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ABSTRACT

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Abstract

The increasing volumes in global maritime trade are associated with accumulating stresses and adverse effects on the environment. Measures such as stricter regulations and renewed legislation are implemented to pivot the industry towards global sustainable development goals. While the end goal of achieving carbon neutrality remains problematic and slow-going, several short-term solutions could be found. This study aims to explore how digitalisation can support the sustainable development of the maritime industry, focusing primarily on enhancing port efficiency. The purpose of the study is divided into two sub-questions: what are the sustainability impacts of the maritime industry, and how could digitalising port calls impact shipping emissions?

The study's theoretical framework consists of three large concepts; sustainability, digital transformation, and the maritime industry's complexity, particularly the port operations, are discussed. The research method used in this study is quantitative, as the research problem is best addressed by processing numerical data.

The results of the study are in line with previous research, indicating that optimising the port operations and reducing waiting time could have significant impacts on CO2 emissions. Lowering the CO2 emissions leads to the sustainable development of the environment and economic and social sustainability as the cost savings have the potential to reach billions of USD and have positive effects on social well-being. While change on a global scale may not be viable to implement due to development maturity, more realistic scenarios, such as a change in top 30 GDP countries, depict the ability to implement digitalisation and JIT shipping effectively and at scale. By leveraging their current infrastructure and economic capabilities, these countries alone could produce significant sustainability impacts while remaining competitive. To tackle the global issue of climate change, the decision-makers should thus invest and incentivise the maritime actors to optimise their operations that directly lead to the industry's sustainable development.

Key words | Sustainability, maritime industry, digitalisation, Just-in-Time

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Tiivistelmä

Maailman meriteollisuuden kasvuun liittyy lisääntyviä stressitekijötä ja haitallisia ympäristövaikutuksia. Toimenpiteitä, kuten tiukempia määräyksiä ja uudistettua lainsäädäntöä, toteutetaan, jotta ala saataisiin kohti globaaleja kestävän kehityksen tavoitteita. Vaikka lopullinen tavoite hiilineutraaliuden saavuttamiseksi on edelleen ongelmallinen ja hidas saavuttaa, voidaan useita lyhyen aikavälin ratkaisuja ottaa käyttöön. Tämän tutkimuksen tarkoituksena on selvittää, miten digitalisaatio voi tukea meriteollisuuden kestävää kehitystä keskittymällä ensisijaisesti satamatehokkuuden parantamiseen. Tutkimuksen tarkoitus on jaettu kahteen alakysymykseen: mitkä ovat merenkulkualan kestävän kehityksen vaikutukset ja miten satamatoimintojen digitalisointi voisi vaikuttaa merenkulun päästöihin?

Tutkimuksen teoreettinen kehys koostuu kolmesta suuresta käsitteestä; kestävästä kehityksestä, digitaalisesta muutoksesta ja merenkulkualan, erityisesti satamatoimintojen monimutkaisuudesta. Tutkimusmenetelmänä käytetään kvantitatiivista menetelmää, sillä tutkimusongelmaan voidaan parhaiten pureutua analysoimalla numeerista dataa.

Tutkimuksen tulokset ovat aiempien tutkimusten mukaisia, ja ne osoittavat, että satamatoimintojen optimoinnilla ja odotusajan lyhentämisellä voi olla merkittäviä vaikutuksia hiilidioksidipäästöihin. Hiilidioksidipäästöjen vähentäminen johtaa ympäristön kestävään kehitykseen sekä taloudelliseen ja sosiaaliseen kestävyyteen, sillä kustannussäästöt voivat saavuttaa miljardeja dollareita ja vaikuttaa myönteisesti sosiaaliseen hyvinvointiin. Vaikka globaalin mittakaavan muutos ei välttämättä ole toteuttamiskelpoinen sen kehityksen kypsyyden vuoksi, realistisemmat skenaariot, kuten muutos 30 parhaan BKT-maan joukossa, kuvaavat kykyä toteuttaa digitalisaatio ja just-in-time (juuri ajoissa) tehokkaasti ja laajamittaisesti. Hyödyntämällä nykyistä infrastruktuuriaan ja taloudellisia valmiuksiaan nämä maat yksin voivat tuottaa merkittäviä kestävyysvaikutuksia pysyen kilpailukykyisinä. Ilmastonmuutoksen maailmanlaajuisen ongelman ratkaisemiseksi päätöksentekijöiden olisi siten investoitava ja kannustettava merenkulun toimijoita optimoimaan toimintaansa, mikä johtaa suoraan alan kestävään kehitykseen.

