incidents occur will allow us to be better at protecting them. And here [in the safety aspect] you can always have a better safety record than you do, unless you have had no workplace injuries and this is something that I know port operators feel very strongly motivated about. Because in the end there are people working in the port and their safety matters massively, and so they [port operators] take it very seriously.” (Respondent R7, 2020)

The economic and environmental benefits that arise when ports are operated more efficiently, as was also found in the Systematic Literature Review, are also pivotal. The stakeholders supported that the use of new technologies can help port operators manage their assets more efficiently and as a result many environmental benefits can arise. The benefits might be indirect, as a more efficient operation in a port can result in savings in terms of less vehicle idling to receive or dispatch cargo, etc. Additionally, the use of digitisation and AI can help in the identification of the exact arrival time of vessels and therefore ships can avoid anchoring before arrival. Sharing information can moreover aid in the decrease of emissions, as ships will be able to identify the correct time to arrive in the Port and will not anchor with their engines running.

More specifically, as far as the environmental benefits are concerned, respondents indicated that moving away from traditional technologies and into automation, electrification and digitalisation will also play a key role into the transition of ports to becoming carbon neutral. Also, the use of hydrogen and other alternative fuels will also be vital for the decarbonisation of the sector, according to all stakeholders:

> "It is the environment that benefits from electrification in ports, as for an electrically driven device, the carbon footprint impact it has is considerably lower to a diesel operating crane or reach stacker or any other equipment." (Respondent R3, 2021)

> "I think the biggest one from a personal point of view is the environmental element, so moving away from traditional technologies to electrification a hydrogen is a strong view drive for our group, and it is something that we are very keen to move on. And particularly from an environmental point of view becoming carbon neutral so that's probably one." (Respondent R4, 2021)

Moreover, the benefits generated through digitilisation are expanding also into the hinterland, in terms of minimising the congestion during peak times through better management of the trucks, etc.:

> "The externalities of that [vehicle booking systems] are actually also positive because it cuts down congestion during peak times which has a really positive impact on the local communities around the port." (Respondent R9, 2020)

> "So we see automation at different terminals at different stages which are largely driven by a business case that's positive for the profit and loss account of the operator, but that can have benefits because it improves efficiency and therefore can remove congestion, pollution and generate benefits also for the hinterland." (Respondent R6, 2020)

Finally, the other benefit that can be generated form the adoption of new technologies in ports, is the upskilling of the region, as higher skills are needed to fill the job roles in modern ports, and thus people need higher education levels to be able to respond to these requirements:

> "…and the other one [benefit] is people relevant, as the training we provide and the ability of upskilling within our teams. In our port group we deal with a tremendous amount of sponsorships to training courses; apprenticeships; university courses; degrees; doctorates, as we have sponsored a lot of people through those processes and that is probably a matter of giving back value to the community. A thriving port and a successful business pushes all those additional benefits out into the local community." (Respondent R4, 2021)

8.6.8 Barriers to the development of smart ports

A number of barriers were identified by respondents that are slowing down the development of smart ports in the UK port sector. According to one respondent, ***geographical location*** can act as a barrier, as there is not always an obvious competitive advantage to investing in new technology because in some cases customers will select the port merely due to its convenient location:

> "I think location is one barrier, in the sense that it often the fact that ports have a specific geographic market. Therefore there is not always an obvious competitive advantage to investing in new technology because in some senses customers are quite sticky to the location they will choose to send their ships, because they are making a certain journey and they will go to the port that makes the most sense. And they are probably not thinking about where is the most technologically advanced port that they can go to. And so in that sense, geography matters. Probably it can disincentivise people from investing in new technology as they know that they will never serve a specific customer base." (Respondent R7, 2020)

Another reason why geographical location can act as a barrier to the development of smart ports, is that a port's location might act as a barrier to good broadband connectivity, to renewable energy generation, etc.:

> "Yes, location can act as a barrier. You can have all sort of things due to a port's location, like bad connectivity to broadband in remote areas or poor energy networks in certain regions. Then you might find that it can also have a major

impact to clean energy provision and renewable energy generation, as somewhere like the northern islands grid connection is much better than in other parts of the world where their access to the grid is not so good." (Respondent R12, 2020)

The ***availability of skills*** required could act as a barrier, as some of the respondents suggested that since the skillset required has changed, and there is not enough young people entering the sector (as was also described in Section 6.4.1), this leads to shortage of the required workforce, and in turn this being a barrier to a faster development of smart ports:

"In the short term, I think lack of required skillset can be a barrier. But I think people, you know, workers and skills trainers and employees are adaptable, so it can maybe move quickly." Respondent R12, 2020)

The majority of participants also agreed that ***size*** plays a significant role and can act as a barrier to the investment of a new technology. There was a common view that typically smaller container ports cannot invest in the same kind of equipment as larger ports:

"I think size has a lot to do with it [being a barrier to the development of smart ports]. So I think it is very difficult for smaller typically - if I just talk container terms – it is very difficult for the small container ports to invest in the same kind of equipment with what you have in a larger port." (Respondent R5, 2021)

Moreover***, unionisation*** was considered a further barrier to the adoption of new technologies in the sector, as labour unions are resistant to anything they see as a threat, and the introduction of automation is often viewed as a major threat to their jobs.

"Unionisation can be a barrier I think, as unions will always be a bit resistant to anything they see it as a threat to their jobs, so that can be a barrier." (Respondent R5, 2021)

However, an interviewee had a different view on the impact of unionisation, as it was supported that the safety side can act as a very good incentive to unions to support automation and modernisation:

"I do not think that unionisation can act as a barrier. I think when we are discussing with them [unions] the concept of automation, as long as we can show why we are

> doing those things, particularly on the safety front, it is a strong argument to move down that route. And also on the payment side of things, as payments have increased since some workforce have been upscaled to managerial positions and the oversight side of things and this have been perceived as a very positive outcome." (Respondent R4, 2021)

With regard to the impact of ***ownership type*** of ports to the adoption of new technologies, the interviews showed that private ports are driven by efficiency and short term ROI (Return on investment) and therefore privatisation in some instances might act as a barrier when the investment of a specific technology might have a long-term ROI:

> "Most ports in the UK are privately owned by pension funds and private equity companies. Typically they invest in projects with a five to ten years maximum horizon. So if you are an investor and you are investing in five year plan, the investment model in the UK is very short-term. It is all about delivering a return on investment immediately, when for example a decarbonisation project might have a 30-year project and therefore private ports will invest harder in such projects compared to trust ports who can have a longer term vision for what is best for the port and the community" (Respondent R10, 2020)

> "The private ports, especially the big ones are driven mainly by efficiency. So, they will invest on the things that will make them efficient and generate more profit in the short term. …. (Respondent R11, 2020)

Therefore, private ports will invest harder in green technologies, as these have a longer-term ROI. On the other hand, private ports will invest easier in automation and digitilisation compared to trust and public ports, as although requiring a higher initial investment in terms of cost, smart technologies can provide a shorter-term ROI which can be easily realised by private ports that have the financial capability to invest in such expensive technologies. This high cost can however be considered a major barrier for other ports. Therefore, the high ***cost*** of smart technologies was considered as a barrier to entry of new technologies in a port. One interviewee suggested that specifically for smaller trust ports it is very hard to incur the kind of capital expenditure needed for large investments. Cost was ranked as number one in the barriers to adoption of new technologies in the container port industry:

> "Cost is definitely a barrier to entry I would suspect that if you take some of those smaller trust ports there's no way they could incur the kind of capital expenditure, you need for these projects. … But I would probably put costs at the top of that list as automating the business is actually very expensive. " (Respondent R5, 2021)

According to one respondent, especially when it comes to green technologies, cost is a major barrier, because the ROI is very long, thus making it difficult for port operators to invest in these technologies:

> "Cost is also a big barrier. Especially when you start talking about green technology, because the ROI in those is very long, maybe up to 50-60 years, and then it is very difficult to convince investment. So if it is a private port, it is a bit harder for them to be convinced to invest in something that might have a long term ROI." (Respondent R11, 2020)

However, apart from the factors listed by the author in the questionnaire, one interviewee mentioned that a major barrier to developing smart ports is ***culture***:

> "I think it is the culture. Being a very conservative industry and with a lot of resistance to change. …people who come from different industries can actually see the problems and they can see the value of new technologies, while it is very difficult for those who have been in this industry for a very long time to see the benefits". (Respondent R11, 2020)

Finally, the drop in the productivity by the use of electric straddle carriers for example instead of diesel because they need to be charged every hour and therefore productivity is lost, might slow down the uptake of their adoption on ports:

> **"**It will almost certainly be the case with electric straddles that they will be less productive for us than the diesel ones, because they need to be charged on a regular basis. So at the moment, once an hour, they need to be charged for five minutes, obviously that loses us production time. …but, at the moment, it will be less efficient than using diesel. (R5, 2021)

8.6.9 Incentives to the development of smart ports

A variety of incentives were also expressed mainly focused around the fact that the ports' client base is pushing them to adopt new technologies, and therefore this might be regarded as the main driver developing smart ports and for adoption of smart technologies into port operations:

> "There is a wider drive across the logistics industry where are expecting to see a more automated and more digital way of working. And if you're investing on digitilisation as a haulier or as a freight forward or as a shipping line and getting your systems up-to-date, using the latest technology, you will not accept that the port refuses to do that. And so clients I think we're just push the ports to keep going in that direction [adopting new technologies and becoming smart]. So I think that I actually think that will be the main incentive in the end." (Respondent R7, 2020)

> "There is a good customer angle, because if you can come back to the prior conversation we had around a digital Port Community System, you can start using your online presence to give customers that visibility so there is a good opportunity in there to provide a lot of benefits to your clients through these developments." (Respondent R4, 2021)

Additionally, another pivotal incentive for developing smart ports, was the decarbonisation target and outcome that is generated through the adoption of smart technologies:

> "…And in many cases it is difficult to persuade for investments to be made, but a lot of ports want to do the right thing around the environment theme. And therefore there is a really good approach that can be made there, as the best and easiest to measure are the environmental and wider social benefits and thus the board can be incentivised more on these technologies". (Respondent R7, 2020)

Another interesting view echoed by one respondent, was that the lack of the required workforce number can lead to a faster adoption of models that include more technology:

> “And it may mean that those shortages and the problem to attract new people, might drive us to move the sector towards a model where we do not need as many people involved, so automation?” Respondent R12, 2020)

Finally, the type of ownership can also act as an incentive, since trust ports for example, have the pivotal drive of trying to help towards greater development of the region through their business:

> “Finding that critical set of stakeholders that will work together and are willing to put the money there is significant, and I think this is why you see places like the Port of Dover and the Port of Tyne which are integrated trust ports leading the way, because they have the wider community benefit.” (Respondent R9, 2021)

8.6.10 Ranking of smart ports

In response to whether ports can be ranked according to their “smartness”, similarly to how ports are ranked according to the tonnage they handle, concerns were expressed about the willingness of ports to be open in sharing their information and relevant data:

> “I think ports would cooperate in terms of getting greener, so ports will generally cooperate and share information around anything safety related and environmentally related, but they will not cooperate and they are very secretive when it comes to sharing efficiency measures, such as crane rate and gross moves per hour. We [the port] will not be willing to share this kind of information, as it is commercially sensitive and the port would not want to see a ranking where they are not high up that list”. (Respondent R5, 2021)

