Investigation of port digital technologies and their impact on GHG emission reduction and energy efficiency

Elizabeth Munyedboh Mbotiji

Follow this and additional works at: https://commons.wmu.se/all_dissertations

Part of the Environmental Monitoring Commons

Recommended Citation

Mbotiji, Elizabeth Munyedboh, "Investigation of port digital technologies and their impact on GHG emission reduction and energy efficiency" (2020). World Maritime University Dissertations. 1400. https://commons.wmu.se/all_dissertations/1400

This Dissertation is brought to you courtesy of Maritime Commons. Open Access items may be downloaded for non-commercial, fair use academic purposes. No items may be hosted on another server or web site without express written permission from the World Maritime University. For more information, please contact library@wmu.se.
INVESTIGATION OF PORT DIGITAL TECHNOLOGIES AND THEIR IMPACT ON GHG EMISSION REDUCTION AND ENERGY EFFICIENCY:

MULTI CASE STUDY PORTS

By

MBOTIJI ELIZABETH MUNYEDBOH

CAMEROON

A dissertation submitted to the World Maritime University in partial fulfilment of the requirements for the award of the degree of

MASTER OF SCIENCE
in
MARITIME AFFAIRS
(MARITIME ENERGY MANAGEMENT)

2020

Copyright Student’s Name, 2020
DECLARATION

I certify that all the material in this dissertation that is not my own work has been identified, and that no material is included for which a degree has previously been conferred on me.

The contents of this dissertation reflect my own personal views, and are not necessarily endorsed by the University.

(Signature): ......................................................

(Date): 17/11/20

Supervised by: Prof. Aykut Oleer

Supervisor's affiliation......
ACKNOWLEDGEMENT

Undertaking this Master’s program has been one of the most challenging life experience I’ve had. A successful completion would not have been possible without the support and understanding of my husband Noupeyou Gouyeze Valery. His patience, trust, moral and financial support gave me the fuel to complete this unique journey.

I express my sincere gratitude to my supervisor Prof. Aykut Olcer who believed in me through his guidance, relentless encouragement, continuous assistance and valuable comments that pushed me to give my best. I would also like to thank Anas Saleh whose valuable input, continuous availability and prompt intervention brought great value to my work and stress relieve from uncertainty.

I am eternally grateful to my parents who have never ceased praying for me, believing in me and encouraging me. Their constant reminder that I can make if I put my mind to it has brought me far in life.

I will be forever indebted to my siblings Noella, Durit, Kah, Boni and Esraela who were always there for me. The group chats and videos gave me some relief and reminded that I am not alone.

A special thank you to Commander Folorunsho Abiodun whose friendship, constant advice, moral support and academic assistance encouraged me and kept me afloat.

I would like to thank my Vetlanda group family who helped ease off the stress with good food and fun activities without which I would not have had the necessary balance and right frame of mind to finish this dissertation.

I would also like to thank Lyndell Lundahl whose messages brought me comfort in the midst of tears, frustration and confusion especially during the pandemic.

Finally, I thank the Almighty God for His faithfulness, provision and strength.
ABSTRACT

Title of Dissertation: Investigation of port digital technologies and their impact on GHG emission reduction and energy efficiency: multi case study ports.

Degree: Master of Science

This dissertation is a study of the application of digital technologies in curbing GHG emission in some selected ports in Europe. It explored how much GreenHouse Gas (GHG) emission can be reduced from the application of Digital Technologies with Specific case study of the Port of Rotterdam, the Port of Antwerp, the Port of Amsterdam and Hamburg port. To verify these assumptions, the author proceeded by collecting data on digital technologies applied in the case study ports. After which a
2.3% reduction on CO₂ emission reported by case study ports. 2.3% was used as a baseline for all the ports, this was the figure stated in The port of Antwerp as a reduction made after Digital Technology application. From the analysis, digital technology has the potential to reduce GHG emission hence save energy in ports. This was evident by the ports with the highest Digital Technology application which recorded the highest reduction in GHG emission.

Consequently, the study also identified some of the challenges and institutional weaknesses relative to the implementing and application of digital technologies in ports such as cyber security, the legal and administrative regime and the non-enforcement of international regulation on the application of Digital Technologies in ports.

The study concludes by acknowledging the tremendous impact of the application of Digital Technology in port efficiency, energy saving, and the reduction of GHG emissions in ports. It is therefore imperative for stakeholders, the international organization (IMO) and countries to promote and encourage the application of Digital Technologies at the port to achieve optimum energy efficiency and sustainable development.

**KEYWORDS:** Digitalization, Energy efficiency, GHG emission, Sustainability, Ports
Table of Contents

ABSTRACT........................................................................................................ iv
Table of Contents ............................................................................................... vi
List of Tables ..................................................................................................... 9
CHAPTER 1 ........................................................................................................ 14
INTRODUCTION ................................................................................................. 14
  1.1 Background................................................................................................. 14
  1.2 Problem Statement..................................................................................... 15
  1.3 Motivation.................................................................................................. 16
  1.4 Aims and Objectives ................................................................................ 17
  1.4.1 Specific Questions .............................................................................. 17
  1.4.2 Research Questions ........................................................................... 17
  1.5 Significance of the study .......................................................................... 17
  1.6 Hypothesis ............................................................................................... 17
  1.7 Assumptions and limitations ................................................................. 18
  1.8 Scope ....................................................................................................... 18
  1.9 Research Methodology ............................................................................ 19
CHAPTER 2 ........................................................................................................ 21
List of Tables

Table 1. Number of studies per digital domain and maritime transport sector .......... 40
Table 2. Shipping emissions in Port .................................................................. 41
Table 3. Estimated effect of damage caused by CC on ports. ............................. 42
Table 4. Emissions Data PoA ........................................................................ 48
Table 5. Emissions in the port of Amsterdam .................................................. 49
Table 6. Application of DT in case study ports ................................................ 52
Table 7. Degree of Penetration of DT in Ports of Antwerp, Hamburg, Rotterdam & Amsterdam ................................................................. 59
Table 8. Weighting for DT Criteria ................................................................. 60
Table 9. Degree of Digital Technology Penetration in Ports with weights .......... 60
Table 10. GHG Emissions of Selected Ports ................. Error! Bookmark not defined.

Table 11. GHG reduction potential .................................................................. 61
List of Figures

Figure 1: Scope ........................................................................................................ 18

Figure 2: The flow chart of the methodology ......................................................... 20

Figure 3: Stages of port development .................................................................. 21

Figure 4: Key criteria of Green port concept ......................................................... 23

Figure 5: Block Chain explained ........................................................................... 26

Figure 6: IoT connects data with physical devices ............................................... 29

Figure 7: Increasing Number of publications on Big Data .................................... 31

Figure 8: Energy consumption areas in Ports ....................................................... 43

Figure 9: Improved EE in one port area affects the whole port ecosystem ........... 45

Figure 10: Chart representing the degree of digital penetration of case study ports . 61

Figure 11: Pie chart illustrating CO2 reduction potential ..................................... 62
List of Abbreviations

EE                      Energy efficiency
GHG                     Greenhouse House Gas
Gt CO₂                  Gig tonnes Carbon dioxide
ICT                     Information and communication technology
IEA                     International Energy Agency
IMO                     International Maritime Organisation
JIT                     Just in Time
kWh                     Kilowatt Hour
PBP                     Pilot Boarding Place
RFID                    Radio frequency identification
SDGs                    Sustainable Development Goals
TBtu                    Trillion British Thermal Units
UN                      United Nations
RFID                    Radio Frequency Identification
PCT                     Port Container Terminal
AGV                     Automated Guided Vehicles
EEDI                    Energy Efficiency Design Index
EU                      European Union
NDC                     National Determining Contribution
IoT                     Internet of Things
PCDM                    Port Collaborative Decision Making
Definition of Terms

Digitalization is the use of digital technologies to change a business model and provide new revenue and value-producing opportunities, that is, the process of entering a digital business. (Sanchez-Gonzalez et al., 2019).
Siemens, (2017) refers to digitalization as the process that turns activities, information and results into data that can be compiled, analyzed and shared. (Siemens, 2017)

Non-energy benefits are mainly augmentation in productivity through decreased capital cost.

Blockchain is a digital, decentralized and distributed ledger in which transactions are logged and added in chronological order with the aim of creating permanent and tamper-proof records (Treiblmaier, 2019).

Internet of Things (IoT): The Internet of Things is the network of physical objects that contain embedded technology to communicate and sense or interact with their internal states or the external environment. (i-SOCOOP.2020)

Drivers can be described as the expected business advantages that result from embedding digital technology in shipping operations, smart shipping systems or new business models, such as blockchain-enabled smart contracts and open, Internet of Ships platforms for data sharing and shipping services. (Lambrou et al., 2019).

Port CDM can be summarised as the digitisation of time stamp information between port actors involved in the same port call (lind, 2016).

Virtual Arrival: Is a concept whereby a vessel is requested to arrive later to a port than she could reach steaming at full speed. The charterer agrees to accept the vessel Notice of Readiness at the time that the vessel would have arrived at the port in case
she steamed at full speed. The vessel is allowed to steam at a lower speed, saving fuel, and arriving at the port at a designated time, which will normally be when the port/berth is ready to receive the ship. This prevents a port anchorage filling up with ships, reduces collision risks in the anchorage area and reduces emissions in the port area. (GIA, 2020).