Avainsanat: Kestävä kehitys, meriteollisuus, digitalisaatio, Just-in-Time

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SUSTAINABILITY IN THE DIGITALLY OPTIMISED MARITIME INDUSTRY

Master's Thesis
in International Business

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Turku

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LIST OF ABBREVIATIONS

AB	Auxiliary boiler
AE	Auxiliary engine
AI	Artificial intelligence
AIS	Automatic Identification System
BIMCO	Baltic and International Marine Council
BoL	Bill of Lading
CO2	Carbon dioxide
DCSA	Digital Container Shipping Association
DSP	Dominant social paradigm
DWT	Dead-weight ton(s)
ECDIS	Electronic chart display and information system
EEA	European Environment Agency
EMSA	European Maritime Safety Agency
GDP	Gross domestic product
GHG	Greenhouse gas
GT	Gross tonnage
IBM	International Business Machines Corporation
ICS	International Chamber of Shipping
IMO	International Maritime Organization
IoT	Internet of Things
JIT	Just-in-Time
LNG	Liquefied natural gas
m/m	Mass by mass
MCR	Maximum continuous rating
ME	Main engine
MST	Marine seaborne trade
NEP	New environmental paradigm
OLS	Ordinary least squares
PortCDM	Port collaborative decision making
Real GDP	Real Gross Domestic Product
SCC	Social cost of carbon
SDGs	Sustainable development goals
SES	Social-ecological system
SFC	Specific fuel consumption
SOx	Sulphur oxide
TEU	Twenty-foot equivalent unit
UN	United Nations
UNCTADstat	United Nations Conference on Trade and Development statistics
UNSD	United Nations Statistics Division
VDR	Voyage data recorder
WEF	World Economic Forum
WPSP	World Ports Sustainability Program
ZB	Zettabytes

1 INTRODUCTION

1.1 Navigating the maritime industry

Ex scientia tridens. - From knowledge, seapower.
(The U.S. Naval Academy motto)

World trade grew dramatically in the second half of the 20th century. After the introduction of rail transport and steamships, containerisation in 1966 revolutionised international trade and the transportation industry further. The intermodal freight transport between ships, trains and trucks supported the establishment of global supply chains, increased shipping capacities, and reduced delivery times. (Bernhofen et al. 2016). Now, over 80 per cent of world trade by volume is carried by sea, and the maritime trade is predicted to continue to expand globally. In 2019, a total of 11.08 billion tons of cargo was shipped internationally. That meant some 811 million twenty-foot equivalent unit (TEU) of containers were handled worldwide, fifty per cent more than in 2010. (UNCTAD 2020b, 1-37).

China is by far the largest single contributor to cargo handling, representing roughly one-third of the total market. From Lloyd's List (2020) top 100 biggest ports, 23 are located in China, number one being the port of Shanghai, with a throughput of 43.3 million TEUs. To put this into perspective, if the containers were laid out end-to-end, the tail would circumnavigate the globe more than six and a half times. (Lloyd's List 2020, 1-10). When looking at other factors, such as Jakobsen et al. (2019) five pillars – shipping centers, maritime finance and law, maritime technology, ports and logistics, attractiveness and competitiveness – Singapore was ranked as the world-leading maritime hub in 2019, followed by Hamburg, Rotterdam, Hong Kong, and London. Some of Singapore's strengths are geographical location, a stable pro-business environment, and operational capabilities. (Jakobsen et al. 2019). In fact, Singapore is currently constructing a next-generation Tuas mega port, which, when completed in 2040, is anticipated to be the world's single largest fully automated terminal with an annual handling capacity of 65 million TEUs. (PSA 2019).

In order to satisfy the demand and carry out the growing number of cargo, the world merchant fleet has increased in number and size. In 2020, the total world fleet amounted to 98,140 ships of 100 gross tons (GT) and above. (UNCTAD 2020b, 37). Figure 1 highlights how the vessel sizes have grown significantly to optimise costs through economies of scale.