> “…Now the big question is whether or not the terminals and ports want that to happen because they may not like the idea of appearing to be less smart, or less efficient or less progressive than other ports, so you might find the big challenge there would be getting the information out of them”. (Respondent R12, 2020)

> “Ports do talk to each other, but not always to the fine detail, as they are quite protective over their operational data.” (Respondent R3, 2021)

Another perspective that was expressed was the fact that ranking ports according to their smartness would drive up competition among ports and this fact can be either regarded as positive or negative. On one hand it would mean that ports would strive to become smarter and therefore would more readily introduce green and smart technologies, on the other hand it would automatically mean that shippers would not choose to go to the less smart ports, and thus the less smart ports might oppose to the development of such ranking as it would not benefit their ‘reputation’:

> “…I am just wondering and I am not sure that everybody would want to be open, because what it [the ranking] would highlight, is that some people are behind in some ways. So I think that will be interesting to see who would be open enough to share where they are at on different aspects. This is because it will not be to their benefit, so the ones that are developed will want to be ranked and the ones that are behind will not, as they will fear that they will lose business.” (Respondent R4, 2021)

> “I think it is a really good idea and I think by large it would probably have a positive outcome. I think more people would want to move themselves up the ranking, especially if it was constructed in such a way where you are kind of tiered. So if there was like a gold standard or silver standard, and when ports would move up the ranking they could be certified for example as gold smart port for example that they could show as certification. …I could see that quickly becoming a kind of annual output. The same way that we have some of the other rankings, both in maritime and other sectors.” (Respondent R7, 2020)

According to the same respondent, if a ‘smart port certification’ would be used as a ‘kitemark’ for smart ports, this could drive the standardisation process in the smart port business as a whole:

> “That could be part of a wider standardization push, which is going to have to happen through this smart ports process. If you're going to have any serious uptake in digitization and kind of automatic messaging, there is going to have to be standard. So a standardization organisation is going to have to get involved in defining and certifying a smart port.” (Respondent R7, 2020)

Another reported view was if such a ranking would be developed, it would have to segregate ports according to the type of cargo they handle:

> "All Ports are complex places. So the bigger the port, the more complex the linkages you should make to be able and rank it compared to other ports. I think you need to focus on each cargo separately." (Respondent R9, 2020)
>
> "I think it would have to be a fragmented approach and it would not just be a ranking of all the ports. But I think sector by sector and container ports with container ports for example". (Respondent R12, 2020)

It was also mentioned that the hardest part would be to identify the factors that would be included in the ranking criteria:

> "…so ranking ports according to smartness, I think is very difficult because it means so many things, and how can you say which things are included in that? That is the hard part." (Respondent R8, 2020)

In summary, the results show that the respondents generally felt that ports are willing to collaborate in getting both greener and safer, but when it comes to efficiency they are not positive to share their data and this might create a problem in being able to create a ranking.

8.7 Conclusion

In summary, Section 8.6 in this Chapter reported on the results of twelve semi-structured in –depth interviews with key industry stakeholders on the current status of UK ports when it comes to the adoption of technological advancements in their operations. In a nutshell, the results show that the port industry is resistant to change and still perceived as a very traditional industry that is many years behind compared to other industries in terms of adopting new technologies. However, currently, there is modernisation and change occurring in the port sector and therefore the wide range of technologies that are currently explored and adopted by UK ports are helping towards the modernisation of the UK port sector *['port industry features' theme]*. Therefore, although it is still perceived as quite traditional by young people, there are significant changes in the required skillset which now requires digitally literate workforce. Therefore, there are many moves towards making the sector more visible and attractive to the younger workforce in order to also close the existing lack of talent and of required skillset. This said, the change of skillset is mainly mentioned by respondents that will just lead to a change in the job type rather than a decrease in the total number of jobs required in the port environment *[‘change in required skillset’ and ‘impact on number of jobs’ themes]*. Therefore, training and advance planning for new technologies is key for keeping the efficiency levels of port operations stable when a technology first arrives and is introduced in the daily operation of the port *[planning for new technologies’ theme]*.

All respondents also felt that data in the UK port sector is currently not being used sufficiently, as it is poorly captured and understood. Opinions agreed that there is great leverage that can be taken out of data, if collected in a more efficient and effective way. This however only being possible if operators know in advance what they need out of the specific data, and then all interviewees shared the view that well-organised and accurately captured data can have enormous benefits generated for the port sector *[‘data collection, challenge and integration’ theme]*.

When referring to the net benefits generated for the hinterland by the adoption of technological advancements in port operations, a number of respondents mentioned the increase in the number of well-paid and good-quality jobs created for the hinterland; the massive increase in safety of port operations as the human-machine interface is minimised due to automation; and also the fact that new technologies are greener and more sustainable compared to old ones in helping towards achieving the decarbonisation targets of the port and maritime sector *[‘net benefits generated from technological advancements’ theme]*.

Moreover, as far as the barriers and incentives for the adoption of new technologies in the port sector are concerned, respondents deeply considered these, with the main barrier being a mix of ownership type and cost, and the main incentive being the client base *[‘barriers to development of smart ports’ and ‘incentives to development of smart ports’ themes]*.

Finally, most responses echoed the view that a potential ranking system for ports according to their smartness, although difficult to decide on the factors to be included and to convince ports to share their data, would seem a quite good incentive for a standardisation push into “what a smart port is”. It would also drive competition up, making ports willing to go up the scale and hence to be more proactive with adopting smart, green and sustainable technologies in their operations *[‘ranking of smart ports’ theme]*. Figure 8.4 illustrates the Word Cloud generated from NVIVO using the overall transcripts’ content.

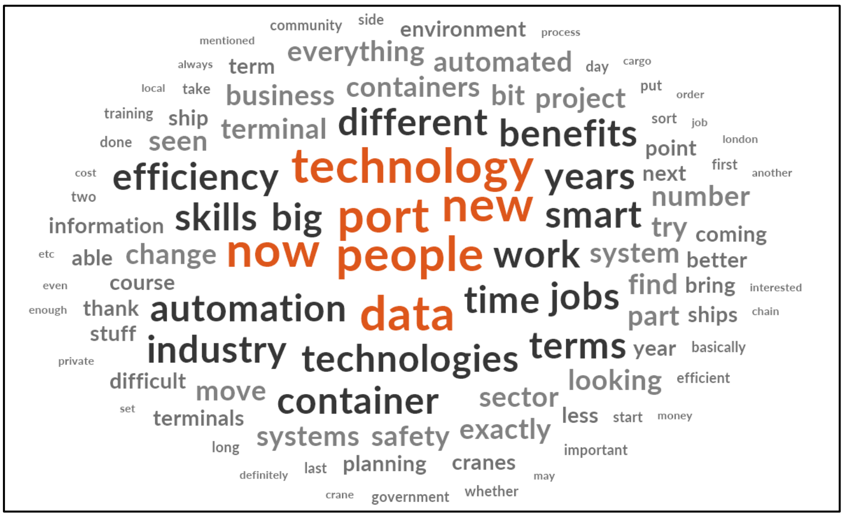

Figure 8.4: Word Cloud generated by the overall transcripts content

Chapter 9: Port of Tyne

9.1 Introduction

Given that ports need to transform into new era smart ports, the author deemed crucial to also observe the transformational journey and procedure that a traditional port follows to become a smart port. To this purpose, the author complemented this research by focusing on a single port study.

The previous Chapter provided insights concerning the fourth and fifth research questions and presented the way UK ports adapt to the technological advancements in the port sector, based on twelve semi-structured in-depth interviews with key industry stakeholders. This Section now moves from the whole sector level, which was the focus of the previous thematic analysis, to the in-depth examination of the case of one particular 'traditional' UK port (the Port of Tyne) which is in the process of a transformational journey with ambition of becoming one of the UK's leading smart ports. This study therefore explores the steps that the Port of Tyne took to achieve its goals, through a Participant Observation study of workshops that assisted the port to develop solutions to technological challenges and map its journey to become smart, green and sustainable over the past 12 months.

This final empirical chapter reports, through a Participant Observation study, on the transformational journey of the Port of Tyne to become a smart port and reach the goals set in Maritime 2050, outlined in the previous Chapter. This involved an in-depth analysis of the steps that Port of Tyne followed to adapt to the technological changes facing the UK port sector and the wider maritime industry.

9.2 Port of Tyne – Background and Smart Score

Port of Tyne (PoT) is a deep-sea port comprising a vital part of the North East region's multi-modal connectivity and a global gateway to the North. PoT handles a diversity of cargoes, including dry bulk, general cargo, containers, cruise/ferry, ro-ro freight, renewables and offshore, and providing an excellent platform for economic growth in the region.

The Port operates under the trust ownership model, as it does not have any shareholders and all profits are reinvested back into the company to benefit the region and future generations. Therefore, the investment, improvement and extension of the Port's leading edge facilities in the River Tyne are a pivotal priority. The Port has 348 employees, supports over 9,300 jobs and is adding more than £557m to the economy (Port of Tyne, 2021).

The Port of Tyne is on a transformational journey to decarbonise, digitise and electrify its operations. As was previously described in Section 8.2, the UK Government's Maritime 2050 Strategy aims to provide a long-term plan of action for the UK maritime sector to adapt to the technological challenges facing the wider port and maritime sector. Following the launch of Maritime 2050, the Port of Tyne towards the end of 2019 launched its own strategic plan, "**Tyne 2050"** strategy, a long-term vision that will aim to see the Tyne become a gateway to help transform both the region and the maritime industry. Tyne 2050 is fully aligned to the Government's Maritime 2050 strategy, and is critical to sustaining the Port for the long-term as it will help lead the way in key areas such as environment and technology, as well as collaboration and innovation.

The author also deemed necessary to explore the smart score of Port of Tyne (local level) and used the same methodology in Chapter 7 (global level - 71 major world ports) and in Chapter 8 (national level - major UK ports), based on the factors and categories used for the Website Content Analysis and as outlined in Table 9.1.

Category	Factors	Port of Tyne
Environment, Sustainability and Community	Environment in Menu Bar	
	Environmental in mission/vision/values	●
	Sustainability in Menu Bar	
	Sustainability in mission/vision/values	●
	Community/social/society in Menu Bar	●
	Social/community vision/mission/values	●
Monitoring	Air monitoring	●
	Water monitoring	
	Noise monitoring	●
	Energy monitoring	●
Certification and Reporting	Online Standalone Environmental Report	
	Environmental ISO 14001 Certification	●
	Online Standalone Sustainability Report	
Energy Sources and Incentives	Renewable Energy Sources	
	Shore-side power supply – cold ironing	
	Fee incentives for clean vessels	
Technology and Innovation	Digital/smart/innovation in Menu Bar	●
	Digital/smart/innovation mission/vision/values	
	Port Community System	
	Blockchain	
	SMART SCORE	**0.45**

Table 9.1: Results from Website Content Analysis of Port of Tyne and smart score

The smart, green and sustainability related practices and efforts of Port of Tyne were therefore explored and its **smart score** was **0.45**. Results show that the Port scores high levels when considering the “Environment, Sustainability and Community” and “Monitoring” categories. On the other hand, the other three categories, namely “Certification and Reporting”, “Energy sources and Incentives” and “Innovation and Technology” are scoring low levels of adoption, based on its website disclosure.