**Automation:** Industrial automation consists in the use of mechanic, hydraulic, pneumatic, electric, electronic and computerised elements or systems to control equipment and processes, thereby reducing the involvement of humans in such activities.
CHAPTER 1
INTRODUCTION

1.1 Background

The Paris Agreement of 2015 set the targets for limiting global temperatures to 2 degree Celsius above pre-industrial level. (UNFCCC, 2020). By extension, parties who signed the Paris Agreement agreed to make efforts towards attaining these goals through the National Determining Contribution (NDCs). Ports are an essential part of shipping as they connect land and sea. According to International Chamber of Shipping, about 70% of global trade by value are handled by ports making them huge contributors to global and national economy. (ICS, 2020). As a result, ports have to make efforts towards contributing to NDCs of their country.

Although ports were not given as much consideration as shipping in the emission abatement measures set by IMO, it recognized that ports play a significant role in curbing emissions from shipping. IMO encouraged ports to enhance voluntary collaboration and cooperation enabled through digitalization within ports in order to reduce GHG emission from shipping (IMO, 2019). The IMO recently released the final report of the Fourth IMO GHG study which indicates that GHG emissions has increased by about 10% since 2012 and is projected to rise up to 50% by 2050. (Fourth IMO GHG study, 2020). Ports emit about 18.3 million tonnes of CO₂ hence contributing to national share of GHG emissions (ITF, 2014). Consequently, ports have invested in technical and operational measures as a means of improving environmental footprint. (Casaju, 2018). However, these measures are insufficient at attaining general IMO target for emission reduction.

Digitalization has increasingly been used by ports to improve productivity, safety and enhance efficiency. These positive effects have not only increased port overall efficiency but also reduced energy consumption which positively impact energy
efficiency in ports. As a result, digitalization presents an important potential tool for improving port sustainability (Fruth & Teuteberg, 2017).

There is no one size fit all measure, be it technical, operational or policy for reducing GHG emissions in ports. At this stage climate change is critical and every little thing matters, it is imperative to not only improve current measures but also adopt measures that can make ports more sustainable and achieve its sustainability goals.

1.2 Problem Statement

Of the 835 active ports out of a total of 8292 ports in the world (Export Virginia,2014; ports.com,2020), about 80% of these ports operations is devoid of cutting edge technology that would improve overall efficiency and reduce harmful emissions. This is despite the inherent benefits in digitalizing ports with the advent of industry 4.0 making technological solutions readily available. However, few ports are adopting digitalization for their operations and many are still dependent on manual operations despite the externalities and cost inefficient port operations poses.

With the dependency of world trade on sea transportation, it has become challenging for the shipping industry to improve efficiency, when port operations are not contributing their quota, by not taking advantage of new technology. The IMO regulations of EEDI is forcing innovations on ships while the sulphur gap is poised to drastically cut back on harmful GHG emissions in shipping. Thus inefficient port operations increase the duration of port calls invariably increasing GHG emissions through increased fuel consumption. Thus, the non-digitization of port operations continues to be a weak link in shipping with many solutions lacking the necessary data to make them work. EU ports have made some strides in going green, however most cargoes are expected to terminate in the developing world who lean on the industries of the first world for goods and services. To reverse this trend, ports would need to deepen technology use just like in ships and other sectors.
Despite ports receiving more and more cargo in their facilities, the potential for increasing their land space is not feasible since they are mostly located in already developed cities. Therefore, it is essential for ports to manage goods and services more efficiently by conveying information about the arrival and departure time of goods to their owners through tracing and tracking. Similarly, Port Authorities need to share information of port traffic to trains, ships and trucks. This can only be achieved with technological solutions that digitalization offers in managing high cargo influxes.

During this research, interactions with Port Authorities showed a general peripheral interest in digitalization with many referring the author to port tenants with secretive operations. This shows that digitalization as a policy option is not gaining the traction needed to make it widespread for ports and shipping to reap its benefits. Port administration would have to play a key role in improving digitalization in their ports thereby improving the sustainability of the entire port operations. It is wrong that only very few ports worldwide are digitising their operations. If this persists, ports would struggle to contribute to the national determined contributions of their countries as agreed by the Paris Agreement of 2015. In addition, world net GHG emissions will continue to rise and the Paris Agreement lofty goals would not be achieved.

1.3 Motivation

This study is motivated by the need to draw inspiration for non-digital ports by undertaking a review of the impact digitalization has had on improving sustainability in port operations. Although there are several studies on port digitalization, very little data is available in terms of energy saving potential. This is even more important for ports in developing economies which could be encouraged to adopt digital technologies if they see overall benefits.
1.4. Aims and Objectives
The aim of this study is to review and categorize digital technologies that can be utilized in ports, then examine its impact on GHGs reduction and energy saving by exploration of reports from various regional ports.

1.4.1 Specific Questions
The specific objectives are reflected in the research questions.

1.4.2 Research Questions
1. What potential does digitalization have in saving energy in ports?
2. How much GHG emission can be reduced from applying DT hence aiding nations to meet their NDC as per Paris Agreement 2015?
3. What are the challenges associated with the application of digital technologies in ports?

1.5 Significance of the study
This study is significant as it highlights benefits in adopting digital technologies for port operations. This creates a road map for developing nations to follow in re-enacting successful technologies that can improve sustainability. It also provides an insight on Energy Efficiency and GHG emissions reduction benefits from applying digital technologies in ports.

1.6 Hypothesis
The hypothesis of this research are as follows:

1. Ports are increasingly adopting digitalization to improve efficiency and remain competitive.
2. Port Authorities would continuously seek avenues to reduce GHG emissions in ports.
1.7 Assumptions and limitations

Presently, no developed indicators exist to measure GHG emissions related to the application of digital technologies in ports. Similarly, the few academic studies on digitalization in ports are at an initial stage and lack theoretical and empirical research on the effect of digitalization on sustainability like GHG emissions, energy saving potential. The research was limited in the ability to get data from ports due to the immature level of implementation of digitalization in these ports. In addition, the travel restriction placed on nations as a result of the COVID 19 pandemic made onsite collection of data for this research impossible.

1.8 Scope

The study analysed the correlation between adopting digital technologies and sustainable port operations as shown in Figure 1. The research focused on digitalization in container terminals of the 4 identified ports in overall efficiency in cargo management particularly as it affects EE. The study will however not cover the cost of implementing these digital technologies but rather on its impact on GHG emissions. The figure below situates the scope of this study which are ports as an interplay with land and ship.

Figure 1: Scope
1.9 Research Methodology

As highlighted in the title, this research aims at evaluating successful implementation of digital applications in the ports of Rotterdam, Antwerp, Amsterdam, and Hamburg and its impact on revenue generation and energy efficiency. In more details, this research aims at answering the research questions enumerated in Section 1.4.2.

Although, initially data for this research was primary data, to be collected from ports. However, responses from many ports offered little value. Hence this research is carried out based on secondary data collected from literature reviews such as online publications, peer-reviewed journals, articles and conference papers.

Key technologies like, data analytics, robotics and automation, big data, IoT/sensors and cloud services will be used as criteria for evaluating the level of digitalization of each port. A weight was attributed to each criterion based on the degree of importance in terms of the level of implementation of the DT. This research then proceeded to analyse and discuss the result of the above analysis. Figure 2 below shows the flowchart of the methodology for this research.
Figure 2: The flow chart of the methodology.

1. Identify DT in Case Study ports and areas where it can be implemented
2. Evaluate how much energy can be saved from DT application
3. Analysis of Data
4. Discussion of Results
5. Conclusion
CHAPTER 2
PORT DIGITAL TECHNOLOGIES

2.1 Introduction

Digital transformation has evolved in the maritime industry in three generations: The first generation took place in the 1960s and involved transformation from analogue to paperless procedures. The second-generation transformation took place between 1990s-2000s and involved increased transformation to automated procedures, finally, the third generation beginning from 2010 to today is the transformation to smart procedures (Heilig et al., 2017; Xisong et al., 2013). Figure 3 below is an illustration of the development of digitalization in ports.

Figure 3 Stages of port development

![Stages of port development](image)

Source: (Deloitte, 2018)
Reducing GHG emission through improving EE is considered essential in achieving green and sustainable ports. Alamoush et al. (2020) identified seven technical and operational measures for reducing of GHG emissions in ports amongst which was
digitalisation. Digitalization and shared collaborative platforms and solutions empowered by new technologies and innovations, such as block chain, are being progressively applied by ports as sustainable approach to improve EE. Hence, digitalization provides benefits which include lower transaction costs and consumer prices, increased market access and competition, better use of underutilized resources and added flexibility for service providers (UNCTAD 2019).

Although the maritime industry is technologically advanced, innovations in the maritime sector have been primarily related to ship construction and propulsion, oil and gas exploration, seabed exploitation technologies, and other—mainly engineering-based—innovations (Tijan, Aksentijević, et al., 2019). There is little study or no systematic literature review on digitalization in ports specifically. (Fruth & Teuteberg, 2017). Further, Sung (2019) wrote in an article “...less has been said about digital technologies’ potential to improve and potentially reduce energy use” (Sung, 2019). It was estimated that by 2030, information and communication technology (ICT) would improve lives and enable sustainable growth and reduce 20% CO₂ emissions by 2030 hence saving about 12 gig tonnes of Carbon dioxide (Gt CO₂) annually and generating about 11 trillion USD in economic benefits per year (John & Berners-lee, 2015).