Figure 1: Average vessel size (Adapted from UNCTAD 2020b, 36)

The average ship sizes have more than doubled since 1996. Oil tankers are roughly nine times bigger, container ships are four times bigger, and bulk carriers twice as big as 20 years ago. However, the average age of the global fleet in 2019 was 18 years, while newbuilding and recycling of ships have been declining significantly. (UNCTAD 2020b, 37-47, 70). Several causes can explain the trend, such as the widening disparity between newbuilding prices and earnings and disruption caused by geopolitical instability and social unrest. In addition, new regulations, such as introducing the global CO2 emission reduction targets and the global 0.5 per cent sulphur cap on marine fuels, bring uncertainty over fuel and technology choices. (UNCTAD 2020b, 56; BRS Group 2020, 7-10, 99).

The increasing volumes in global maritime trade are associated with increasing stresses and adverse effects on the environment. Numerous performance indicator frameworks have been established nationally, regionally and internationally to mitigate environmental impacts and steer the maritime industry toward sustainability. These indicators include, for example, air and water quality, greenhouse gas (GHG) emissions, energy consumption, noise pollution, impacts on local communities, ship and shore-based garbage, port development, and dredging operations. (Walker et al. 2019, 1-4). A study conducted by the International Maritime Organization (IMO) estimated that the GHG emissions of total shipping in 2018 were 1,076 million tonnes. From that, 1,056 million tonnes were carbon dioxide (CO2) emissions alone. (IMO 2021a, 1). An estimated 160 million tonnes of CO2 emissions result just from bad planning – early arrivals and the time ships spent waiting for permission to enter the ports, unload goods and move on. (Valeur 2019).

Sustainable development has become an urgent concern and a widely recognised goal globally. One of the most commonly cited definitions of sustainability is "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (Brundtland 1987, 37). (Bossel 1999; Steurer et al. 2005; Voss & Kemp 2006; Purvis et al. 2019). To make the concept operational, it needs to be translated into practical dimensions with proper indicators that show sustainability changes and progress. One basic, and perhaps the oldest, analytical approach is the three-pillar theory: an interaction among environment, economy and social systems which aims to maximise the objectives while balancing trade-offs. (Barbier 1987; Purvis et al. 2019). In 2015, the United Nations (UN) adopted the 2030 Agenda for Sustainable Development, integrating 17 Sustainable Development Goals (SDGs). These goals act as a blueprint for a more sustainable planet and include, for example, industry, innovation and infrastructure (9), life below water (13) and partnership for the goals (17). (UN 2015).

Ports are nodes in global supply chains and embedded in local and regional communities. To respond to sustainability challenges, in 2018, the International Association of Ports and Harbors launched the World Ports Sustainability Program (WPSP) which single guiding principles are the SDGs. The program will tackle five themes: Climate and energy, governance and ethics, safety and security, community outreach and port-city dialogue, and resilient infrastructure. It can be recognised that digitalisation could reinforce the operational and process efficiency around all five themes, supporting sustainable development. For example, the concept of *smart ports* employs innovative technologies, such as artificial intelligence (AI), big data, Internet of Things (IoT) and blockchain to create an infrastructure that optimises maritime logistics operations. (WPSP 2020). Finland is at the global forefront of developing digital solutions that optimise the entire maritime logistics' infrastructure and connect sea, port and land operations to work more efficiently, safely and sustainably - unlocking new value streams with information (Business Finland 2020).

1.2 Purpose and structure of the study

The massive growth of the maritime industry is not just impacting the economy; it is also leading to social and environmental problems. With only better planning and communication of the logistics chain, an estimated 17 per cent of the shipping's total annual CO2 emissions can be reduced – on top of, of course, decreasing other air and water pollutants and increasing safety and efficiency. A study conducted by GeSI and Deloitte (2019) found that digital technologies can have a positive impact on the SDGs with four functions:

- connect and communicate
- monitor and track
- analyse, optimise and predict
- augment and autonomate

In this way, digital transformation could accelerate the sustainable development of the maritime industry. Several studies on port call optimisation and Just-in-Time (JIT) have been done in some of the world's leading ports, such as Rotterdam and Singapore. Studies showed that optimising speed results in fuel savings, emission reduction and up to 20 per cent shorter waiting time. (GEF et al. 2020, 12; Port of Rotterdam 2021; Tijan et al. 2019, 8).

The purpose of this study is to explore how digitalisation can support the sustainable development of the maritime industry. Given the lack of studies on the overall implications of digitalisation on sustainability in the context of Industry 4.0, this study proposes the following two research questions:

1. What are the sustainability impacts of the maritime industry?
2. How could digitalising port calls impact shipping emissions?