Port of Tyne’s smart score places it among the top 20 major world ports analysed in Chapter 7, as some of the other ports that scored 0.45 are the port of New York – New Jersey, the Port of Rio Grande, the port of Moerdijk and the port of Zeebrugge, all leading ports around the world. The spread of smart scores presented in the results of the Website Content Analysis in Chapter 7 was from 0 to 0.75, with the average smart score in the sample being 0.3. Therefore, Port of Tyne’s smart score is above the average, indicating that according to its website disclosure, its efforts and commitments towards being smart, green and sustainable are higher than those of some of the world’s major ports that scored under 0.45. Additionally, when comparing the Port of Tyne’s smart score with the smart score of the ten UK major ports presented in Chapter 8, it is found that the ports that also scored 0.45 are the ports of Hull and Belfast. These ports, similarly to the Port of Tyne, have achieved a high level on the “Environment, Sustainability and Community” category, indicating that they are putting great efforts towards decarbonising their operations. Interestingly, the Port of Felixstowe, ranked 1st on the UK major port’s list (Tables 8.1 and 8.2) scored lower than Port of Tyne (ranked 13th) as its smart score was only 0.35.

Moreover, the Port of Tyne hosts the UK’s first **2050 Maritime Innovation Hub**, aligned to the UK’s Maritime 2050 strategy. The 2050 Maritime Innovation Hub is a partnership with Port of Tyne, Drax, Offshore Renewable Energy Catapult (OREC), Nissan, Connected Places Catapult, Accenture, Royal HaskoningDHV, Ubisoft and the Department for Transport (Appendix E). The Hub’s mission is to inspire partners to collaborate to develop solutions to technological challenges facing the maritime sector and the wider logistics industry both nationally and globally. It serves as an enabler for collaboration, for sharing ideas, harnessing research and development, advancing technology and tackling shared challenges, and also commits to be open to innovation and advance technology solutions. Skills and innovation from all industrial sectors are also harnessed to enhance maritime competitiveness. Hence, this partnership aims to co-create tailored solutions that will both shape businesses through digital transformation and drive innovation in the wider UK maritime sector.

Maritime innovation has always been important and never more so than now, as the community collectively addresses the challenges and opportunities of the current operational landscape which was thoroughly described in Chapter 1. The 2050 Maritime Innovation Hub has hosted a wide range of events and workshops, through collaboration with stakeholders from hundreds of businesses from diverse industries - including space, defence, renewable energy, the rail industry, the Royal Air Force (RAF), data science and Artificial Intelligence (AI) – academics, the public as well as non-profit sectors, to share ideas, concepts and strategies in order for the Port of Tyne and the UK maritime sector as a whole to adapt to this challenging new era transition. The 2050 Innovation Hub workshops focused on the areas illustrated in Figure 9.1.

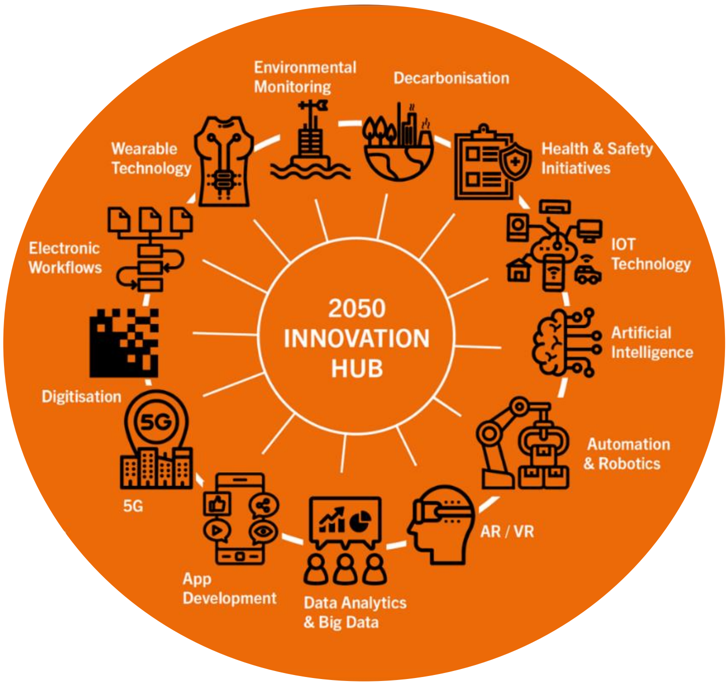

Figure 9.1: 2050 Maritime Innovation Hub focus areas

Source: Port of Tyne

9.3 Participant Observation of workshops

Given that traditional and old ports need to transform into new era ports, it was crucial to scrutinize closely the process that a UK port follows to become smart, green and sustainable. To this purpose, the author selected the Participant Observation methodology to explore deeper the mechanisms, ideas, procedures and timeline of this transition. The following section provides an analysis of the steps that Port of Tyne followed, in collaboration with the Maritime 2050 Innovation Hub located at the port, to develop solutions to adapt to the technological changes facing the port sector and the wider maritime industry. This step also contributed to investigating the different ways that a port can follow to develop its strategy and map its transformational journey to become smart, green and sustainable from being a traditional port. This study also highlights the importance of cross-sector collaboration and the significance of sharing knowledge across different industries to increase the UK ports' global competitiveness and rebalance the economy.

As part of a 12-month Participant Observation study at the Port of Tyne's Maritime 2050 Innovation Hub (October 2019 – November 2020), the author conducted a focused case study research. In this study 16 events and workshops were observed by the author, in an attempt to scrutinize the importance and benefits that can be generated through cross-sector collaboration, in order for the Port of Tyne to map its journey to achieve the Tyne 2050 goals and to tackle shared challenges through innovation with other ports and the maritime sector as a whole.

Table 9.2 gives an overview of the 16 events, workshops, sprints and webinars attended by the author from October 2019 to November 2020 for the Participant Observation study. These activities were designed to help the port's stakeholders set the priorities to reach the Tyne 2050 goals.

No.	Name of event	Date	Synopsis
1	**Berth Utilisation and Cargo Characteristics – Data & Automation Sprint**	30 October 2019	→ Identified some specific data opportunities and challenges and begun to consider how sharing and using some key data collaboratively can benefit not only Ports, but also regional and maritime stakeholders. → Started to advance the current state-of-the-art through automation of different data feeds into user-friendly interfaces, collaboratively shaping MVP (minimum viable product) outlines for the important operational activities; namely berth optimisation and cargo characterisation.
2	**Berth Utilisation and Cargo Capability MVP - Hackathon**	22 November 2019	→ Tech partners, maritime industry experts, coders, developers, programmers and app builders came together with subject matter experts and developed software solutions that will optimise cargo capabilities at ports and in the supply chain, advance the current state-of-the-art of the technology available and begin the process of making the MVP outlines a reality. → Teams developed solutions that advance any current solutions available and achieved the MVP outline objectives.
3	**Smart Ports**	31 March 2020	Discussions and workshop focused on: → What really makes a port smart? → Defining a smart port, Smart = Sustainable and what tools RH DH is using, reports, etc.
4	**Blockchain**	9 April 2020	The event focused on Blockchain and its applications in the Maritime Industry and Supply Chain.

5	**Maritime Innovation –Collaborative Sustainability**	21 April 2020	Discussions focused on: → Business creativity and innovation in the context of Maritime 2050 → The processes behind business creativity and the innovation process → How to think more creatively individually, in teams and collaboratively with other organisations → How we can support each other to develop a more sustainable maritime sector for the future.
6	**Artificial Intelligence**	28 April 2020	Discussion on current business applications for Robotic Process Automation and AI, looked into the future to discuss what is to come in the AI world in view of Accenture's recently released 2020 Technology Vision.
7	**Clean Energy Workshop**	5 May 2020	→ Review of new technology and techniques around clean energy and decarbonisation projects. →A series of Clean Energy deep dives followed with extra workshops and webinar focused on clean energy sources as per Figure 6.6
8	**Space Technology Seminar**	12 May 2020	→ Review of Space Technology and its applications in the wider business sector.
9	**Data Strategy Workshop**	19 May 2020	→ Review of current data strategies within business and throughout the supply chain. → Discussion around open source engagement opportunities and applications.
10	**Smart North Sea Seminar**	26 May 2020	→ The Oil and Gas Technology Centre (OGTC) and the National Decommissioning Centre (NDC) are working to develop a "Smart North Sea" concept – an integrated platform that could access data from all assets in the UKCS, fixed, floating and mobile, human, machine and environmental. The seas around the UK generate vast amounts of data, and discussion focused on how we can best utilise that data for the greater good of the UK and for the collective benefit of associated industries
11	**RAF Innovation - Insights for UK Maritime Seminar**	2 June 2020	→ Insight into RAFX, the Innovation Hub for the Royal Air Force. → Discussion focused on how the RAF are embracing innovation and what insights can be transferred to the Maritime Sector.
12	**Sustainovate—Combining Sustainability and Innovation!**	11 September 2020	→ Discussion focused on how the global leading producer of outdoor power products for forest, park and garden care has transitioned to a more sustainable business with innovations opening up sustainable opportunities. → Description on how digitalization and battery technology create conditions to achieve its sustainability ambitions in a way that is good for customers, the company and the planet.
13	**Connected and Autonomous Vehicles in Logistics (5G Create)**	16 October 2020	→ Description of the project in which NEAA and Connected Places Catapult are members, of focused on launching a 5G enabled connected and automated logistics (CAL) pilot and proof of concept project. → This work is building on the strengths of the North East and the potential opportunities for ports, connected logistics and the region. → The use of 5G in the project will uniquely enable the removal of the safety driver from the process, allowing remote teleoperations to overcome abnormal situations.

14	**Simplifying and Demystifying the Digital Transformation Journey**	10 November 2020	→ Discussion focused on: • What is a digital transformation? • Why should businesses automate business processes? • Who should take advantage? • How is digitalisation achieved? → Discussed the importance of establishing the right culture for change, the software options available, and the potential benefits. → Real-life case studies illustrated the reasoning behind a digital journey, key challenges organisations face, how to create the right culture for change, and the road map to achieve a successful digitalisation outcome to deliver operational efficiencies.
15	**Big Data – The benefits, the challenges and what it means for Maritime**	17 November 2020	→ Looked at defining 'big data', the approaches used to get the most from it and, using real world examples from both maritime and from other verticals. → Illustrated the benefits and challenges associated with this opportunity.
16	**How to reinvent your operating model for the digital world**	24 November 2020	→ Covered the two big organisational shifts required to create and implement new operating models that will achieve step-change improvements in revenue, customer experience, and cost. → Provided an overview of McKinsey's Next Generation Operating Model—a robust and practical framework for reinventing the business to win in the digital world and capture the full value of digital transformation. → Presented the 5 key approaches and capabilities that drive the new operating model. → How to work out the right place to start a digital transformation journey.

Table 9.2: Overview of events attended by the author for the Participant Observation study

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Additionally, the outputs of the "Maritime Innovation – Collaborative Sustainability" and "Clean Energy Workshop" sessions led to the need for a deeper dive into clean energy sources. The participants identified the key themes as illustrated in Figure 9.2, and following this, 10 additional workshops – **Clean Energy Deep Dives** as listed in Table 9.3 below were conducted.