Investing in the new technologies will lead to a greener and smarter transport systems worldwide. the Green Corridors are becoming essential feature for denoting smart transport, where advanced technology and co-modality is applied to gain energy efficiency and reduce environmental impact. The characteristics of a green corridor is shown in figure 4.
Figure 4 Key criteria of Green port concept

Source: (EL Sakty, 2016)

Figure 4 illustrates a general overview of the environmental, operational benefits amongst others that can be derived from the application of digital technologies in ports.
The literature covered for this research focused on studies that evoke the benefits of digital technologies such as Big data, Artificial intelligence, Internet of Things (IoT), virtual reality has on improving sustainability, Energy Efficiency or decreasing GHG emission.

2.2 Literature Review

Worrel et al (2005) analysed 54 EE technologies applied in the United States (US) industries. He characterised these technologies with EE, economics and environmental performance to understand the dynamics that motivates the decision to invest in new and efficient technologies. He demonstrated that new technologies follow the S-curve, a situation where a new technology has cost and overtime becomes common causing a decline in cost of this technology. They identified technologies that can be applied to various industry sectors. The result showed that more than two-thirds of these technologies not only save energy but yield environmental and non-energy benefits. Out of the fifty-four technologies analysed, 20 had environmental benefits that were either compelling or significant such as reducing emissions. Though energy saving is not always the determining factor in the decision to develop or invest in an emerging technology, it has a great potential of saving energy.

Jin et al., (2018) investigated the relationship between energy consumption and technological innovation in China. They also questioned the role of technology on innovation for sustainable development. In other to verify this, they proposed two hypothesis

**Hypothesis 1a (H1a).** In the short term, technological innovation can reduce energy consumption.

**Hypothesis 1b (H1b).** In the long run, technological innovation can make energy consumption increase.

**Hypothesis 2a (H2a).** In the short term, energy consumption growth has no effect on technological innovation.
**Hypothesis 2b (H2b).** In the long run, energy consumption can also promote technological innovation.

Jin et al. (2018), confirmed that technological innovation positively affects energy saving in the long run and might however have a rebound effect. Based on their analysis, they proposed that if sustainable development is to be achieved, it is important to focus on detecting and exploiting new energies and energy price while developing energy-saving technologies for efficient use. This would help address the issue of technological innovation and to improve energy efficiency and avoid the occurrence of a rebound effect (Jin et al., 2018)

After analysing the impact of emerging technologies in the US, Lung, concluded that, these technologies have important productivity and other benefits. This depends on the available market portions in which these technologies can be implemented; sector-wide energy savings could range from 1.49 TBtu and 134 million kWh to 2.22 TBtu and 186 million kWh. Also, non-energy benefits such as improved product quality, better, production and decreased GHG emissions are probable. Effective adoption of digital technologies can help improve the flexibility and sustainability of industries (Lung, 2006). After situating DT and its relation with energy saving and GHG emission reduction, the following are some DT that can be applied in ports and their characteristics.

### 2.2.1 Block Chain

One of the most efficient ways to attain efficiency in ports where huge quantities of cargo move between transport routes and producing large information is by capturing and sharing data. Profitability, product tractability and process automation through smart contracts constitute some of the key potentials of implementing block chain technology for supply chains. Paardenkooper, (2018) & Jović et al., (2009) reviewed the implementation of block chain technology in ports. They identified certain benefits of block chain as well as the challenges in the maritime industry. Block chain could
help reduce time of document processing, reduce cost, improve transparency due to decreased paper work, tracking ownership and location of cargo. However, successful implementation can only be possible if all stakeholders are involved in the process like shipping lines, terminal operators, manufacturers, banks insurers, brokers and port authorities. Maersk and IBM came together to develop a block chain solution aimed at digitalizing global trade, and they called it “TradeLens”. IBM reported that, the joint block chain initiative had the potential to “vastly reduce the complexity of trading” (IBM 2017). Similarly, the ports of Rotterdam and Antwerp are currently experimenting with block chain technology specifically for container security and tracking freight (Delenclos et al., 2020).

Despite the potential for development and improvement of maritime transport through block chain technology, challenges such as low level of maturity, lack of underlying standard, concepts are difficult to be mastered and there is need for programming intervention even in the simplest forms of implementation (Tijan, Aksentijević, et al., 2019). Figure 5 gives a detailed explanation of how block chain technology works.

**Figure 5.BlockChain explained**
Source: (Paardenkooper, 2018)

2.2.2 Just in Time/Virtual Arrival (port call processes.)

Port call operations are complex and involve substantial number of actors. Port authorities, pilots and tug operators, mooring personnel, terminal operators amongst others are responsible for getting the ship ready to berth or depart. It is essential for all these actors to collaborate and synchronize their activities in order to be effective. (Lind et al., 2016). “Information transparency leads to better informed decisions for all stakeholders. Ship owners can save fuel, port operators can use their capacity better, and goods owners will know when and where their goods are handled.

The IMO, though still considering the operation of ships as its main focus, is now encouraging initiatives for “just-in-time” (JIT) operations together with other regulations such as emission controls to limit environmental pollution and to promote sustainable development (IMO, 2018). This can be attained through a combination of measures: operational, technical, as well as the use of alternative low-carbon and zero-carbon fuels as well as collaborative efforts from all stakeholders in the maritime industry. There is increasing awareness of the important role of ports in the wider supply chain and the action that ports can take to facilitate the reduction of GHG emissions from shipping. The adoption of resolution MEPC.323 (74), in May 2019, encourages voluntary cooperation between the port and shipping sectors to contribute to reducing GHG emissions from ships (IMO, 2019).

The concept of JIT arrival of ships allows ships to optimize their speed during the voyage in order to arrive at the Pilot Boarding Place (PBP) when the availability of berth, fairway and nautical services is ensured. Hence, reducing GHG emissions and reduced air pollution attributable to ports (in approaches and at anchorages). Effective implementation of JIT processes could also improve competitiveness, better capacity planning of berth and resources as well as optimize planning for hinterland. A prerequisite for JIT Arrival is the optimization of the port call (GIA, 2020).
An average reduction of 1% sailed distance per ship within the Baltic Sea Region (supported by a cost benefit analysis) would save about € 100 million annually for traffic sailing in the region. Approx. half of the savings are due to less emissions cost for society, and the other half are fuel and other costs for the ship owners (Andersson & Iverhammar, 2014).

Watson & Boudreau (2011) further claims that by sharing data, firms can create tighter coupling of their activities. Just-in-time (JIT) is one of the well-known applications of episodic tight coupling. Firms in a supply chain share their input needs for a specific time so that suppliers can deliver as needed.” (Watson & Boudreau, 2011)

**Port CDM**

The main objective of Port CDM is to improve coordination among port call actors. By sharing their time stamp data connected to port calls, information will be available for actors to use in real time. This will ease just-in-time arrivals, increase predictability, berth productivity, punctuality, reduce waiting and anchoring times and boost resource utilization.

Port Collaborative Decision Making (Port CDM) services will make port calls more efficient for all stakeholders through improved information sharing, situational awareness, optimised processes, and collaborative decision making during port calls (Lind, 2016). Collaborative data sharing by all parties is an imperative success factor. An ecosystem, where the performance of each party relies on the integrated performance of different entities, requires information to be exchanged between entities efficiently and seamlessly (Lind et al, 2014).

**2.2.3 Internet of Things (IoT)**

Intelligent Ports are new generation of ports, which has a new, intelligent port infrastructure and integrated and smart management and service (Siorr et al., 2011). Currently, the applications of IoT in ports' production and management
include Container RFID, electronic seals, port equipment, condition monitoring, engineering equipment asset management, wireless automatic meter reading, etc (Siror et al., 2011).

Xisong et al. (2013) identified key technologies and products of IoT needed for building intelligent ports whose performance needed high security, high reliability, high recognition rate and high stability (Xisong et al., 2013). Similarly, Heilig et al., (2017) provided an overview on the state-of-the-art of digital transformation in seaports, together with the historical evolution that ports have experienced in their digitalization. They also, illustrated the application of IoT in ports such as Hamburg on the use of big data technics, combined with IoT and other technics. Figure 6 illustrates how IoT connects the data it collects to physical devices such as smart phones and computers.

*Figure 6. IoT connects data with physical devices*

Source: (i-SOOOP,2020)
2.2.4 Automation/Robotics

Fully automated as well as semi-automated terminals, can contribute towards increased sustainable operations of ports in several ways. High optimization of container flows that can be achieved, can lead to reduced energy consumption and the lifetime of the equipment is also extended making it possible for better preservation of resources. Looking at its contribution to environmental sustainability, though automation has fundamentally been conceived to improve the productivity of Port Container Terminals (PCTs), it has a great impact on PCTs global energy use. From the energy efficiency standpoint automating a PCT manifests one of the best improvements in management that can be implemented. Automation helps to optimise operations in all aspects, minimising travels made by equipment, empty runs, shuffling containers, etc., directly prompting a decrease in energy use. In addition, in automated PCTs most of the equipment use renewable power sources, which are more efficient and reduce consumption, emissions and noise (Martín-Soberón et al., 2014).