The sea, land and port operations are complex and often siloed, with no end-to-end collaboration leading to bottlenecks at handover points. Collaboration and better planning can act as a crucial parallel solution to reaching the IMO targets supporting the SDGs, as studies suggest the maritime industry's most significant impact on sustainability are the emissions, most felt around the ports (WSPS 2020, 18). For this reason, the research focuses particularly on quantifying emissions of vessels during port-calls and how implementing digitalisation could support sustainability efforts. At the same time, the study provides examples of how the current operating models could be improved with digitalisation to contribute to the sustainable development of the environment, economy and social systems.

In this study, maritime logistics is understood as per Lee et al. (2012, 11-14), distinguishing it from maritime transportation in both focus point and managerial function. The focus point of Maritime transportation is on individual functions related to sea transportation, whereas maritime logistics is an entity part of the entire logistics integration system and emphasises the flow of the entire logistics system. It can be divided into three parts; shipping, port/terminal operating and freight forwarding. These can be further split into specific managerial functions, such as sea voyage, loading/unloading and warehousing. (Lee et al. 2012, 11-14). This study focuses primarily on the logistics chain's port operations and will only touch on sea and land logistics that directly affect port operations. The rest of the maritime transport and hinterland operations are intentionally excluded.

The study is structured as follows: Chapter 2 describes the theoretical background and previous research. The first part elucidates the concept of sustainability and further presents the three dimensions of sustainable development: economic, social and environmental. The second part examines digitalisation, the use of digital technologies towards digital transformation. The third part explores the maritime industry, particularly the complexity of port operations, and introduces the links with the two parts mentioned above. The chapter is concluded with a synthesis of the theoretical framework where these three parts are further combined, as together they form the basis for the empirical research. Chapter 3 focuses on the methodology of the research; what was the research setting and approach, how was data collected and analysed as well as the trustworthiness and ethics of the research. Chapter 4 analyses the data and compares it to the theory to present the research findings and answer the research question. Chapter 5 concludes the research by providing theoretical contribution, practical implications and suggestions for further research.

2 THEORETICAL BACKGROUND

2.1 Sustainability

The most widely used definition of sustainability was popularised by the Brundtland Commission 1987 report. The principle is that the current generation must not unfairly and without compensation exploit all resources to maximise its own well-being, but with certain constraints, take into account the well-being of the environment and future generations. At the same time, however, the well-being of the current generation must not be compromised. In other words, the current generation is allowed to use exhaustible natural resources for its own well-being, as long as future generations also have the opportunity for continuous progress and well-being. (Haukioja 2007, 12-15, 43-44). When the primary threshold values - safeguarding long-term ecological sustainability, satisfying basic human needs, and promoting intra-generational and inter-generational equity - are met, sustainable development succeeds (Holden et al. 2014, 131-132).

The dominant representation of sustainability or sustainable development is the three pillar conception: economic, environmental and social factors or goals, as shown in the following Figure 2.

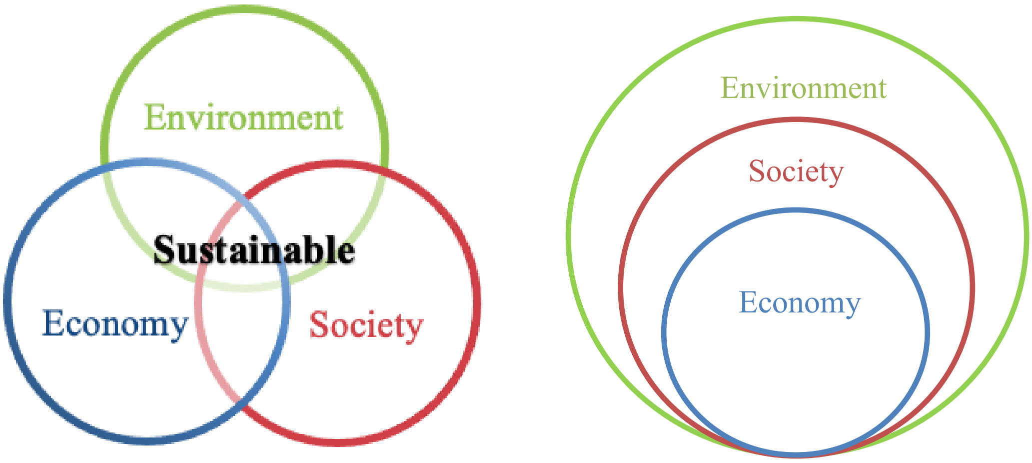


Figure 2: Sustainability pillars as Venn diagram and concentric circles (Adapted from Purvis et al. 2019, 682)