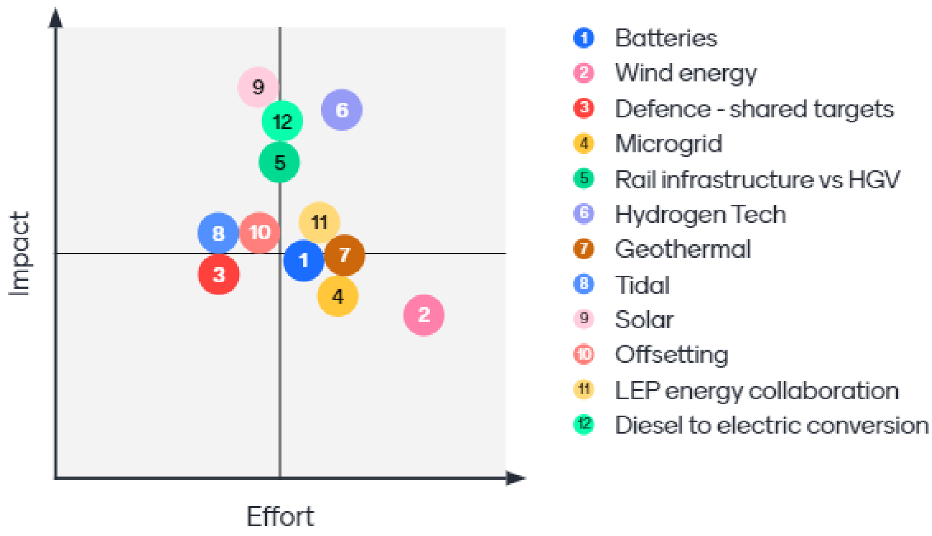


Figure 9.2: Outputs from sessions "Maritime Innovation – Collaborative Sustainability" and "Clean Energy Workshop"

The participants in the "Maritime Innovation – Collaborative Sustainability" (No.5) and "Clean Energy Workshop" (No.7) sessions identified the significant impact and benefits that each of the 12 actions (coloured bullet points in Figure 9.2) can have in the decarbonisation of the sector, compared to the effort (installation) needed to implement each of them. As Figure 9.2 illustrates, the impact of solar power compared to the efforts needed to implement it, are the most beneficial. This is because harnessing solar power can have a big impact in the greening of ports, since the power that can be generated is significant, while the effort (monetary and feasibility assessment) to install solar panels is quite low. Moreover, the biggest effort appears to be focused on wind power, as the feasibility assessment and installation of wind turbines appears to be the most complicated method, with the lower impact compared to other clean energy sources or other solutions (e.g. rail infrastructure linkage to ports).

Therefore, the next step was to get a deeper focus on the key themes listed in Figure 9.2, in order to become more specific and begin to get collaborative work streams identifying the ways in which each of these actions can be implemented. Table 9.4 lists the 10 Clean Energy Deep Dives that were conducted in May - June 2020 and outlines the summary of their content. The aim of the Clean Energy Deep Dives was to explore the use cases of each clean energy source, identify the ways in which they could assist the UK port sector and the supply chain with its carbon reduction commitments, and help shape the direction of decarbonisation strategies for the UK maritime sector. Figures 9.3, 9.4 and 9.5 demonstrate the participants during some of the workshops held in the 2050 Maritime Innovation Hub.

No.	Clean Energy Deep Dive workshops	Date	Synopsis
1	Solar Innovation in UK Ports	22 May 2020	→ Deep Dive into the potential of Solar Energy and its uses in UK Ports and their supply chain → Investigated the potential applications of Solar Energy within the UK Port sector to assist with its carbon reduction commitments.
2	Leading with Green Hydrogen	28 May 2020	→ Investigated the potential applications and uses of Hydrogen Energy and Technology within the UK Port sector to assist with its carbon reduction commitments.
3	Harnessing the Potential of Wind Energy	28 May 2020	→ Investigated the potential applications and use cases of Wind Energy within the UK Port sector to assist with its carbon reduction commitments.
4	Port Integration with Road & Rail	29 May 2020	→ Investigated the potential benefits of Port Integration with Road & Rail to assist with its carbon reduction in the UK Port sector.
5	Shared Clean Energy Objectives – Defence & UK Ports	2 June 2020	→ Investigated the potential benefits of cross functional innovation and collaboration, particularly with the Defence sector.
6	Carbon Offsetting through North East Projects	9 June 2020	→ Investigated potential Carbon Offsetting techniques that could be implemented within the UK Port sector.
7	Solutions for Battery Power	9 June 2020	→ Investigated the potential applications and use cases of Battery Power within the UK Port sector.
8	Tidal Power	18 June 2020	→ Investigated the potential applications and use cases of Tidal Energy within the UK Port sector.
9	Innovating with Microgrids	19 June 2020	→ Investigated the potential applications and use cases of Microgrids within the UK Port sector.
10	Exploring Geothermal for UK Ports	30 June 2020	→ Investigated the potential applications and use cases of Geothermal Energy within the UK Port sector.

Table 9.3: Clean Energy Deep Dive workshops

Figure 9.3: Photo from workshop

Figure 9.4: Photo from workshop

Figure 9.5: Photo from workshop

9.4 Discussion

The Participant Observation led the author to the following conclusions:

- The 2050 Maritime Innovation Hub created opportunities to raise awareness about how the port and maritime sector can benefit from advanced technology and innovation techniques, collaborate and learn, allowing the Port of Tyne to stay at the forefront of maritime innovation.
- All events organised by the 2050 Maritime Innovation Hub were designed to encourage innovation through the cross-sector engagement and collaboration of organisations across the wider spectrum of academia, logistics, technology and maritime sectors.
- The events concentrated on the brainstorm of ideas, innovation, and knowledge among all the aforementioned sectors, to achieve the UK's Maritime 2050 long-term goals, as well as the Port's Tyne 2050 strategy.
- Collaboration with Universities through such workshops and events will increase awareness on the significant change happening currently in the maritime sector, thus making it more attractive to younger people, and accordingly solving the big lack of skillset required in the port sector, as was identified in Section 8.6.4.
- Today's operational landscape and the Fourth Industrial Revolution have created the need for the transformation of the maritime and port sector, this requiring the sector to explore novel opportunities, while continuing to exploit the existing ones. The way to accelerate this transition is to be open to innovation paths that have been already taken from other industries and sectors, as the port sector has always been reluctant to change and hesitant to make the first steps in adopting a new technology.
- Port operatives and management staff participated in the events held at the 2050 Maritime Innovation Hub and presented the challenges faced in their day-to-day job. Their involvement in these events, given their experience and deep knowledge, hence led to the identification the current needs in the sector.
- Mutual learning, engagement and active participation of key stakeholders in such workshops and events, is promoting the generation of innovative projects, solutions and transformative actions that can lead to the development of the path to decarbonisation, digitilisation and enhancement of the port sector's efficiency and performance.

Overall, the workshops held by the 2050 Maritime Innovation Hub have helped the Port of Tyne set its direction and inform its strategy. Lessons learnt from other ports, sectors, academia have significantly contributed to the Port's net zero and digitilisation acceleration and have led to various initiatives such as:

- Collaborations with academia and other companies for government funded projects, linked to feasibility studies for the Port's decarbonisation.
- The development of the "Clean Energy testbed" project, which was inspired by the Clean Energy Deep Dives, where the Port through collaboration with industry and academic partners is creating testbeds for new clean energy solutions. More specifically, living 'labs' are created within the port to assess how potential solutions perform in the real environment – e.g. prototypes of innovative products designed for clean energy, such as solar, wind, energy storage, and more.
- The participation of the Port's workforce has brought a culture change within the business, which has helped the Port accelerate projects linked to decarbonisation and digitilisation, as all employees are very engaged with the delivery of these projects. This is due to the fact that they have actively participated in the workshops and have interpreted the importance of transitioning from a traditional port to a smart port.
- The participation of cross-sector companies in the workshops has brought fresh thinking from outside the port sector, which is often resistant to change and conservative. The lessons learnt from the positive impact that new technologies and innovation has brought to other sectors, has helped the Port of Tyne adopt an innovative approach within its strategy.

All the above have helped the Port of Tyne accelerate its transformation and be open to innovation and collaboration. This in turn will lead to an increase in its future smart score, as the pace of change is rapid and the Port aims to not only achieve its goals, but also become an exemplar to other ports.

9.5 Conclusion

This Chapter explored the ways in which a traditional port accelerates its transformational journey to becoming smart, green and sustainable. This analysis was based on the experience of a 12-month engagement process and participation of the author in 16 events and 10 clean energy deep dive sessions held at the 2050 Maritime Innovation Hub, located at the Port of Tyne. The study addressed the importance of collaboration across the wider spectrum of academia, logistics, technology and maritime sectors, to achieve the need for the transition to achieve the UK Government's Maritime 2050 goals.

Observing the 16 workshops and 10 deep dives complemented the insights provided by the 12 in-depth semi-structured interviews with industry stakeholders and provided further guidelines into the path to become a **Smart Port.** Overall, the Participant Observation process showed real value in bringing together diverse stakeholder groups to generate fresh insights and tackle shared challenges. It also highlighted, in particular, a pivot towards smart ports needing to focus on new clean energy sources and identified the challenges of where these fuels will be bunkered, while also emphasising the fact that ports will need to act as 'energy hubs' for the maritime sector.

Finally, experience from this study provided managerial and practical policy implications for the choices needed to be made by stakeholders involved in the maritime sector, highlighting the effectiveness of cross-sector collaboration. The continuous learning and active participation of the relevant stakeholders is crucial to the development of tools and practices needed to obtain solutions to the current challenges faced by the port and maritime sector as a whole.

Chapter 10. Conclusion

10.1 Introduction

In this final Chapter the author concludes the dissertation by summarising the core objective and questions (Section 10.2), as well as the research design that guided this thesis (Section 10.3). The key findings and results are summarised, based on the research objective and questions (Section 10.4). The value and contribution of this research are presented (Section 10.5), while recommendations to policy makers, government are given based on the Results of the research (Section 10.6). Finally, the areas and opportunities for future research are proposed (Section 10.7).

10.2 Justification and Research Objective

The current landscape in the maritime industry is portrayed by the advent of the Fourth Industrial Revolution, economic globalisation, fast changing port operational and shipping patterns, continuous search of economies of scale, and accelerated environmental and sustainability regulations. In turn, barriers to the smooth development of smart, green and sustainable ports create significant challenges for ports to adapt to the tremendous speed required to respond and to compete nationally and internationally. Factors affecting the need for fast transformation of the port sector and adoption of technological advancements in port operations can harm ports' competitiveness and their ability to serve effectively and efficiently their supply chain. Barriers to the fast adoption of new technologies also impact on the opportunity for the hinterland and stakeholders to benefit and leverage economic, environmental and social gains from this transformation. Therefore, the need for ports to embrace and adopt digitalisation-driven, environmental and sustainable innovations and technologies are crucial to keep up with the fast paced transformation and modernisation required in the port sector. As a result, it was pivotal to understand deeper the strategies in which port operations can become smart, green and sustainable, and the factors driving or restraining this development.

In recent years, the extensive number of studies focusing on this topic and amount of conferences organised with this focus acknowledge the critical need for ports to adapt in the new operational landscape and respond to the global environmental and sustainability agenda. However, the examination of available literature showed that the knowledge gap remains on how technological advancements in port operations affect the efficiency and performance of a port, what benefits and impacts are generated for the hinterland, and what are the different barriers and incentives for the development of smart, green and sustainable ports.