Automated Guided Vehicles (AGVs) are mature and can add value to the digitalisation of the Supply Chain (SC) by promoting the use of a holistic approach to the available knowledge. The authors predict the progress of information technology, industrial robots, service robots and logistic systems as a SC sustainability context with great potential. In addition, digital SCs and smart manufacturing are paving novel research areas where the use of automation will be closer than ever to the final consumer needs. However, there is very little research on the potential AGVs have on sustainability. Most research focuses on addressing issues such as improving network, and very little on promoting economic, environmental and social sustainability. 2015 saw a 70% increase in publication in this area which is quite positive (Bechtsis et al., 2017). However, Robotics in ports is still the least developed sector in terms of studies (Fancellu et al., 2011)
2.2.5 Big Data
There is increasing research and application of Big Data in ports coupled with its benefits on overall efficiency and energy saving in operations. Processing and analysing huge data flow and using them for reports is helping in faster and better decision making. Great amount of data collected from GPS, sensors and RFID is processed and used to solve problems or anticipate situations or challenges. Applying big data in ports could lead to a dramatic decrease in CO2 emissions (Bilogistik, S. A.2018). Ports generate huge data from activities such as: out and inbound traffic, productivity of equipment and workers, details and information of payments and billing, cargo loading and unloading deadlines. Big data can be applied to improve operations and decision making in several port areas. Real time status of crane and truck, equipment replacement and maintenance planning, understand the ports need in accordance with physical condition by observing the weather (Papadomanolakis, Georgios,2019). Figure 7 shows the increasing number of publications on Big data in recent years.

Figure 7. Increasing Number of publications on Big Data

[Graph showing the increasing number of publications on Big Data from 2010 to 2019]

Source: (Ghalekhondabi et al., 2020)
2.3 Chapter Summary

The literature covered mainly studies that related digital Technologies and energy saving or GHG emission. It further looked into the characteristics of the technologies covered and the areas where they can be applied in ports. There are several studies on port operation efficiency derived from the application of DT hence, the literature review exempted studies that specifically reviewed DT efficiency and cost, rather it focused on the studies that related the application of Digital Technologies with energy saving and GHG emissions. Internet of Things, Big data, Virtual arrival, automation and Blockchain technologies and their application to ports, were covered in this chapter.

Anthropogenic activities in ports have adverse impacts on the climate, therefore understanding these effects is necessary in grasping the urgency needed in taking action by using among other tools DT to improve GHG emission reduction. This will create awareness on the benefits that ports can gain from using DTs not only in improving energy efficiency but also in contributing to GHG emission reduction and complying with national and international regulations on GHG emissions. Hence, Chapter 3 of this study shall expatiate on not only the effects of emissions but also on the benefits of digitalization in ports as well as some challenges in implementing DT in ports.
CHAPTER 3
ESTABLISHING PORT EVALUATION CRITERIA

3.1 INTRODUCTION

This chapter will address three aspects, first, it will examine how ports can benefit from digital technologies. Afterwards, the barriers and opportunities for adopting and implementing digital technologies will be identified, and finally evaluate the impact emissions have on ports and port cities. The integration of UN SDGs in port practice is necessary to improve port sustainability. This study relates to UN SDGs 7, 9 and 13 in the following ways.

SDG 7: Affordable and clean energy (UN SDGS, 2020).
- Supporting research and development on clean energy technology
- Investing in energy efficient port equipment (technology and lighting)
- Optimizing port operation processes (WPSR, 2020)

SDG 9: Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation (UN SDGs, 2020)
- Digitally optimizing infrastructure and port operations/processes/services
- Adapt port infrastructure and processes to meet market demands (like increase in ship size
- Minimize environmental impact of port activities
(WPSR, 2020)

SDG 13: Take urgent action to combat climate change and its impacts (UN SDGs, 2020)

- Improve EE of port operations, processes and services
- Enable reduction of carbon and GHG emissions within the port area
- Adapt port infrastructure and port related operations to climate change (WPSR, 2020).

3.2 Drivers of Digitalization

Technology is evolving as it is compelling companies to incorporate some form of technology in their operations. Incorporating these technologies in industries is essential in improving communication, propel marketing and business growth, streamlines decision making, boost competitive edge, enhance customer relationship and maintain industry relevance (Today, 2020).

3.2.1 Competitiveness

Ports represent an important part of economic growth, leading to increased competition and prompting them to innovate and upgrade in other to maintain their economic status. Similarly, sustaining a competitive advantage is crucial for their development and operation in this sophisticated port competition (Kang & Kim, 2017; Sánchez et al., 2003). Certain studies assert that sustainability strategy and practices can improve the sustainable competitive advantage. For instance, certain company reports indicate a significant role of digitalization and Industry 4.0 to significantly impact competitiveness as well as higher economic, environmental and social values (Parida & Wincent, 2019).

Therefore, adopting smart port technologies is a gateway for companies who want to sustain a competitive edge and differentiate themselves from other competitors. Ports such as Rotterdam and Singapore are embracing these digital technologies that are already disrupting other companies in order to stay productive, efficient, customer friendly and competitive.
3.2.2 Efficiency and profitability

Petrou (2006) describes efficiency as a term used to denote the state of best possible operation of a product or service market. Also, several company leaders remark that improving efficiency can minimize cost, increase overall efficiency and increase productivity.

The use of digitalization has expanded with increase in fleet size and the safety, efficiency and accessibility of ports is affected. In addition, the need to connect people, systems, companies and the huge data they produce is imperative for companies who want to increase profitability, remain competitive and improve sustainability. Also, digitalization gives ports the tools to overcome the challenges of urbanization, demographic change and globalization by making port operations more flexible, efficient and agile. Specifically, using data analytics to analyse data and make conclusions enables faster decision making and more precise decisions. Moreover, unifying processes and information on a single platform through IoT and big data applications would ease consumer and employees access to information.

Ports as sea land interface act as a focal point for intermodal transport. They are recognised as the gateway to trade since they link global markets even for landlocked countries. Therefore, developing and improving not only physical but digital port infrastructure and facilities are fundamental aspects of port strategies to improve attractiveness as ports of call for shipping companies.

3.2.3 Sustainability

Pressure on ports to curb GHG emissions is led by factors such as international environmental regulations as well as national policies on environment. Emissions in ports accounted for 18 million tonnes of CO₂ in 2011 (Olaf MERK, 2014). Also, European ports recognize energy consumption as the second most important environmental priority after air quality between 2016 and 2018 (Sdoukopoulos et al., 2019). Consequently, for ports to manage present and future needs, finding a balance between valuable land, labour and technology as well as produce added-value and growth in their host cities is vital (Kang & Kim, 2017).
There is a positive correlation between port operational efficiency and port energy efficiency. Maximising the operational efficiency of resources can reduce the energy consumption and enhance energy efficiency hence sustainability (Iris & Lam, 2019). Additionally, the rising awareness of the influential role of ports in the wider supply chain and the procedures that ports can take to facilitate the reduction of GHG emissions from shipping is causing them to take greater measures towards contributing to global GHG emission reduction. Thus, IMO recognized through MEPC.323(74), in May 2019, and called for voluntary cooperation between ports and shipping sectors to contribute to reducing GHG emissions from ships (IMO, 2020).

Ports must plan and manage their operations and future expansion (growth) in a sustainable way in order to cope with the limited or reduced environmental area and high interactions with their hinterlands. The acceptance and accommodation of port development concept in concordance with the surrounding cities clearly render green growth an important economic driver (Black, 1996).

Various research and publication on digitalization and digital technology emphasise its ability to improve productivity and customer relationship, increase efficiency, improve business model, operations, cost saving and competitive advantage but barely associate or analyse the benefits it has on energy saving. This could result from the conflicting idea that digital technologies/systems lead to increase use of electricity, computers and data systems which are highly energivorous hence would not lead to energy saving. On the contrary, these smart technologies are known to save 10 times the carbon emission they generate while other authors debate that overall technology as it is currently used is unsustainable. (Morley et al., 2018).

3.3 Barriers

3.3.1 Standardization
Standardization is one of the challenges that make the implementation of digital technologies to large behind. Currently, the European Union (EU) lacks a clear
strategy towards digitalization in the maritime industry (ECSAs, 2017). The basis for any energy policy should be to save energy, since using energy better is a cost-effective way of decreasing GHG emissions (PEMA, 2011).

3.3.2 Collaboration

The shipping industry is only now waking up to the concept of cooperation and collaboration, which is greatly supported, even enabled, by the latest developments in digitalisation, Internet of Things (IoT), and advanced inexpensive connectivity (Lind et al., 2017). Collaboration through data sharing is important for effective implementation of digitalization. It is however not the current mindset in ports who are sceptical about “fully open-data” approach.

3.3.3 Cyber security

Security is still more of an aim than a reality. Even with the tools of the internet of things (IoT), which are as widely-used as radio frequency identification (RFID), it is difficult to find commercial systems without critical security flaws and vulnerabilities (Fernández-Caramés et al., 2016).