The most often used representation is the Venn diagram which integrates the three pillars to a balanced and holistic approach. Here the argument is that sustainability is achieved merely when the three pillars are simultaneously protected. It is the intersecting commonality between all three pillars, emphasising the trade-offs between economic growth, the decline in the quality of life, and deteriorating environmental conditions. Another way is to view sustainability as the three nested concentric circles. This representation takes into consideration that the three pillars are subsystems of each other - Economic development is limited within the sphere of social welfare and quality of life, which in turn is constrained by the environmental limits within the biosphere. (Purvis et al. 2019, 681-688). Several scholars (Brown et al. 1987; Kidd 1992) have been trying to better understand the general concept and define the specific targets of sustainability. The following subchapters will focus on briefly explaining the three pillars of sustainability and their intrarelationship and targets – *exactly what is it that is supposed to be sustained.*

2.1.1 Economy

From Adam Smith until World War II, economic development was known as material progress. After the second world war, outside of Marxist discourse, the colonial development continued the materialistic views with specific denotations of exploiting the natural resources to the utmost. Economic development was defined as the improvement in material well-being, increasing flow of goods and services or even the growth in per capita income. Thus, economic development became synonymous with economic growth. (Arndt 1981). In the late 1960s and early 1970s, when the basic economic needs had been met after the post-war period, the modern environment and quality of life issues emerged. Environmental disasters came to the fore with widespread media coverage, which increased awareness of the environmental destruction caused by humans. The growth-based economy had limitations and was fundamentally incompatible with ecological and social sustainability on a finite planet. (Purvis et al. 2019, 683).

Over the years, the concept of economic development has been shaped to consider society and the environment to achieve sustainability. The concept of sustainable economic development serves a variety of values. While it still promotes the more traditional economic goals, i.e. gain of monetary wealth, goods and services, being rich is not a guarantee of high quality of life and happiness. Instead, we should strive to move away from the single-minded pursuit of material wealth by incorporating other social values such as good health, meaningful work and a fair justice system. We should preserve our natural ecosystem, protect living species, be mindful of natural resources and be cautious of waste management. (Milbrath 1984, 121-123). Holden et al. (2014, 131) even argue that economic development should be more of a facilitator of the sustainability goals than a primary goal itself.

"Maritime transport is the backbone of international trade and the global economy." (UNCTAD 2018). Over 80 per cent of world trade by volume is carried by sea, and the number is predicted to grow. In 2017 over 70 per cent of global trade by value was carried by sea and handled by ports worldwide, which translates to approximately 12.25 trillion USD. (UNCTAD 2018; UNCTAD 2019, 5; UNCTAD 2020b, 1-37). The players with interest in the maritime industry include ship and cargo owners, shipbuilders, shippers, brokers and insurers, as well as states with economic dependence on seaborne trade and transport. Similarly, some are interested in the sea and its ecosystems, such as fisheries, aquaculture industries, tourism, and marine life itself. Currently, they are the ones who pay the highest costs of the growing economic value of the maritime industry. (Andersson et al. 2016, 105,140).

Andersson et al. (2016) find the shipping industry to have the following main environmental impacts:

- discharges to the sea
- emissions to the air
- anthropogenic noise and infrastructure
- marine spatial planning and shipwrecks.

All of these impose an economic cost to society and the environment. Possibly the most costly issues are oil spills and CO2 emissions. (Andersson et al. 2016, 139, 181-182). The IMO estimated that the CO2 emissions of total shipping in 2018 were 1,056 million tonnes (IMO 2021a, 1). The current median estimate of the social cost of carbon (SCC) per ton is 50 USD. Which would mean the SCC alone in 2018 was 5,28 billion USD. (Howard & Sylvan 2015, 1-3, 18, 23). The largest oil spill in history, the Deepwater Horizon spill in 2010, totalled over 200 million gallons of oil, resulting in around 60-100 billion USD total cost. From society's perspective, these can be divided into private costs to the oil rig operator(s) (i.e. cleanup, lost oil, litigation) and external costs or third-party costs to the government, victims, and natural resources (i.e. loss of life and injury to workers, natural resource damages, lost income by affected businesses). (Cohen 2010, 1-3).