The core **Research Objective** of this research was:

- ❖ **To investigate the relationship between technological advancements in ports, port performance, net benefits for the hinterland, benefits to stakeholders and the development of smart, green and sustainable ports.**

To address this Research Objective (RO), the following Research Questions (RQs) were developed:

RQ1. Which are the latest technologies and smart, green and sustainability related practices adopted in ports?

RQ2. What is the relationship between port efficiency and local economic development?

RQ3. What are the key characteristics of the world's leading container ports and how can a representative port sample be identified for further analysis?

RQ4. What are the net benefits generated by technological advancements regarding both port performance and the local economy?

RQ5. How do different external factors affect the maximisation of the potential gains for port operators and the local economy?

10.3 Research Design

The complexity of the topic under investigation in this research and the interrelated concepts analysed required the adoption of a range of research approaches. To holistically address the research objective, the author adopted a multi-phased, triangulated, mixed methods approach. The research design outlined in Table 10.1 facilitated the author to answer the research questions encompassing this study in the most multi-perspective and valid way possible. Also, Table 10.2 reiterates the philosophy, theoretical framework, methodology and methods that were adopted in this thesis.

Research Objective	Research Questions	Method / Approach
RO. To investigate the relationship between technological advancements in port operations, port performance, net benefits for the hinterland, benefits to stakeholders and the development of smart, green and sustainable ports.	**RQ1.** Which are the latest technologies and smart, green and sustainability related practices adopted in ports?	Literature Review Scoping Study - Preliminary Interviews Website Content Analysis
	RQ2. What is the relationship between port efficiency and local economic development?	Systematic Literature Review
	RQ3. What are the key characteristics of the world's leading container ports and how can a representative port sample be identified for further analysis?	Sampling
	RQ4. What are the net benefits generated by technological advancements regarding both port performance and the local economy?	UK Case Study – 12 Interviews Participant Observation
	RQ5. How do different external factors affect the maximisation of the potential gains for port operators and the local economy?	Systematic Literature Review UK Case Study - 12 Interviews Participant Observation

Table 10.1: Overall research design

Element	**Selection**
Paradigm	Pragmatism
Theoretical Framework	Abductive approach
Methodology	Mixed methodology
Methods	Mixed methods

Table 10.2: Summary of the selected research design

10.4 Results – Phases and Research Questions

This Section presents the main results obtained by this research. The author adopted a mixed methods approach, as summarised in Section 10.3, and addressed the Research Objective and five Research Questions that encompassed this study through a six phase design as described in Chapter 3 and outlined below in Table 10.3. The analysis of the characteristics of 71 leading ports around the world and the Website Content Analysis focused specifically on container ports, while the UK Case study and the Participant Observation addressed all types of ports.

Phase	**Research Questions encompassed**
Phase 1	Scoping Study - Preliminary Interviews (RQ1), Literature Review (RQ1), Systematic Literature Review (RQ2)
Phase 2	Primary and Secondary data collection tasks for this study
Phase 3	Analysis of the key characteristics of the world's leading container ports (RQ3)
Phase 4	Website Content analysis of the world's leading container ports (RQ1, RQ4, RQ5)
Phase 5	UK Case study (RQ4, RQ5) and Participant Observation (RQ4, RQ5)
Phase 6	Result aggregation and final writing of the thesis

Table 10.3: Six phase design and Research Questions

During **<u>Phase 1</u>** of the research, the author explored through the scoping study - preliminary interviews, the literature review and the systematic literature review, the current port operational landscape, shed light into the challenges faced by the port industry and hence refined the phenomenon under study that guided the focus of this research.

Initially, the scoping study through the preliminary interviews contributed into the deeper understanding of the main challenges and built the current port operational landscape. The findings of the scoping study revealed that: (i) ports are under pressure to adopt new technologies to respond to the fast-changing requirements generated by the advent of the Fourth Industrial Revolution; (ii) the environmental regulatory framework and the green agenda developed for ports dictate the need for fast-paced embracement required by ports to mitigate GHG emissions; (iii) the changing patterns in port employment and required skillsets; (iv) the need for end-to-end efficiency improvements in the whole supply chain where ports play a crucial part.

Phase 2 of the research involved the primary and secondary data collection tasks for this study (i.e no research conclusions as such emerged from this particular phase).

Phase 3 included an analysis of the characteristics of the world's leading container ports and explored the patterns that arose from their performance and automation levels.

Next, during **Phase 4** the author used Website Content Analysis to investigate the world's major ports regarding the disclosure of information in their corporate websites focusing on their smart, green and sustainability related practices and efforts. A smart score was elaborated for each port in the sample by finding the horizontal sum of the 20 factors included in the five categories that were used for the Website Content Analysis. The five categories generated for the Website Content Analysis were reflecting the strategies that ports reported in their websites:

- Environment, sustainability and community;
- Monitoring;
- Certification and reporting;
- Energy sources and incentives;
- Technology and innovation.

Each of the five categories contained a number of different factors, as was thoroughly analysed in Chapter 7. The "smart score" for each port in the sample was elaborated by finding the horizontal sum of factors for each port and then dividing it by 20 (the total number of factors). Smart scores varied between 0 and 0.75. The 'smartest' port in the sample was Antwerp, while next in the ranking were the ports of Amsterdam, Rotterdam and Los Angeles scoring 0.7. On the other hand, the ports with lowest smart scores were mostly situated in Asia, as from the 18 ports that scored under 0.1, 14 of them were situated in Asia. Overall, findings revealed that ports located in Europe, US and Australia tended to have higher levels of smart, green and sustainability related practices compared to Asian ports, in terms of disclosure extent in their corporate websites. Hence, ports that are increasingly taking steps to improve their smart and green agendas can lead the way for other ports that still have a long road ahead to become smart.

The author also performed a correlation analysis between the “smart score” and the “CPPI scores”. Surprisingly, the correlation analysis was in line with the significant conclusion drawn on Chapter 6 (Phase 3); ***that automation does not also imply increased performance, contrariwise, it implies a decreased performance as the median time of vessels spent in port (days) of automated ports was high.*** Similarly, in the correlation analysis performed in the final Section of Chapter 7 (Phase 4), results indicated that ***as the smart score increases the performance of ports drops, as ports with high scores in CPPI showed a low smart score***. In conclusion, ports in the sample that put high effort on smart, green and sustainability priorities (considering from the information outlined in their websites) appeared in aggregate to demonstrate lower performance, and vice versa.

In **Phase 5** the author analysed the UK Case, through the twelve semi-structured in-depth interviews, and reflected the current status of UK ports with regards to their status when it comes to technological advancements’ adoption in their operations. It also provided deep insights and interesting findings on the benefits generated from the adoption of technological advancements, the barriers to adoption, future plans and policies adopted for UK ports to become smarter, greener and more sustainable. A Thematic Analysis using NVIVO software and manual coding identified ***10 themes***, namely:

- Port industry features
- Technological advancements in UK ports
- Planning for new technologies
- Change in required skillset
- Impact on number of jobs
- Data collection challenge, value and integration
- Net benefits generated from technological advancements
- Barriers to development of smart ports
- Incentives to development of smart ports
- Ranking of smart ports

The author, based on the insights provided from the twelve interviews (and more specifically through the “technological advancements in the UK port sector” theme) and the Literature Review findings, generated Figure 10.1 which illustrates the top technological trends in the UK port sector.

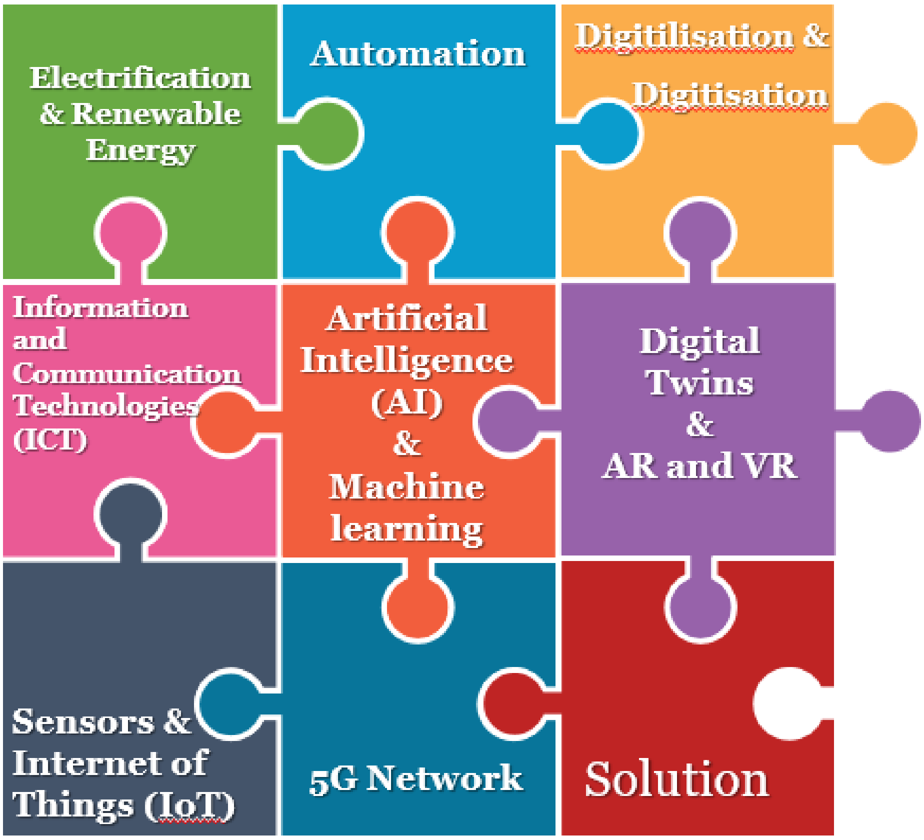


Figure 10.1: Puzzle of Top technological trends in the UK Port sector

Source: Author elaboration based on Literature review and UK Case study interviews

Overall, the twelve interviews provided critical insights for the UK port industry as outlined below:

- The port industry is resistant to change and still perceived as a very traditional industry that is many years behind compared to other industries in terms of adopting new technologies.
- The change occurring currently in the UK port sector and therefore the wide range of technologies that are adopted by ports are helping towards the modernisation of the UK port sector.
- 'Automation' and 'environmental technologies' are increasingly at the centre of the UK port sector's policies and concerns.
- The significant changes in the required skillset require a digitally literate workforce, and therefore this will make the port sector more attractive to a younger workforce and help towards addressing the existing lack of talent and required skillset.