Trust and privacy are at the core of the block chain technologies, and have the potential to either make them a success or cause them to fail (Karame & Capkun, 2018). Personal data, and sensitive data in general, should not be trusted in the hands of third-parties, where they are susceptible to intrusion and misuse (Zyskind et al., 2015). Instead, users should own and control their data without compromising security or limiting companies’ and authorities’ ability to provide personalized services. One of the solutions is a platform which will combine a block chain, re-purposed as an access-control moderator for block chain storage solution (Jović et al., 2019). Users do not have to trust third parties and are always aware of the data that is being collected about them and how it is used. In addition, the block chain recognizes the users as the owners of their personal data. Companies, in turn, can focus on utilizing data without being overly concerned about properly securing and compartmentalizing them (Jovic et al., 2010). It is worth mentioning at this stage that, during the process of data collection,
emails were sent to some ports requesting for data on the energy saving potential of DT application. One of the responses from the Port of Long Beach was “because of the cyber security risk associated with DTs like block chain they are refraining from using them”.

3.3.4 Regulations and Policies

Legislation has been quite slow in responding to digitalization challenges as well as changes in in environmental requirements driven by the IMO on shipping which also impacts on ports. Ambitious environmental policies and regulations such as the EU 2011 white paper. In addition, the EU in January 2013 identified key areas that will strengthen the competitiveness of the sector while improving environmental performance. This was facilitated by the Maritime Transport Strategy. One of the focus points of this committee dwells on “digitalization and simplification for more efficient waterborne transport”. The use of digital services and operations in ports to reduce administrative obstacles, improving electronic transmission through the creation of “e-maritime systems” has been introduced. For example, a list of documents to be presented by ships to port authorities should rather be reported in electronic format to Harmonised National Single Window”.

3.3.5 Economic

Stakeholders

Ports involve a complex hub of different stakeholders, making the ability of the former to reach consensus solutions difficult. These may typically include shipping companies, shipyards, terminal and warehouse operators, other infrastructure operators, equipment manufacturers, cargo owners (shippers), nongovernmental organisations (NGOs), environmental organisations, classification societies, public
officials and politicians, other industries (e.g., repair yards, recycling), and R&D organisations and universities. Each of these stakeholders have their own agenda and objectives that are many times conflicting with the objectives of other stakeholders. (Psaraftis, 2016).

**Initial Cost**

The implementation of activities and measures that can support the shift to greener and more sustainable ports has cost implications. It requires further funding, development of new capabilities and the promotion of new technologies and their transfer, especially to developing countries. (UNCTAD, 2019). For instance, looking from an economic and financial profitability point, the automation of Port Container Terminals (PCTs) signifies a reduction in the variable costs per container (OPEX). Port practitioners acknowledge the economic benefits and importance of operational efficiency to conform with environmental regulations (Lim et al., 2019). Increasingly, ports are expected to adapt their performance with sustainability considerations. Since labour costs are decreased by generating economies of scale in operations and maintenance costs are reduced (PEMA, 2012). However, automation requires a large capital investment (CAPEX) for the acquisition of solutions and for training human resources. Hence, the choice to implement strategic initiatives related to automation requires a feasibility study of the implementation plan to assess such initiatives, this is applicable to other technologies. (Martín-Soberón et al., 2014)

**3.3.6 Adaptation**

With the current pandemic, COVID, ports are increasingly providing information and managing most of their operation online. They are mainly service providers, linking the hinterlands and the sea, providing their services while keeping their workers and customers is crucial and can be easily achieved through DTs. Ports with a certain degree of technological penetration are adapting better to the current changing situation.

**3.3.7 Human Element**
Employee jobs and functions will be affected by digital transformation. It is necessary to involve them in these transformation processes. Constant training of employees at all levels in order to retool them to adapt to the disruptive technologies is important.

3.3.8 Limited Research/Study

Most studies on digitalization in ports or digitalization and sustainability in ports are either from journals, magazines or conferences, business websites. The traditional analysis of maritime transport logistics problems has been in terms of cost-benefit, economic or other optimisation criteria from the point of view of the logistics provider, carrier, shipper, or other end-user. Such traditional analysis by and large either ignores environmental issues, or considers them of secondary importance. There is still a gap in the literature on energy saving potential and GHG emission reduction advantages that ports DT can provide (Psaraftis, 2016; Bechtsis et al., 2017). Table 1 below illustrates that ports have the least research or amount of studies with regards to digital applications. In addition, Davarzani et al., (2016) states “to the best of our knowledge, a comprehensive review on the literature of green ports and maritime logistics is none-existent.”

Table 1 Number of studies per digital domain and maritime transport sector

<table>
<thead>
<tr>
<th>Maritime Transport Sector</th>
<th>Number of Manuscripts</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Robotics</td>
</tr>
<tr>
<td>Design and Ship Building</td>
<td>34</td>
</tr>
<tr>
<td>Shipping</td>
<td>1</td>
</tr>
<tr>
<td>Ports</td>
<td>1</td>
</tr>
</tbody>
</table>

Source: Sanchez-Gonzalez et al., 2019
3.4 Impact of Emissions in Ports and port cities

Global air emission from shipping is estimated to be about 2-3% CO₂, 5-10% SOx and 17-31% NOx. (port technology,2015). Emissions in ports are substantial and are expected to increase greatly by 50-2505% by 2050 if measures are not taken. 85 % of emissions in ports are attributed to port calls from tanker and container. Improving port operations will have an influence both land and sea. Hence Ports GHG emission reduction strategies will decrease emissions not only from port side but also from shipping and hinterland transport. Table 2 below contains the global amount and type of emission from ports in 2012.

Table 2. Port emissions in Port for the year 2012

<table>
<thead>
<tr>
<th>Type of Emission</th>
<th>Amount (Million tonnes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO₂</td>
<td>18.3</td>
</tr>
<tr>
<td>NOx</td>
<td>0.4</td>
</tr>
<tr>
<td>Sox</td>
<td>0.2</td>
</tr>
<tr>
<td>PM10</td>
<td>0.03</td>
</tr>
<tr>
<td>PM2.5</td>
<td>0.03</td>
</tr>
<tr>
<td>CO</td>
<td>0.03</td>
</tr>
<tr>
<td>CH4</td>
<td>0.002</td>
</tr>
</tbody>
</table>

Source: ITF 2014

3.4.1 EXTERNALITIES

3.4.1.1 Health

Emissions from ports have been linked with health issues, specifically respiratory diseases such as asthma, lung cancer and premature death (The Scientific World Journal, 2019). Approximately 60,000 cardio pulmonary and lung cancer deaths that
occur annually near coastlines in Europe, East and South Asia are attributed to shipping-related PM emissions.

3.4.1.2 Climate change (CC)

Increase in temperature, extreme weather changes (droughts), sea level rise (floods), ocean acidification has severe economic, social and security impact on populations living in port cities. (UNCTAD, 2018).

3.4.2 INTERNALITIES

3.4.2.1 Infrastructure damage

Ports are generally located in coastal zones, low-lying areas and deltas making them, susceptible to risk from climate change such as sea level rise, ocean acidification, storms and strong winds. These can cause serious damage on port assets and infrastructure (Periera & Oliveira, 2015). A survey by UNCTAD reveals that 16% of port infrastructure are for sea defences and CC adaptation. (UNCTAD, 2018)

3.4.2.2 Cost

*Table 3. Estimated effect of damage caused by CC on ports.*

<table>
<thead>
<tr>
<th>Physical damage</th>
<th>50%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operational</td>
<td>55%</td>
</tr>
<tr>
<td>Delays</td>
<td>36%</td>
</tr>
<tr>
<td>Interruption</td>
<td>52%</td>
</tr>
<tr>
<td>Others</td>
<td>38%</td>
</tr>
</tbody>
</table>

Source: (UNCTAD, 2018).

Table 3 represents the percentage of damage caused by CC on ports. These damages have an indirect effect on the economy of the ports since it creates an additional cost
for maintenance. Ports are essentially service providers, hence interruptions or hindrances could also lead to customer dissatisfaction and decrease customer loyalty. Reported cost for existing, planned or adaptation measures range from adaptation measures varies between US$ 500 000 million to US$ 500 million. UNCTAD, 2018).

3.5 Areas of Energy Consumption in ports

Energy consumption is essential port operations and port related activities. Port infrastructure that consume energy are represented in figure 8.

Figure 8 Energy consumption areas in Ports

Source: (Spengler & Wilsmeier, 2016)

3.6. Benefits of digitalization to ports

Varying port areas can benefit from digitalization in ports and save energy directly or indirectly in addition to improved energy efficiency hence reduce GHG emission.
Delenclos et al., (2020) identified different port areas that can benefit from digitalization.

- **Intermodal traffic**: In addition to improving cargo-moving efficiency, it is also necessary for terminals to trains and trucks through congested terminals as fast as possible. The use of advance slot booking, appointment system can limit time spent by trucks in terminal and of course reduce emission from exhaust pipes.

- **Customs and collections**: Efficient management of cargo information and payments, import and exports permit, and customs clearance with the use of block chain technology can reduce cost related to paper based cargo documentation and customs payment.

- **Safety and security**: Ports can adopt digital technologies to improve security. Security surveillance devices that can detect intrusion and alert security personnel. employees, truck drivers and visitors can login through networked biometric scanners. These technologies can better improve safety and security for infrastructures and personnel.