2.1.2 Society

The development of society involves changes in not only the economy but also political, social and cultural transformation. For many, social sustainability means the productivity of livelihood and basic needs such as food, shelter and safety. In a broader sense, sustainable social development can also be understood to consider the environment and optimising present benefits without jeopardising the future use of kindred benefits. In order to be socially sustainable, society must commit to certain values. (Barbier 1987, 101-105, 109). Having values is a uniquely human phenomenon. For most human existence, the values were oriented towards living in harmony with nature and only relatively recently pivoted to dominate nature for merely human goals. This damages the natural systems and threatens other species and thus also humans, who cannot live without a viable ecosystem. (Milbrath 1984, 114-119).

Milbrath (1984, 113-119) argues that humans are selfish by nature with a desire for a higher standard of living. However, in order to achieve a sustainable society, humans need to link ecosystem viability as the central societal value. This can be achieved by emphasising compassion and empathy over competition and aggression. Figure 3 demonstrates how these value modifiers shape the societal direction.

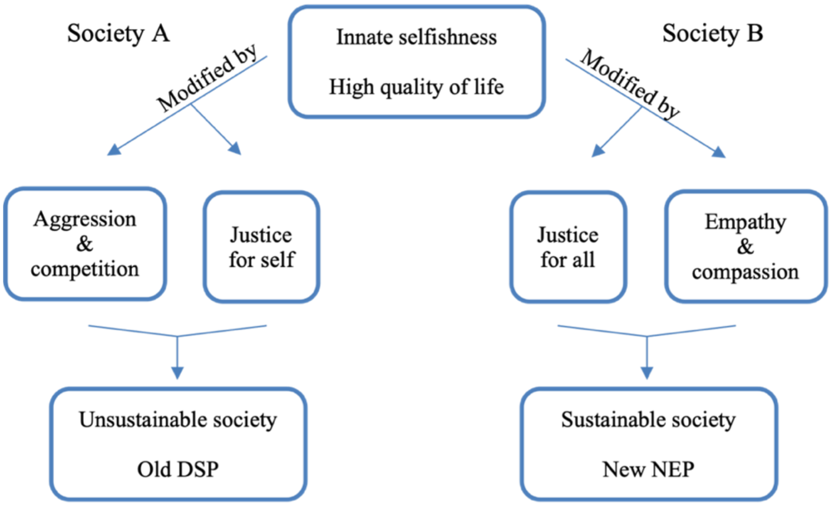


Figure 3: Biological value modifiers shaping the societal direction (Adapted from Milbrath 1984, 116)

Market economies tend to be competitive, result-oriented, emphasise selfish motives and value material wealth. Science and technology are seen as a tool to dominate nature and its resources. This is believed to result in a greater supply of goods and services at an efficient price – improving the quality of life. Milbrath calls this *Society A*, where the dominant social paradigm (DSP) structures society's beliefs and values. Increasingly we are questioning the sustainability of this kind of society and realising that it is causing damage to natural systems and forcing other species from their habitats. We should instead link the valuation we place on our own lives to the lives of other species and nature itself. This *Society B* operates by a new environmental paradigm (NEP) that is more balanced, emphasising immaterial things, and compassionate, recognising the common good enabling a sustainable society. Milbrath (1984, 116-123).

Containerisation in 1966 revolutionised international trade and the transportation industry, which is the key to globalisation and economic development. (Bernhofen et al. 2016, 2, 25). The International Chamber of Shipping (ICS) estimates 1.89 million seafarers are serving the world merchant fleet in 2021, operating over 74,000 vessels worldwide. Women represent only 1.28 per cent of the global seafarer workforce, but a positive trend in gender balance can be seen, as the number has increased 45.8 per cent since the last report in 2015. (ICS 2021). The IMO's Women in Maritime programme supports gender diversity and the participation of women in both shore-based and sea-going posts. This is in line with the UN 2030 Agenda for Sustainable Development and SDGs to "Achieve gender equality and empower all women and girls". (IMO 2021b).