- The change of skillset will lead to a change in the job type rather than a decrease in the total number of jobs required in the port environment.
- Training and advance planning for new technologies is pivotal for keeping the efficiency levels of port operations stable when a technology first arrives and is introduced in the daily operation of the port.
- Data in the UK port sector is currently not being used sufficiently, as it is poorly captured and understood. Significant value can be harnessed from data, if collected in a more efficient and effective way, this being possible only if operators know in advance what they need out of the specific data.
- The increase in the number of well-paid and good-quality jobs created for the hinterland is one of the bigger benefits generated by the adoption of new technologies in the port sector.
- The significant increase in safety of port operations as the human-machine interface is minimised due to automation is another pivotal benefit generated from the adoption of new technologies.
- New technologies are greener and more sustainable compared to old ones and are helping towards achieving the decarbonisation targets of the UK port sector.
- Private ports are driven by efficiency and short term ROI, and therefore the private ownership type in some instances might act as a barrier when the investment of a specific technology might have a long-term ROI, such as green technologies for example.
- The use of electric straddle carriers might lead to a drop in the productivity of port terminals, as compared to diesel ones, they need to be charged every hour and therefore productivity is lost, and in turn this might act as a barrier and slow down the uptake of their adoption on port operations.
- The client base of ports can act as the main driver towards the development of smart ports, as the wider drive across the supply chain and logistics sector to digitilise and become more sustainable will push ports to also adopt smart and green technologies to be able to keep up with the customers' requirements.
- The decarbonisation target set for the UK port sector is also pivotal to the acceleration of the adoption of new technologies and to incentivise investments towards that direction.
- A potential ranking system for ports according to their smartness would seem a quite good incentive for a standardisation push into "what a smart port is". It would also

drive competition up, making ports willing to go up the scale and hence to be more proactive with adopting smart, green and sustainable technologies in their operation.

Additionally, **<u>Phase 5</u>** incorporated the Participant Observation for which the author attended a series of 16 workshops and 10 clean energy deep dives over a 12-month period. The findings of the Participant Observation, provided strong evidence for the importance of collaboration among academia, logistics, technology providers and stakeholders from other sectors, for innovation to be encouraged and advanced in the port sector to achieve the UK Government's Maritime 2050 goals. This cross-sector engagement drives the sharing of knowledge and gives the opportunity to brainstorm ideas and solutions which would not otherwise be generated. The Participant Observation process also showed a pivot towards smart ports needing to focus on new clean energy sources and emphasised the fact that ports could transform into 'energy hubs' in the coming years, thus playing a key role in the decarbonisation of the sector.

Finally, **<u>Phase 6</u>** of the research involved the result aggregation and final writing of the thesis and therefore no conclusions emerged from this Phase.

Overall, from Phases 4,5 and 6, and having performed a **three level analysis of port smart scores** (global level – 71 major world ports in Chapter 7; national level – 10 major UK ports in Chapter 8; and local level - Port of Tyne in Chapter 9) it is concluded that ports have started to hugely consider having green and sustainable strategies, as based on the results more and more ports are including sustainability and environmental commitments in their mission / vision / values. However, ports need to improve their efforts towards being smart, as their overall smart scores are quite low, with ports located in Europe and the US having a clear predominance in higher smart scores. Thus, ports that have higher smart scores can lead the way and become exemplars to ports with lower smart scores. Interestingly, the UK's average smart score was found to be the same with the average smart score of the 71 world ports, namely 0.3, showing that ports within the UK are at the same level with ports worldwide when it comes to efforts towards becoming smart. However, it has been also identified that the efforts linked to "Technology and Innovation" are significantly low within UK ports, as none of the four factors included in this category were identified within the website content analysis of most UK ports.

The next sub-sections briefly summarise the findings to the **Research Questions** that span this research.

10.4.1 Research Question 1

RQ1: Which are the latest technologies and smart, green and sustainability related practices adopted in ports?

Within the Literature Review the author highlighted that a *smart port*, a *green port* and a *sustainable port* are not independent of each other, as under the basis of green ports, smart ports are applying advanced technologies to reduce environmental pollution and simultaneously to achieve the goal of sustainable port development. Therefore, smart, green and sustainable ports represent a significant direction in port development in recent years.

In Figure 10.2 the author replicates Figure 2.2 generated in Chapter 2, which summarised the interrelated relationships that exist between the smart port concept, the green port concept and sustainable port development. The author in Figure 10.2 has also plotted the technological advancements explored in the previous Chapters to reflect their contribution and relevance in regards with the sustainability pillars.

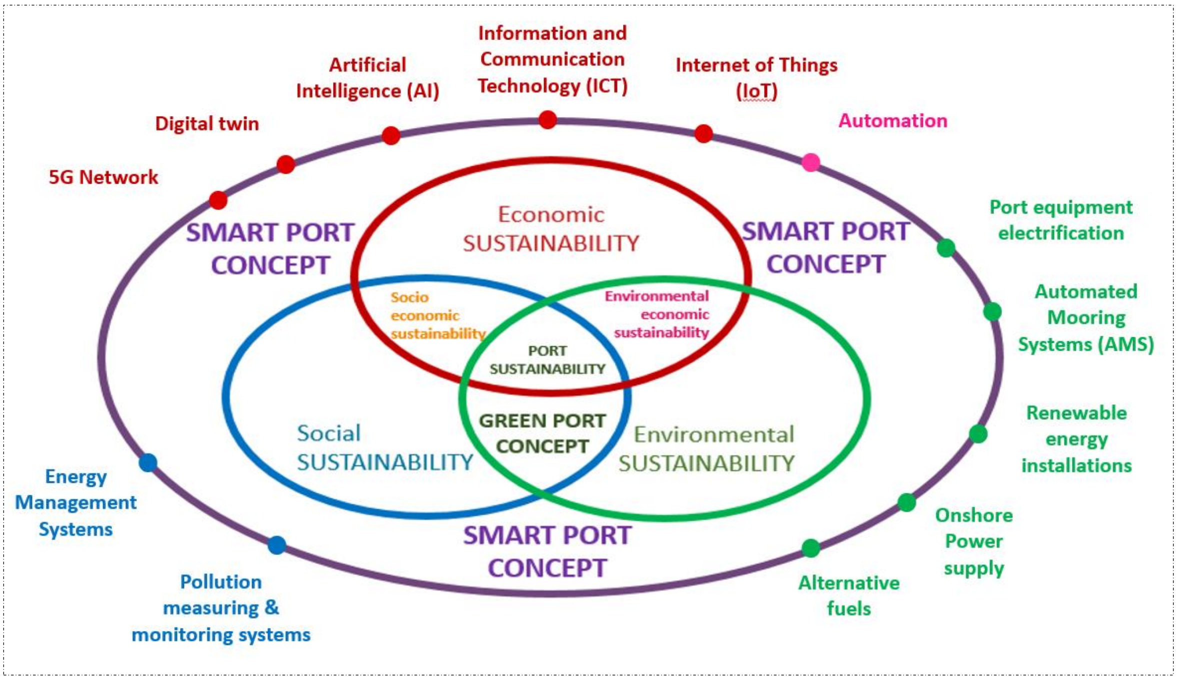


Figure 10.2: “Smart Port Bubble” - The three pillars of port sustainability, the green port concept, the smart port concept and technological advancements

Source: Author

The author concluded that the smart, green and sustainable dimensions should be regarded as a multi-dimensional concept and illustrated the interrelated relationships in the “Smart Port Bubble”. These three dimensions are interrelated and complementary, as in order for a port to be sustainable, it also needs to be green, and if a port is green it uses smart technologies to achieve its green status. Therefore, the green port concept refers to social and environmental sustainability, while all the three dimensions of sustainability generate the smart port which adopts innovative, green and cost-efficient technologies.

The technological advancements described in Chapter 2 can be plotted within the “Smart Port Bubble” as illustrated in Figure 10.2, reflecting the contribution of each technology in each of the sustainability pillars that are encompassed by the smart port concept.

10.4.2 Research Question 2

RQ2. What is the relationship between port efficiency and local economic development?

The author, through the Systematic Literature Review, identified the crucial relationship between port efficiency and economic development. Interestingly, port efficiency can reduce international maritime costs, which can in turn increase bilateral trade and have a positive effect on trade flows, leading to a positive effect on the economic development of a region/country.

Figure 10.3 illustrates the relationships among all the pivotal concepts analysed in the discussion of the systematic literature review (SLR).

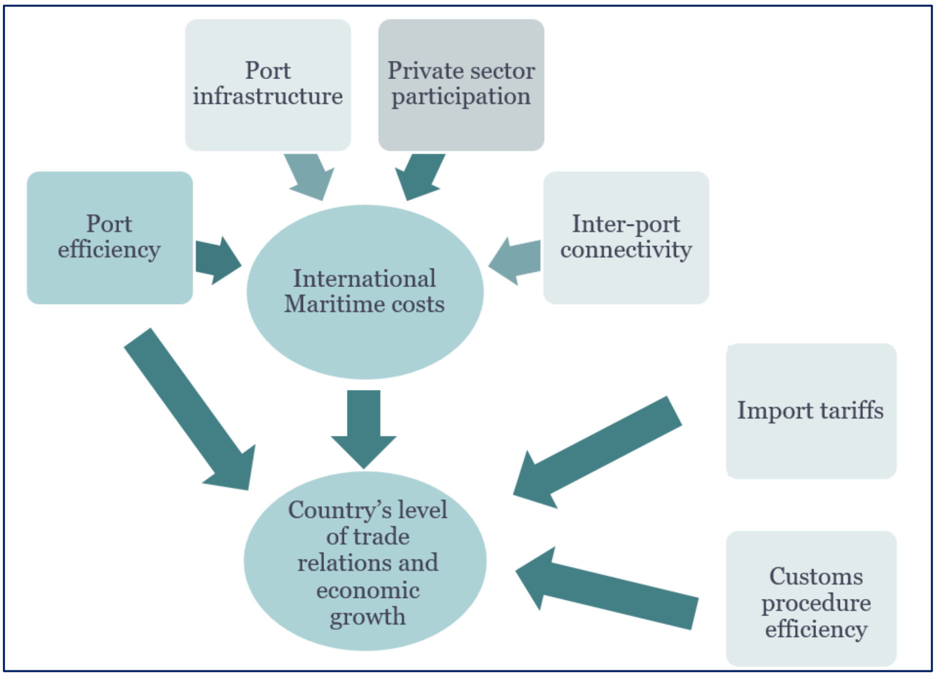


Figure 10.3: Relationship among critical concepts under scrutiny in the SLR

Overall, and given the relationships described in Chapter 5, it can be concluded that international maritime costs, which dictate the country's level of trade relations and economic growth, are affected by port efficiency, as well as by port infrastructure, private sector participation and inter-port connectivity. Moreover, the findings highlight that an improvement in port efficiency can generate a reduction in shipping costs and can improve the quality of maritime transport, thus increasing bilateral trade and creating a large and positive effect on trade flows, which consecutively leads to the economic development of a region or country.

10.4.3 Research Question 3

RQ3. What are the key characteristics of the world's leading container ports and how can a representative port sample be identified for further analysis?

Having analysed the characteristics of the world's leading container ports and explored the patterns that arose from their performance and automation levels, results showed that ports having high levels of automation (according to the ITF 2021 Report) scored quite low in the CPPI (Container Port Performance Index generated by the World Bank and IHS Markit).

Additionally, when median time vessels spent in port was taken as a proxy for efficiency, results indicated that ports with high degree of automation showed that their efficiency levels were not high compared to their conventional counterparts, which scored higher in both CPPI and median time vessels spent in port indicators.

More specifically, findings suggested that countries with a high degree of automation in their ports did not appear to score a fast median turnaround time, as Australia and the US for example had the longest average times spent in port and scored quite low in the CPPI score, although all their ports included in the sample had some degree of automation.

Overall, although it is often assumed that ports with high automation levels have higher performance levels than their conventional counterparts, findings suggested that **automated ports were not more productive and efficient than their conventional counterparts**.

As far as the representative sample that was selected is concerned, the author demonstrated that by including ports located in all geographical regions of the world, with various governance models, with various types of equipment and automation levels, with different strategies and priorities, a holistic approach was taken and the research was representative and able to reflect the status of world ports in regards with technological advancements.