- **Energy and environment**: Interconnected technologies assist ports to decrease energy consumption and waste. One alternative of such is a motion-based terminal lighting systems that lights up just when vehicles are approaching. The port of Valencia reduced energy consumption by 80% in less than two years after installing a prototype motion-system. Other ports use drones as cheaper option for inspecting equipment and patrolling.

For these benefits to be effective there is need for effective port hinterland performance that requires interaction and collaboration between all stakeholders from public and private sector (Inkinen et al., 2019; Lind et al., 2017). The maritime transport chain
constitutes a group of actors, each performing often specific and specialized duty as part of transporting goods from consignor to consignee. Each could be subject to different requirements, regulations and profit drivers. What tends not to be recognised is that many if not most of the actors in the transportation chain have at least some dependency on the activities and the actions of others in the chain. This is particularly so in terms of the timing of affairs and guaranteeing the availability of appropriate supporting resources (Lind et al., 2020).

**Figure 9. Improved EE in one port area affects the whole port ecosystem**
CHAPTER 4
CASE STUDY OF PORTS

4.1 Introduction

The case study is based on the review of the 4 industrialised ports of Rotterdam, Antwerp, Hamburg and Amsterdam. The general details of these ports and their unique characteristics have a bearing on their revenue generation capacity, hence the level of digital penetration. The chapter looks at the individual ports, their digitization effort, and ultimately the impact their investment has had on entrenching sustainable port operations.

4.1.1 The Port of Rotterdam (PoR)

4.1.1.1 General Description

The PoR is part in the municipality of Rotterdam in the Netherlands. It occupies about 8,114 hectares of land and 4,572 hectares of water. The container, liquid bulk, and dry bulk it handles amounts to 469.4 million tonnes of cargo. The Port generated about 254.1 million Euros profit in 2019.

4.1.1.2 Emissions

The Municipality of Rotterdam as well as the PoR set a target for curbing CO₂ by 50% (also part of Netherlands climate objective) no later than 2025, resulting in the Rotterdam Energy and Climate Programme in March 2007. The port of Rotterdam emitted about 28 million Ton CO₂ in 2006. The PoR is making efforts achieving the Dutch climate objectives.
4.1.1.3 Digital technologies

PoR created a platform comprising of software tools that enable Port of Rotterdam to manage their port operations more efficiently and safely.

1- **Port Insider**: is a single data entry point, reduce phone calls and emails, provide real time information that is secure for all port actors: customs, terminals, agents, shipping lines et cetera. Saved 10 to 20 Euro per container.

2- **PortXchange**: This is call optimization software, this enables port actors to monitored and execute activities leading to rapid and efficient handling of port calls.

3- **Box insider**: used to track and trace container cargo and providing reliable ETA of vessels. Save 20-50% less time on container tracking.

**AI**: the PR uses AI to predict arrival times in the port with the use of an application they Developed-Pronto which is a product of PortXchange. This application helps to standardise data exchange during port calls. AI and big data are making the arrival times of vessels in sea and inland ports to be predicted earlier and with more precision. This application was initially fed with 12,000 items initial data. It then recognises patterns in these and gets better at predicting how long a vessel needs to move from the loading platform to the berth and has reduced vessel waiting time by 20%. Most of the shipping companies, agents, terminals and other nautical service providers in the port use this application to plan, implement and monitor their activities during a port call. Self-learning robots such as AI can cause problems sometimes with their complexity and getting predictions wrong (World Maritime News, 2020)

**Cyber security**: The PoR do not use any privacy-sensitive data to decrease cyber-attacks.
4.1.2 The Port of Antwerp (PoA)

General Description
The port of Antwerp located is Belgium precisely in Flanders covering an area of 12,068 hectares. In addition, trade by volume accounts 235,330,980 tonnes of which container, liquid bulk, break and dry bulk cargoes. Port of Antwerp's total added value was 20,737 million euros in 2017 and profit of 182,300,000 million euros. Port of Antwerp emitted about 190 million tonnesCO₂ in 2016.

4.1.2.1 Emissions
The port of Antwerp reports considerable decrease in emissions levels, specifically energy consumption decreased by 2.3% after applying DTs despite growth of activities. Emissions produced by the port of Antwerp are:

Table 4 Emissions Data PoA

<table>
<thead>
<tr>
<th>Emissions Quantity</th>
<th>NOx (tonnes)</th>
<th>SOx (tonnes)</th>
<th>PM (tonnes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>19000 (15% of emission of Flanders)</td>
<td>33,000 tonnes</td>
<td>16,000 tonnes</td>
<td></td>
</tr>
</tbody>
</table>

Source: (Port of Antwerp, 2019)

4.1.2.3 Digital Technologies

The port of Antwerp is gradually incorporating digital technologies to improve efficiency. Nonetheless, they face challenges with bottleneck hence reduced accessibility and reachability making it a major hindrance towards achieving efficiency. So far they've made progress in the following areas:

- **IoT** through “capital of thing”, and Beacon used a IoT solutions to ensure more efficient logistics developed in an effort to improve sustainable transport and services.
- **Blockchain technology** applied in goods management
- **Virtual arrival** through APICA created by the port to act as virtual assistant, virtual reality, real time
- **Digital cameras and sensors** for automatic image recognition which also acts as a truck identifier.
- **Automation** currently testing autonomous trucks in terminal
- **NxtPort** (Antwerp based company). Developed as an innovative smart data sharing platform to streamline maritime and logistical processes in the port. Also, includes logistic optimization tools such as ETA predictions.

In their strategy to evolve from an analogue to a digital technology. The sustainable potential is enormous, because digitisation of the port processes, with the restriction of the physical document flow, would have a positive effect on the environment and can lead to even higher efficiency (Port of Antwerp 2019).

### 4.1.3 The Port of Amsterdam (PoAm)

**General Description**

The PoAm in The Netherlands resides on 4,500 hectares. Profit, 68.5 Million Euros. Multifunctional port liquid bulk, dry bulk, agro bulk, and containers and making up 82.3 million tonnes cargo.

#### 4.1.3.1 Emissions

Port of Amsterdam set an objective to reduce CO₂ emissions by 25% to 1,773 kilotons of CO₂ (compared with 2,364 kilotons in 2014) by 2021. Table 5 below shows the emissions produced by the Port of Amsterdam in 2012.

**Table 5. Emissions in the port of Amsterdam**

<table>
<thead>
<tr>
<th>PM₁₀</th>
<th>PM₂₅</th>
<th>NOₓ</th>
<th>NO₂</th>
<th>SOₓ</th>
</tr>
</thead>
<tbody>
<tr>
<td>17.3</td>
<td>12.2</td>
<td>7.3</td>
<td>21.9</td>
<td>1.7</td>
</tr>
</tbody>
</table>

#### 4.1.3.2 Digital Technologies

Roadmap Digital Port for 3 core fields: nautical operations, commerce, assets & infrastructures. It includes pilot projects for the use of data, IoT, sensors.

- BLIS for connected inland vessels, mooring and docking
• River Guide (Netherlands route & berth data sharing on Dutch waterways)
• Easy dock app for inland cruise ships docking and paperless duties
• DSP Dynamic lock planning to minimize waiting times
• Technical coordination center TCC for Harbor master operation
• Rail Freight transportation program (PoR and ProRail)
• Test on traffic and parking optimization (sensors & analytics)
• AIS data analytics for waterway monitoring, berth occupancy evolution

4.1.4 The Port of Hamburg (PoH)
General Description

The Port of Hamburg in Germany covers 4,460 hectares is specialised in container, dry bulk and liquid bulk cargoes approximately 135.1 million tonnes. Moreover, it made profit of 68.5 million Euros.

4.1.4.1 Emissions

PoH emits about 152,000,000 tonnes CO₂ yearly. Port of Hamburg is targeting a 30% reduction of CO₂ emissions per handled container in 2020.

4.1.4.2 Digital Technologies

The Port of Hamburg is applying the following technologies:

• 5G program with Telekom and Nokia
• Building Information Modelling (BIM) used to enhance planning and operation. Also an Intermodal Port traffic center for traffic flow monitoring and optimization.
• InfoPORT: Data capture and sharing for logistic efficiency. Sharing information on, traffic, parking, infrastructures, bridges closures.
• Monitoring of vehicles and infrastructure through

4.2 Application

The adoption of DT in ports is still at an immature stage. So far only big ports (in terms of cargo and freight) are implementing or experimenting (for others) these
technologies. Ports are mainly service providers, but also, they need to comply with international regulations and national laws on reducing GHG emission. In addition, good practices such as incorporating Corporate Social Responsibility and green policies attract more customers, receive incentives from governments to encourage efforts towards sustainability.

As such, ports are seeking ways that not only help them remain profitable but at the same time contribute towards their share of NDCs. DTs by improving efficiency could indirectly affect not only productivity and energy saving but also GHG emission. Hence, this section (4.2) seeks to verify the energy reduction potential of DTs. Qualitative data for application of DT were sourced from ports sustainability reports, other online articles and reports. Each port was chosen based on the availability of data.