The growth of the maritime industry results in integrating ports and port activities into urban development. Ports, in turn, further promote the economic growth in a region, which again expands the infrastructure. Ports and their activities that require large land and water areas have various negative impacts on people and the environment. The environmental impacts can be divided into three sectors: from the port itself, ship traffic through the ports and emissions from the transport network linked to the port. One of the aforementioned environmental impacts is anthropogenic noise and infrastructure. The issue originates from vessels, cargo handling operations and the supporting infrastructure often active throughout day and night. Noise pollution affects both humans and marine organisms. For humans, the negative health effects include hearing and cardio-vascular disturbance, increased blood pressure and chronic annoyance. (Andersson et al. 2016, 229-234, 238-240, 270).

2.1.3 Environment

"In many countries today, the life-support system of soil, water, air, minerals and living things is being stressed to a degree that could result in the failure of one or more critical components... The most widespread cause of ecological bankruptcy may be the gradual wearing out of the environment – the stressing of natural systems beyond their capacity for regeneration."

(L.K. Caldwell, 1968)

The foregoing quote was written in 1968, yet it still resonates with the current environmental situation. The environment can be understood as the relationships between the object and its surroundings, or more commonly, nature and its species. Humans then only exist within environmental relationships, and the question of sustainable development should be asked from the point of view of the ecosystem; *How to make the development serve the purpose of sustainability?* This way, we acknowledge, what is good for the environment is fundamentally good for humans, but not necessarily the other way around. (Caldwell 1990, 5-7, 183). To tackle the issues of environmental sustainability, we should identify what exactly is considered nature. For example, we view farmed land or planted forests as a component of the environment which means we do not consider them an environmental problem created by human activities. (Andersson et al. 2016, 13).

The increase in global population and use of natural resources has put such a strain on nature it is becoming harder for it to recover from the effects of human activities. Some scientists even argue that we are entering the Anthropocene, a geological epoch where human dominance is threatening the stable state of the Holocene. To avoid this shift, there needs to be a set of values, planetary boundaries, that cannot be crossed if the stable state of the Earth wants to be sustained. In addition, the system needs to be resilient, addressing disturbance while retaining its basic function and structure. (Andersson et al. 2016, 13-16). Resilience thinking investigates how social-ecological systems (SES) can be best managed in complex and continuously dynamic conditions. This approach highlights how SES are changing and evolving, moving through phases or adaptive cycles. While optimisation may be efficient, it sets limitations and predisposes SES to shocks and disruption. Rather than denying or constraining changes, resilience thinking tries to understand and embrace them, which helps build the capacity to work with the change. (Walker & Salt 2012, 10-15, 145-150).

The ocean is the largest ecosystem on our planet. It nurtures biodiversity, stores carbon, stabilises climate and “supports human well-being through food and energy resources, as well as by providing cultural and recreational services”. (UNESCO 2020, 7). Taking care of seas and oceans is not only an environmental act for marine life. Studies suggest a direct link between activities in and around the seas and oceans and human health and well-being. For example, by taking better care of fisheries and aquaculture, we can ensure healthy fish stocks, improve nutrition and food security, and prevent chronic disease. From the negative impacts, only some are immediately visible, for example, oil spills. In addition, human activities increase risks such as marine plastic pollution, ocean acidification and extreme weather events, which are downstream consequences we might not directly associate with human actions. (Short et al. 2021).

In 2017 the UN proclaimed a Decade of Ocean Science for Sustainable Development program (2021-2030) to support efforts to achieve the 2030 SDGs. The program aims to improve the scientific knowledge base of the pressures and changes to better predict, mitigate and adapt to possible consequences of ocean disruption. (UNESCO 2020, 4-7). The IMO is doing its part by aiming to eliminate the shipping industry's CO2 emissions, which poses many challenges. There are yet no clear alternative low- or zero-carbon fuels, nor could the vessels adapt them in a trice. For now, several short-term solutions could be implemented, such as using liquefied natural gas (LNG), lowering fuel consumption by lengthening transit times, and enhancing port efficiency. Massive investment in new technologies and infrastructure, knowledge sharing and promoting innovation is necessary to achieve the common goal, but the complex coordination challenge must first be solved with unified regulations and transparent collaboration. (OceanEconomist, 2021).

2.2 Digitalisation

The third industrial revolution, the digital revolution, began in the 1960s. It was catalysed by mainframe computing, personal computer and the internet. Those may seem self-evident for most of today's generation even though about half of the world population lacks internet access. Nevertheless, the development and innovation of digital technologies have been so rapid that we are already in the midst of the fourth industrial revolution that builds on the digital revolution. The interdependencies among different technologies and smart systems are so dexterous that the machine ecosystem is teaching and improving itself to the point that it is virtually impossible to predict what is next. (Schwab 2016, 11-17). The use of digital technologies, such as AI, IoT, blockchain and data analytics, can be defined as digitalisation, a process for digital transformation, redefining and creating something new (Gong & Ribiere 2021, 1-12).