10.4.4 Research Question 4

RQ4. What are the net benefits generated by technological advancements regarding both port performance and the local economy?

The scoping study through the preliminary interviews captured some benefits generated by technological advancements that were subsequently explored in detail within the UK Case study. Overall, during the scoping study, the four interviewees highlighted that the benefits generated for the hinterland from the adoption of new technologies can vary from **work safety** to **upskilling of the local economy**.

More specifically, since automation and digitalisation require different skills, this in turn means that a highly qualified and IT literate workforce is required to fill the new job roles created in the port sector, this in turn leading to the upskilling of the local region. Moreover, the safety aspect that new technologies bring into the operational environment of ports was also regarded as one of the main generated benefits, as the human-machine interface is minimised due to automation. Another significant benefit highlighted by one of the respondents, was that **connectivity** is greatly enhanced due to the adoption of technological advancements in ports, as road and rail links are improved to enable the need of the maximisation of port performance levels, and consequently these benefits are also passed on to the port region.

Moreover, and within Chapter 8, the net benefits generated for the hinterland were also thoroughly explored. One of the identified themes, namely the **"Net benefits generated from technological advancements"** in Section 8.5.7, revealed that the **creation of jobs** is one of the main factors highlighted by respondents, as they argued that every direct job creates three or four indirect jobs in the hinterland. It was also emphasised that these new jobs are highly paid which in turns means that more money are spent in the local economy thereafter. Moreover, and similarly to the safety aspect mentioned in the Scoping Study, interviewees in the UK Case Study also underlined the importance of the reduced human interaction with machinery, which eliminates substantially the injuries and brings massive safety enhancements.

Additionally, the **environmental** and **economic** benefits that are generated when ports adopt new technologies and are operated more efficiently, are also of vital importance. The use of new technologies and digitisation can help port operators manage their assets and transport flows more efficiently, resulting in indirect benefits, such as less vehicle idling / less unnecessary anchorage of ships (less emissions generated) due to the more efficient scheduling of arrivals. Decreased emissions are therefore one of the main advantages of the of digitilisation, while the automation and electrification of port equipment also play a pivotal role in the decarbonisation of the port, with the benefits of enhanced air quality having a positive effect in the region.

Another benefit or the hinterland that arises from digitilisation is the **minimisation of congestion** during peak times, due to the better management of trucks (vehicle booking systems).

Finally, the **upskilling** of the region was also emphasised by respondents in the UK Case study, as modern ports require different types of jobs that can be filled by people with a diverse skillset compared to traditional ports. Ports to be able and attract the talent they need, offer apprenticeships, training course, sponsor doctorates, thus giving back value to the local community.

On the other hand, when considering the impacts generated by the adoption of new technologies, some respondents within the Scoping Study pointed out that labour unions are increasingly fearing job loss and this is the reason why in some countries they are strongly opposed to automation. The four interviewees gave a wider perspective into this matter, as they represented different geographical areas of the world, while the respondents of the UK Case study gave a view focusing only in the UK port sector and workforce.

10.4.5 Research Question 5

RQ5. How do different external factors affect the maximisation of the potential gains for port operators and the local economy?

Technological advancements can generate significant benefits to both port operators and the hinterland. However, some external factors might create blockages to the maximisation of these potential gains. Some of the barriers to the development of smart ports that prevent the port operators to benefit from the adoption of new technologies were identified within Chapter 5 (Systematic Literature Review); Chapter 8 within Section 8.5.8 (theme "Barriers to the development of smart ports"); and Chapter 9.

Overall, some of the main barriers are geographical location, ownership type, port size, availability of skills needed, unionisation, culture, insufficient use of data, and lack of open collaboration.

10.5 Contribution

The results outlined in Section 10.4 underpin the contribution of this research to advance the literature on port performance, port impact, and smart, green and sustainable port studies. The contribution of this research can be summarised as follows:

- Comprehensive review of the technological advancements presently adopted in port operations;
- Understanding of the relationship between port efficiency and economic development, as well as the factors affecting port efficiency;
- Understanding of the key characteristics of container ports and provision of a method of identification of a representative sample;
- Contribution to understanding the different net benefits that are generated from the application of technological advancements in port operations, as far as port performance and the hinterland are concerned;
- Provision of insights and benchmarking of the world's major container ports with regard to their smart, green and sustainability related practices and efforts, according to their website disclosure and reported practices;
- Provision of insights on the factors behind the barriers for the maximisation of the potential gains generated for both port operators and local communities from the application of technological advancements in port operations;

The results of this research advanced knowledge in a topic that is increasingly gaining attention in the port sector. The detailed analysis and more precise understanding of the relationship between technological advancements in port operations, the benefits and impacts generated, the barriers to the development of smart, green and sustainable ports, can provide better guidance for port operators, supply chain stakeholders and governments for policy-making and investment. In addition, with particular reference to the UK port sector and by providing strong evidence of the importance of cross-sector collaboration, the author highlighted that the transformational journey of ports can be accelerated and the UK's Maritime 2050 goals could be achieved, through the design of effective policies to address barriers to the fast and smooth development of smart, green and sustainable ports.

10.6 Recommendations

The results of this research shed light into what a smart, green and sustainable port is and explored the main drivers and barriers to the adoption of technological advancements in port operations. The author in this Section outlines some main recommendations and provides guidance to the port industry's main stakeholders, namely port operators, policy makers, international bodies, government agencies, investors.

1. Ports need to quickly adapt the fast-changing operational landscape and obtain a competitive advantage over their counterparts, as nowadays more and more customers require their whole supply chain to be as efficient, green and sustainable as possible. Therefore, it is suggested that port operators set intentionally ambitious targets for the **decarbonisation** of their ports, as well as develop clear sustainability strategies and publish annual reports of progress. The annual reports could outline the progress of all initiatives adopted as well as new goals set, since an increasing number of key customers have started to request annual updates about the sustainability commitments, energy efficiency, adoption of alternative fuels of the ports that are linked with their supply chain. The ports' websites must also mirror the strategies, goals, progress of their decarbonisation journey, since a port's website can be seen as a main means of communication to customers of its sustainability commitments and is an opportunity to become more competitive by showcasing its sustainable development strategy.

2. **Collaboration** with Universities will promote the port sector to the younger workforce, showcasing the new skillsets required, which will in turn help close the current skills gap that is currently slowing down the adoption of new technologies in the port sector. The

Government must also play a key role in opening the maritime sector to the younger workforce, in order for ports to be able and meet the great demand of new skillsets required in the industry, given the need for digitilisation and decarbonisation.

3. A key way to accelerate the transformation of the port sector is through **openness to innovation paths** that might have already been taken from other industries or even by finding solutions to existing challenges through the help and brainstorming of transformative actions together with relevant stakeholders, port operatives and also stakeholders belonging to different industries leading to the development of an accelerated journey to smart, green and sustainable port development. Therefore, cross-sectoral collaboration is also regarded as pivotal for the transformational journey of traditional ports into being smart, green and sustainable.

4. The adoption of clean energy sources is one of the main drivers to accelerate the decarbonisation of the shipping industry. Ports have a huge potential to **become clean energy hubs**, through the generation and bunkering of clean fuels. This opportunity should be seen by port operators, investors, policy makers and governments, as they should all collaborate to set a direction towards which clean fuels will be adopted in the short, medium and long-term by ships. In this way, ports will be able to decide on which fuels they will be able to bunker to ships (specialisation), but also to be used within their own operation, as a means of decarbonisation. Regulation set by governments for the quick adoption of clean fuels for the operation of ships would accelerate the decisions that need to be made by ports in order to start either both generating and bunkering or only bunkering clean fuels to their customers.

5. The development of efficient **data strategies** within ports can massively benefit their operation. The correct use and optimisation of the huge amounts of data held by ports can solve many of the bottlenecks that exist in port operations. Thus, ports should use their data as valuable intelligence to drive safety, efficiency, customer experience, profitability, net zero/decarbonisation, and achieve a purpose. To achieve this goal, it would be vital for port operators to start incorporating within their main workforce data scientists and data analysts who would be able to transform datasets into valuable assets, as intelligent data use will drive better decisions leading to improved performance and efficiency.

6. Ports should analyse meticulously their **investment decisions** because not all solutions/technological advancements are suitable for all ports. The size, location, type of governance and type of cargo handled all play a significant role into whether a smart

technology would be efficient to be adopted by ports. Therefore, ports must act individually based on their needs and individual characteristics, rather than adopt technologies just because they have been efficient for other ports (e.g. automation not being the solution to all ports, as some have seen their efficiency drop when adopting automation rather than becoming more efficient).

10.7 Further Research

Based on the outcomes of this study the author identified a number of areas for future research. This Section outlines the four potential areas for further research that can be built upon the findings of this thesis.

1. The outcomes of the Website Content Analysis and the insights provided in the UK Case study, and more specifically in the 'ranking of smart ports' theme, can be the basis for further research in developing and applying an internationally recognised ranking system for ports to reflect their 'smartness' levels. A clear distinction among all different port terminal types would however be required, as was highlighted by the respondents of the UK Case study interviews (container, bulk cargo, etc.). Hence, a further study into a smart port ranking system would be critical for ports to be ranked according to their 'smartness'. This ranking could be similar to how ports in the world are ranked according to their performance (e.g. CPPI developed by the World Bank and IHS Markit). It would provide the opportunity for shippers to select the port that would most suit their aspirations in terms of being part of a smart, green and sustainable supply chain. In turn, selecting a port that demonstrates strong environmental and sustainability commitments for example, would help shippers in their goal for a green end-to-end supply chain.

   Finally, given the increased focus in developing smart, green and sustainable ports, a global standardisation of the components of a smart port would be a useful tool for ports to be incentivised and act faster towards their transformation in terms of decarbonisation and digitilisation. It would also help compare smartness levels with other countries, track changes over time and incentivise ports to climb up in the ranking by investing more in their smart, green and sustainable technologies and strategies. This would potentially create an increased competition among ports and would also act in favour of the faster digitilisation and decarbonisation of the sector, as if ports know that shippers will select a smarter port they would strive to invest more in becoming smarter as well.

2. The insights provided by the UK Case study led to the conclusion that the skillset required in the port industry is changing. A detailed port skills audit for the skillset required to respond to the requirements of the smart port of the future would constitute an important tool for governments and ports stakeholders to promote these newly created job roles to the younger workforce, in order for them to be attracted to the port industry and change their current perception (i.e. that the port is an old-fashioned industry). However, the complexity of such an audit, is likely to require the collaboration of education and skills providers, Government and the industry, to be able to identify the skills required, promote the job roles and attract the young workforce with the required skillset in the correct timing, so that the skills gap identified would close and in turn help ports accelerate their transition to being smart.

3. The Participant Observation shed light into the fact that ports will need to be considered as clean energy hubs and become essential to the greening of maritime transport in the next few years. Specifically, future research could focus on analysing the role of ports as clean energy hubs, as well as the potential for clean energy generation and exploitation in ports. The findings of this thesis highlighted the changing direction of ports and that clean energy generation and exploitation is considered one of the top priorities in the current and future port operational landscape. Therefore, this further work could have profound effects in truly achieving the transformation of ports into clean energy hubs leading to a significant contribution to the global agenda of environmental and sustainability goals and policies.