4.2.1. Discussion of results

Table 6 below shows the amount of application per DT (IoT, big data, analytics, automation/robotics, cloud services and sensors) in the ports of Antwerp, Rotterdam, Amsterdam and Hamburg.
Table 6. Application of DT in case study ports

<table>
<thead>
<tr>
<th>PORT OF ANTWERP</th>
<th>DT</th>
<th>APPLICATION</th>
<th>SOURCE</th>
</tr>
</thead>
<tbody>
<tr>
<td>PORT</td>
<td>IoT</td>
<td>- IoT project through sensors to enable docking</td>
<td>- Port of Antwerp</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Blockchain pilot project for hygiene &amp; phytosanitary certificate</td>
<td>2016, 2017, 2018, 2019, 2020</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- improve efficient and secure document flow</td>
<td>- Deloitte, 2018</td>
</tr>
<tr>
<td></td>
<td>Data analytics</td>
<td>- NexPort (port based software) involves logistic optimization tools such as ETA predictions</td>
<td>- Accenture, 2016</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- provides personalized traffic for truck drivers.</td>
<td>- Frost &amp; Sullivan, 2020</td>
</tr>
<tr>
<td></td>
<td>Automation/robotics</td>
<td>- Testing of autonomous trucks in terminals</td>
<td>- Siemens, 2017</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Closures of movable bridge</td>
<td>- Shannon et al., 2019</td>
</tr>
<tr>
<td></td>
<td>Cloud services</td>
<td>- Build port communities, facilitate the deal process</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sensors</td>
<td>- To identify and limit idle containers</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Direct traffic flow for trucks</td>
<td></td>
</tr>
<tr>
<td>Big Data</td>
<td>IoT</td>
<td></td>
<td></td>
</tr>
<tr>
<td>----------</td>
<td>-----</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
| - Data driven digital dart port community Platform  
- Virtual port container terminal  
- Collect and share information about access to parking and infrastructure  
- Develop waterview technology which collects extensive data from photographs of quay walls, fender and bridges in order to detect any damage and repair them quickly. | - Logistic processes, delivery and payment  
- Speed up physical flow of goods  
- Blockchain Cargo monitoring |
| PORT OF ROTTERDAM | - application relying on block chain for tracking ownership and location of cargo  
| | - IoT platform, collect data from several sensors within a cloud platform, processed in real time to improve Port services  
| | 2020)  
| | - (Deloitte, 2018)  
| | - (Accenture, 2016)  
| Data analytics | - Trade and Logistics  
| | - Paperless Trade  
| | - Supply Chains Synchronization  
| | - Pronto (port based application) Communication & Call Optimization application with the aim of reducing vessel waiting time.  
| | - (Frost & Sullivan, 2020)  
| | - (Siemens, 2017)  
| | - (Shannon et al., 2019)  
| Automation | - container handling, transport and stacking  
| | - improve operational performance and save service crane time by 23%  
| | - use of 3D printing technologies to assist the maintenance and repair of parts and accessories.  
| | - PoR also has a fully automated deep sea terminal including automated guided vehicles.  
| Cloud services | - Collects data from installed sensors  
| | - collects data from cargo registration  
| | - Operating flow model for Optical Symbol Recognition  

54
<table>
<thead>
<tr>
<th></th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Sensors</strong></td>
<td>- 5G testing to enable use of large scale wireless sensors</td>
</tr>
<tr>
<td></td>
<td>- remote controlling of heating and cooling</td>
</tr>
<tr>
<td></td>
<td>- reduce truck turnaround times</td>
</tr>
<tr>
<td></td>
<td>- sensors were installed across a 42KM stretch of the port's roads, quay walls, and mooring posts.</td>
</tr>
<tr>
<td><strong>Big Data</strong></td>
<td>- Vessel Traffic services improvement</td>
</tr>
<tr>
<td></td>
<td>- collect real time data to use on a unified platform, analysis it and provide information used in transportation monitoring tools, improve port security and detect defects in vessels and infrastructure.</td>
</tr>
<tr>
<td></td>
<td>- uses the Portbase Port Community System for bilateral connections and information exchange.</td>
</tr>
</tbody>
</table>
| PORT OF HAMBURG | IoT | - The Port of Hamburg uses intranets, cloud computing, mobile terminal equipment, the Internet of Things and big data technologies to manage the port area, parking lots, terminal and roads.  
- Use IoT platform to reverse the expected rise in traffic and increasing negative externalities in areas such as pollution, traffic congestion and road safety due to the seaport's activities | -Fort of Hamburg  
- (Deloitte, 2018)  
- (Accenture, 2016)  
- (Frost & Sullivan, 2020)  
- (Siemens, 2017)  
- (Shannon et al., 2019) |
| --- | --- | --- |
| Data Analytics | - InfoPORT: capture data and share for logistic efficiency.  
Sharing information on, traffic, parking, infrastructures, bridges closures.  
-smartPort logistic app allows trucks to reserve parking space before time and locate unreserved open spaces. |  |
| Automation | - container handling, transport and stacking  
- improve operational performance and save service crane time.  
-currently PoH is exploring ways to incorporate electric vehicles into its operations. |  |
| Cloud services | - collect data concerning parking for optimization app for trucks |  |
| Sensor Data | - TransPORT rail which is a Traffic Management system for Rail transport – optimization & user data sharing  
  - remote controlling of heating and cooling  
  - reduce truck turnaround times  
  - Sensors have been attached to frequently-used points along the harbor railway that transmit real-time data to a central IT location  
  - Monitor vehicles and infrastructure through centralized information through control room software  
  - DIVA system which is a dynamic information on traffic volumes and information sharing together with informative LED panels  
  - Building Information Modelling (BIM) used to enhance planning and operation  
  - collect real time data to use on a unified platform, analysis it and provide information used in transportation monitoring tools, improve port security and detect defects in vessels and infrastructure. |
<table>
<thead>
<tr>
<th>PORT OF AMSTERDAM</th>
<th>IoT</th>
<th>-provide information and access to information about all ship movements</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Data analytics</td>
<td>-Facilitating open data to create value for (digital) business climate and environment benefits by making data available to port stakeholders.</td>
</tr>
<tr>
<td></td>
<td>Automation/robotics</td>
<td>-Use to control traffic of trucks and cranes -used AGV to handle storage an interchange of equipment</td>
</tr>
<tr>
<td></td>
<td>Cloud services</td>
<td>- Data collected during unshipping process is received in real time by management and maintenance department.</td>
</tr>
<tr>
<td></td>
<td>sensors</td>
<td>-use to verify condition of some port infrastructure hence identify maintenance location -record movement on bulk carriers during unshipping process. -live image of port traffic</td>
</tr>
<tr>
<td></td>
<td>Big Data</td>
<td>-collect real time data to use on a unified platform, analysis it and provide information used in transportation monitoring tools, improve port security and detect defects in vessels and infrastructure.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>-Fort of Amsterdam -Deloitte, 2018) - (Frost &amp; Sullivan, 2020) - (Siemens, 2017) - (Shannon et al., 2019) - (Amsterdam smart city, 2018)</td>
</tr>
</tbody>
</table>
4.2.3. Number of DT application for case study ports

Table 7 below rates the degree of penetration of each technology based on literature read about the implementation of DT that these ports have adopted. The numbers in the table were derived based on the authors judgement as a result of the literature read. Sensors have the highest figures for all ports since they were read to be the most applied, however, the PoR for example has applied sensors in every port infrastructure. The use of Big Data and cloud services is still at an immature stage in most these ports since it requires high security concerning protection of information from customers and port stakeholders. So far only the Ports of Rotterdam and Antwerp are advanced in the use of Big Data and cloud services.

Table 7. Degree of Penetration of DT in Ports of Antwerp, Hamburg, Rotterdam & Amsterdam.

<table>
<thead>
<tr>
<th>Ports</th>
<th>IoT (10)</th>
<th>Big Data (10)</th>
<th>Sensors (10)</th>
<th>Data Analytics (10)</th>
<th>Robotics (10)</th>
<th>Cloud Svs (10)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Antwerp</td>
<td>7</td>
<td>5</td>
<td>10</td>
<td>7</td>
<td>8</td>
<td>6</td>
</tr>
<tr>
<td>Rotterdam</td>
<td>8</td>
<td>7</td>
<td>10</td>
<td>9</td>
<td>9</td>
<td>8</td>
</tr>
<tr>
<td>Amsterdam</td>
<td>6</td>
<td>4</td>
<td>8</td>
<td>6</td>
<td>8</td>
<td>3</td>
</tr>
<tr>
<td>Hamburg</td>
<td>5</td>
<td>3</td>
<td>9</td>
<td>5</td>
<td>7</td>
<td>4</td>
</tr>
</tbody>
</table>

Source: Author, 2020

4.2.4 Attributed Weighting for each DT

Weight Scale

The weight scale is determined by the degree of importance each criteria plays in achieving a DT status for the ports as shown in Table 8. The weights were decided by the author through extensive review of literature and indications provided by subject matter experts on Port digitalization. The table illustrates the weight or importance of each DT in terms of energy saving. The DT with the highest figure has a better ability to reduce energy consumption. It could be deduced from the literature that there is a
greater decrease in energy consumption from the application of IoT and sensors than from big data and cloud services.