4. Future research should also consider the vulnerability of ports given increased digitilisation adoption that is expected to be transforming the port sector in the coming years. Cyber-attacks might create huge problems in the operation of ports, and hence developing a comprehensive study with all the impacts that a cyber-attack might create would help port stakeholders be prepared to overcome these and to develop strong cyber security systems to prevent them from happening. The deeper understanding of all potential areas and targets of cyber-attacks in the smart port of

the future will be essential for the development of the appropriate tools to be protected against them.

10.8 Conclusion

This research provided evidence that the port industry is currently moving away from being resistant to change, traditional, old-fashioned and technologically immature, towards an extensive smart, green and sustainable transformation. However, this transformation comes with its challenges, as was highlighted by exploring deeper the barriers to the development of smart, green and sustainable ports. The drivers for investment were also analysed, as they will in turn help towards the acceleration of the transformational journey of ports into being smart, green and sustainable.

The current change in the required skillset is creating a skills gap, which can however be closed if the relevant stakeholders communicate the transformational journey of ports to the younger workforce. Since the young workforce is digitally literate, it will be able to contribute into the faster transformation of the port sector, with collaboration being the key into delivering this message to young people. Cross-sector collaboration was also found to be a crucial driver for tackling the challenges and creating innovation opportunities for the port sector. Opportunities are also currently created in terms of ports becoming clean energy hubs and contributing in the greening of the maritime sector. Finally, findings showed that great leverage can be taken out of efficient and effective data collection and analysis, as digitilisation can drive the port sector forward and help towards becoming smarter, greener and more sustainable.

Appendix A

The modified CASP checklist for evaluating studies (Wang and Notteboom, 2014)

A: Screening questions: Does this study address a clear question?

	Yes	Can't tell	No
#1. Does the study address a clearly focused issue? ➢ A clear statement of the aims of the research? ➢ Have an appropriate study design?	☐	☐	☐
#2. Is the study relevant to the synthesis topic? ➢ Address the formulated review questions?	☐	☐	☐

B: Are the results of this study valid?

	Yes	Can't tell	No
3. Does the study clearly explain the research method which fits for authors' stated aims?	☐	☐	☐
***4. Does the study describe explicitly about the data collection?** ➢ How and why the data collected?	☐	☐	☐
5. Does the study explain clearly how the data analysis is done?	☐	☐	☐
***6. Is the data analysis sufficiently rigorous to address the aims?** ➢ Links between data and interpretations?	☐	☐	☐

C: How are the results?

	Yes	Can't tell	No
7. Are the findings of the study explicit and easy to understand?	☐	☐	☐
***8. Are data collection and analysis sufficiently presented to support the descriptive findings?**	☐	☐	☐
9. Does the study add to knowledge or theory in the field?	☐	☐	☐
10. Are these findings important to practice?	☐	☐	☐

Overall assessment of study **<u>This study will be included in the synthesis or not?</u>**	Yes	No
Two requirements are considered of the inclusion of studies: • Two screening questions with # must be 'Yes' • Not all answers to the three key questions with * are 'No'	☐	☐

Appendix B

UNCTAD 2017 Table with Countries used for the sample used in Chapter 6 and Chapter 7

Container port throughput, annual

Other: MEASURE (TEU (Twenty foot Equivalent Unit))

YEAR / ECONOMY	2017
World	754 207 829
China	222 155 820
United States of America	52 132 844
Singapore	33 667 000
Korea, Republic of	27 415 800
Malaysia	23 784 100
Japan	21 962 500
China, Hong Kong SAR	20 760 000
Germany	19 718 533
United Arab Emirates	19 128 300
Spain	15 979 051
India	15 429 000
China, Taiwan Province of	14 911 000
Netherlands	13 911 000
Indonesia	12 829 600
Belgium	11 967 553
United Kingdom	10 240 000
Turkey	10 140 996
Thailand	9 938 000

Container port throughput, annual

Other: MEASURE (TEU (Twenty foot Equivalent Unit))

YEAR / ECONOMY	2017
Viet Nam	(10) 9 390 935
Brazil	8 972 506
Philippines	8 095 420
Saudi Arabia	8 082 000
Australia	7 995 040

APPENDIX C

UNCTAD Table with Top 20 Ports by TEU Throughput in 2017 used for sample in Chapter 6 and Chapter 7

(Review of Maritime Transport 2018, UNCTAD)

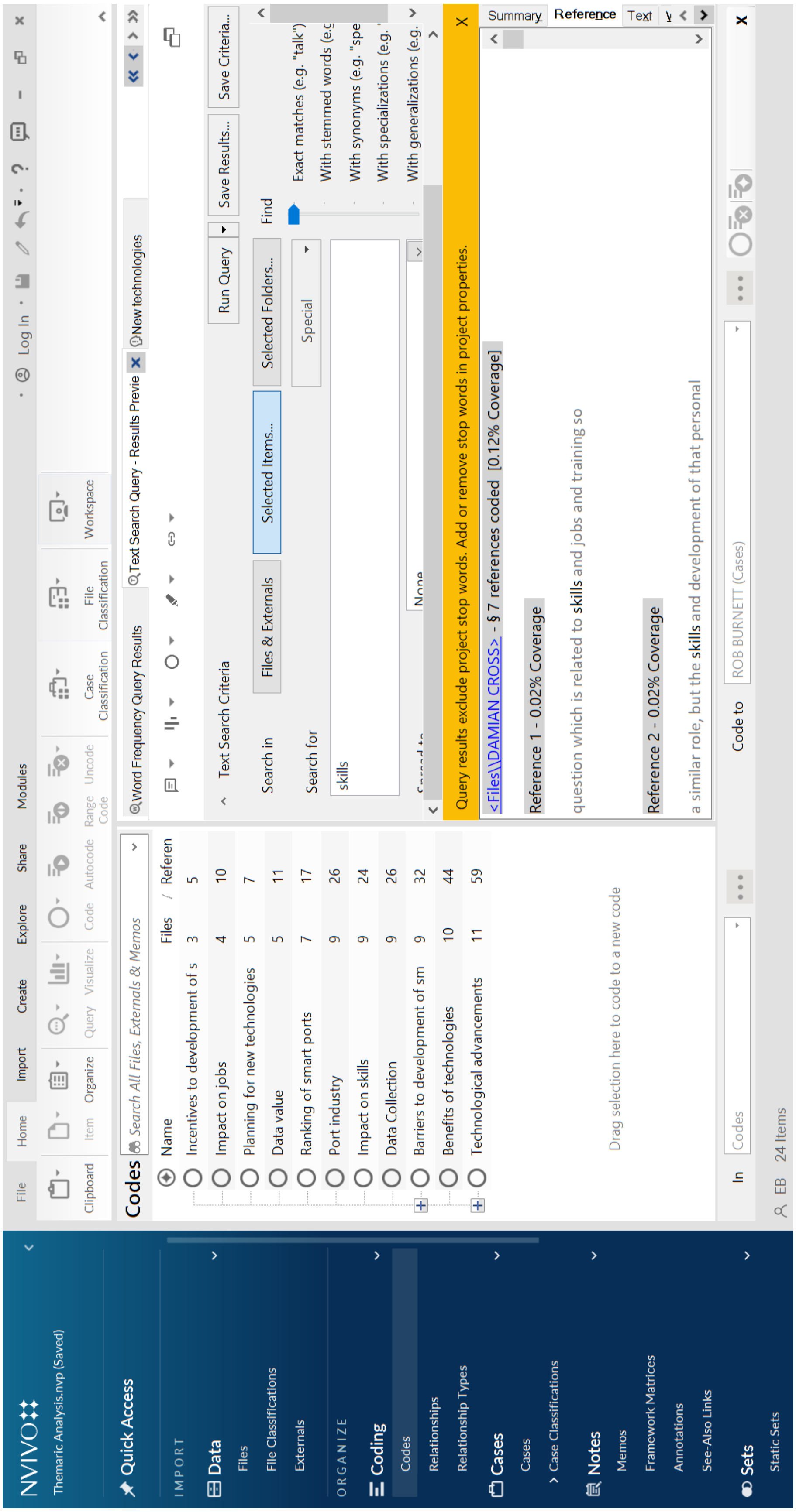
Table 4.4 Leading 20 global container ports, 2017
(Thousand 20-foot equivalent units, percentage annual change and rank)

Port	Economy	Throughput 2017	Throughput 2016	Percentage change 2016–2017	Rank 2017
Shanghai	China	40 230	37 133	8,3	1
Singapore	Singapore	33 670	30 904	9,0	2
Shenzhen	China	25 210	23 979	5,1	3
Ningbo-Zhoushan	China	24 610	21 560	14,1	4
Busan	Republic of Korea	21 400	19 850	7,8	5
Hong Kong	Hong Kong SAR	20 760	19 813	4,8	6
Guangzhou (Nansha)	China	20 370	18 858	8,0	7
Qingdao	China	18 260	18 010	1,4	8
Dubai	United Arab Emirates	15 440	14 772	4,5	9
Tianjin	China	15 210	14 490	5,0	10
Rotterdam	Netherlands	13 600	12 385	9,8	11
Port Klang	Malaysia	12 060	13 170	-8,4	12
Antwerp	Belgium	10 450	10 037	4,1	13
Xiamen	China	10 380	9 614	8,0	14
Kaohsiung	Taiwan Province of China	10 240	10 465	-2,2	15
Dalian	China	9 710	9 614	1,0	16
Los Angeles	United States	9 340	8 857	5,5	17
Hamburg	Germany	9 600	8 910	7,7	18
Tanjung Pelepas	Malaysia	8 330	8 281	0,6	19
Laem Chabang	Thailand	7 760	7 227	7,4	20
Total		**336 630**	**317 929**	**5,9**	

Source: UNCTAD secretariat calculations, based on various industry sources.
Abbreviation: SAR, Special Administrative Region.

APPENDIX D

Exemplary Coding Extract / NVIVO Software



APPENDIX E

Maritime 2050 Innovation Hub Partners

Source: Port of Tyne website

PD Ports is one of the UK's major port operators, which owns and operates Teesport, England's largest exporting port by tonnage and a key driver in the North East economy. With headquarters in Middlesbrough, PD Ports is the Statutory Harbour Authority for the Ports of Teesport and Hartlepool.

Nissan has one of the most comprehensive European presences of any overseas manufacturer, employing more than 16,000 staff across locally based design, research and development, manufacturing, logistics and sales and marketing operations.

Connected Places Catapult focus on growing businesses with innovations in mobility services and the built environment that enable new levels of physical, digital and social connectedness. The Connected Places Catapult operates at the intersection between public and private sectors and between local government and transport authorities.

Accenture solves challenges by providing unmatched services in strategy, consulting, digital, technology and operations. Leveraging the power of global insight, relationships, collaboration and learning to deliver exceptional service to clients wherever they do business.

Royal HaskoningDHV are a world leading engineering and project management consultancy leading the way in sustainable development and innovation, they have been connecting people for more than 137 years through a vision of expertise and passion for contributing to a better society and improving people's lives.

Ubisoft is a leading producer, publisher and distributor of interactive entertainment products and services worldwide. Ubisoft is committed to enriching players' lives with original and memorable entertainment experiences.

Department for Transport work with agencies and partners to support the transport network that helps the UK's businesses and gets people and goods travelling around the country. The Department's work is directed and overseen by the Secretary of State for Transport and their Ministerial team.

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