Table 8: Weighting for DT Criteria

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Weight Scale (5)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Internet of Things (IoT)</td>
<td>5</td>
</tr>
<tr>
<td>Big Data</td>
<td>4</td>
</tr>
<tr>
<td>Sensors</td>
<td>4</td>
</tr>
<tr>
<td>Data analytics</td>
<td>5</td>
</tr>
<tr>
<td>Robotics/automation</td>
<td>4</td>
</tr>
<tr>
<td>Cloud services</td>
<td>3</td>
</tr>
</tbody>
</table>

Source: Author, 2020

4.2.5. Degree of Digital Technology application

Table 9 illustrates the total amount and the level of readiness of DT for each port. Basically higher figures mean higher degree of digitalization. The figures were arrived at by multiplying the weighting with the rate of each DT. The chart depicted at Figure 10 is a representation of the digital technology penetration in the case ports of Antwerp, Rotterdam, Hamburg and Amsterdam.

Table 9: Degree of Digital Technology Penetration in Ports with weights

<table>
<thead>
<tr>
<th>Ports</th>
<th>IoT</th>
<th>BD</th>
<th>Sensors</th>
<th>Data Analytics</th>
<th>Robotics</th>
<th>Cloud Svs</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Antwerp</td>
<td>35</td>
<td>20</td>
<td>40</td>
<td>35</td>
<td>32</td>
<td>32</td>
<td>194</td>
</tr>
<tr>
<td>Rotterdam</td>
<td>40</td>
<td>28</td>
<td>40</td>
<td>45</td>
<td>36</td>
<td>36</td>
<td>225</td>
</tr>
<tr>
<td>Amsterdam</td>
<td>30</td>
<td>16</td>
<td>32</td>
<td>30</td>
<td>32</td>
<td>32</td>
<td>172</td>
</tr>
<tr>
<td>Hamburg</td>
<td>25</td>
<td>13</td>
<td>36</td>
<td>25</td>
<td>28</td>
<td>28</td>
<td>155</td>
</tr>
</tbody>
</table>

Source: Author, 2020
Figure 10: Chart representing the degree of digital penetration of case study ports

![Chart representing Degree of Digital Penetration](image)

Source: Author, 2020

Since the Port of Antwerp reported a 2.3% (section 4.1.2.1.) decrease in CO2 emission from applying DT, the author used this as a baseline to extrapolate and derive how much energy other ports could reduce. To arrive at this, the author reduced the total emissions for each port by 2.3% as shown in Table 10. Figure 11 describes the CO2 reducing potential of the ports using a pie chart.

Table 10. CO2 reduction potential

<table>
<thead>
<tr>
<th>Ports</th>
<th>DTP</th>
<th>CO2 emission</th>
<th>Reduction by 2.3% = (CO2*0.023%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Antwerp</td>
<td>194</td>
<td>19,000,000</td>
<td>437,000</td>
</tr>
<tr>
<td>Rotterdam</td>
<td>225</td>
<td>28,000,000</td>
<td>664,000</td>
</tr>
<tr>
<td>Amsterdam</td>
<td>172</td>
<td>2,364,000</td>
<td>54,372</td>
</tr>
<tr>
<td>Hamburg</td>
<td>155</td>
<td>1,520,000</td>
<td>34,960</td>
</tr>
</tbody>
</table>

Source: Author, 2020
4.3 Implications

For this analysis, the author proceeded thus:

- Firstly, IoT, Big Data, digital analytics, robotics/automation, cloud services where chosen since they are considered by Digital Transformation Scoreboard to be key technologies for digitalization.
- The degree of penetration for each port was evaluated with 10 as a baseline and it was evaluated based on data gotten from literature as shown in Table 6. Some functions of DT overlap, for example data collected from sensors will go through data analytics, then IoT transfers these data to physical devices such as customers’ smart phones, Port Authority computers and big data stores these large and complex data generated. So basically, the same data can go through several technologies. Therefore, the number of applications represented in
table 7 might not reflect the data in table 6 but rather from the authors' judgement based on literature read of how these ports applied DT.

- Furthermore, an estimation of possible energy reduction from ports was made by reducing the CO₂ of each port by 2.3% as in the port of Antwerp. 2.3% was the only data available in the literature. The result shown in Figure 11 clearly reveals that a higher application of DT leads to a higher decrease in emissions.

- The port of Amsterdam had a total of 194 applications of DT and had a CO₂ reduction slightly lower than the port of Rotterdam which has 225 applications. Likewise, the port of Amsterdam has more application per DT than the port of Hamburg. This is reflected in their CO₂ savings as the port of Amsterdam has higher CO₂ reduction than the port of Hamburg. (Refer to figure 11).

- It is evident from the results in Figure 11 that DT can help save energy and reduce GHG emissions. The Port with greater DT application has the better CO₂ reduction potential as is the case with the Port of Rotterdam that has the greatest amount of DT application in this research.

There are 8292 in the world of which 823 are active. If these ports apply at least a minimum of DT in their operations, CO2 reduction from ports will greatly reduce thus contributing to global CO2 reduction and Climate Change reversal. This amount should not be neglected because over the years it accumulates and becomes significant in reducing climate change casualties.
CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1. CONCLUSION

Digitalization of port operations is still at an immature stage; very little literature is available on the energy saving potential of these technologies. Also, GHG emission and digitalization are not usually linked in the literature, but rather with profitability and productivity.

This study investigated the amount of GHG emissions that can be saved from the application of digital technology by seeking answers to the research questions earlier stated in Chapter 1, section 1.4.2. The DT identified were those already identified as essential by the Digital Transformation Scoreboard. The technologies identified were, Internet of Things, Data Analytics, Sensors, Automation, Big data and Cloud services.

After identifying these technologies, a review of DT applied and how they are applied in the ports of Antwerp, Rotterdam, Hamburg and Amsterdam was made. Cybersecurity and collaboration through data sharing are key to effective implementation and managing of these DT. However, the key challenges of DT application in ports are the lack of policy and the fact that there exist varying models.

Several stakeholders mostly serving their interest manage most ports around the world. The lack of common vision and the ability for stakeholders to cooperate in reaching a consensus on DT application poses a serious challenge for digitalization in ports. Further to this, policies both at national and international levels are responding slowly to DT application in ports. Criteria of regulations is thus important to effectively manage and control how data used in these technologies are managed.

From the findings in Table 11, it is evident that DT reduces GHG emissions. The Port of Rotterdam, which applied the highest amount of DT, had the highest reduction in GHG emission. However, this study did not consider the cost of applying DT neither
did it consider over what period the benefits on GHG emission reduction would be achieved. Further research in this area is necessary. Also, the case studies were done mainly with ports considered to be among the largest and busiest ports in Europe. This implied that there is constant port calls and activities that keep them busy which may not be the case with small ports that manage operations in a traditional way. This however has to be investigated.

The emissions reduction assessed in this study though little, holds tremendous value when viewed through a lifecycle lens. Similarly, overtime it has remarkable impact on reducing GHG emissions hence a positive impact on climate change. It is pertinent to state that ports could treat DT as one method among several other energy efficiency improvements available for reducing GHG emissions. Thus, Ports could study other different methods available and effectively employ them to reduce GHG emission. This will help contribute their own share of the NDC. Therefore, DT might have contributed its bit but the combination of reduction from other methods would be large hence a larger impact on abatement of anthropogenic effect on climate change in ports worldwide.

5.2 Recommendation

The following are the recommendations:

- Adopting digital technology alone is not enough to improve energy efficiency, reduce energy consumption and GHG emission. Staff training, including energy management system for DT as well as adopting just the right technology based on specific needs of the port is necessary to make the most out of it.

- The effect of DT on energy saving is still a debate that needs extensive research. “Explosion of data” (ITIF,2020) from implementing digital technologies could lead to a peak increase in energy consumption and environmental footprint. DT might not necessarily reduce energy or GHG emission directly. However, it could affect other processes in reducing energy consumption.
• It is crucial that when adopting DT in ports aspects like, Training of personnel, studies on the DT needed and how much should be applied is important since applying DT alone is not sufficient in reducing GHG emissions.

• Increased research on the subject of DT and GHG emission is needed to better inform ports that are still sceptical about the benefits DT could provide in terms of reducing GHG emissions hence contributing to their compliance of environmental regulations.
References


https://www.academia.edu/5703038/The.Importance_of_Technology_in_Industrial_Development


68


https://sdgs.un.org/goals/goal9

https://sdgs.un.org/goals/goal13

https://www.semanticscholar.org/paper/Digitalization-of-Sea-Transports-Enabling-Haraldson/d61f4ddc5a0b2da6a6a2ef271ce2ee2c0ac446d2

72


74


https://doi.org/10.3390/joitmc5020030

https://doi.org/10.1016/j.rser.2019.04.069


75
technology can help improve workplaces that improve business cohesion.


[https://doi.org/10.13140/RG.2.2.29807.69285](https://doi.org/10.13140/RG.2.2.29807.69285)


[https://doi.org/10.1016/j.sbspro.2014.12.131](https://doi.org/10.1016/j.sbspro.2014.12.131)


79


82

https://doi.org/10.1016/j.compind.2011.08.004

Spengler, T., & Wilsmeier, G. (2016). Energy Consumption and Energy Efficiency Indicators in Container Terminals - a national inventory. IAME, HAMBURG, GERMANY.

http://www.europeanenergyinnovation.eu/Articles/Autumn-2019/How-digitalisation-is-modernising-energy-efficiency