2.2.1 Digital transformation

Digital transformation can be conceptualised into six defining primitives: nature, entity, means, expected outcome, impact and scope. Figure 4 illustrates the logic of the primitives with their defining attributes (Gong & Ribiere 2021, 7-12).

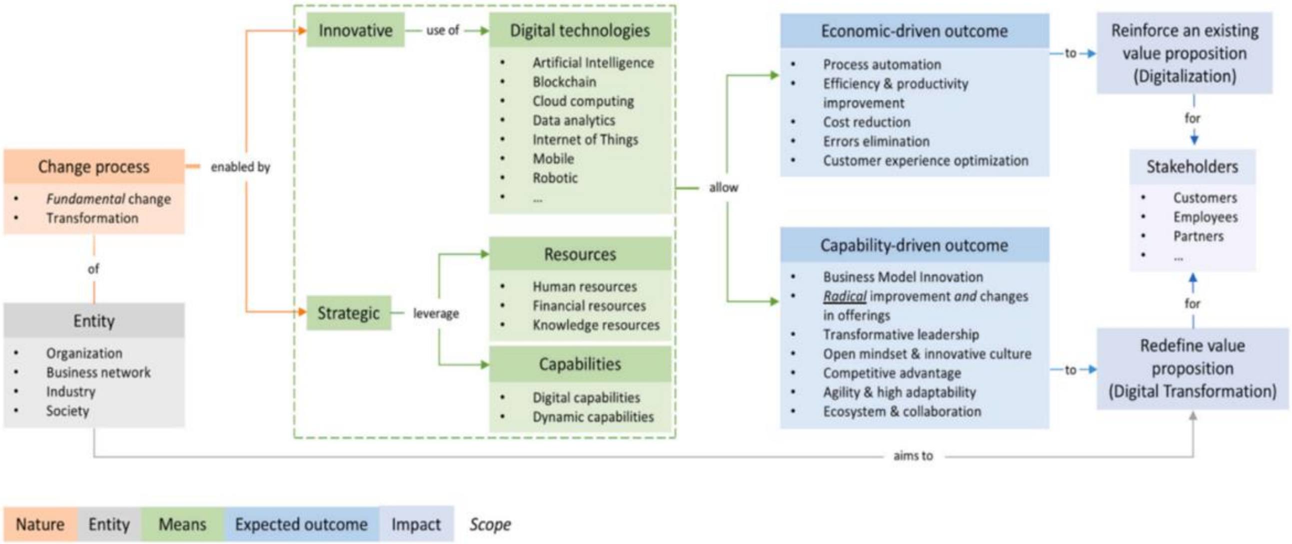


Figure 4: Digital transformation conceptual diagram (Gong & Ribiere 2021, 12)

An entity is a unit affected by digital transformation, for example, society, industry, business network or organisation. The nature of digital transformation is the fundamental change process itself. Transformation should not be confused with any change, transition, innovation or process improvement. It is rather a change that structurally redefines existing or creates something completely new. "*While all transformation is change, not all change is transformation*." (Gong & Ribiere 2021, 9-12). In each industrial revolution, the society underwent a fundamental socio-economic change where new processes emerged and values were redefined. The difference between the previous revolutions and industry 4.0 is how fast so many dramatic changes co-occur, transforming entire systems. The merger of technologies and interaction across the physical, digital and biological domains is so radical that it demands an entirely new way of working or thinking. (Schwab 2016, 7-37).

The outcomes or the consequences of digital transformation can be divided into two: capability-driven and economic-driven outcomes. The capability-driven refers to processes and tools which require skills and knowledge. The non-tangible outcomes, such as innovative culture, high adaptability and competitive advantages, differentiate entities from others and create lasting, redefined value. On the other hand, economic-driven implies quantifiable outcomes, such as cost reduction, enhanced efficiency, and process automation. These add value by reinforcing the existing value of an entity. (Gong & Ribiere 2021, 11-12). The value impact of digital transformation leads to industry impact, allowing value migration and addition, and societal impact, adding to sustainable economic, societal and environmental development. Inhibitors, such as lack of collaboration, insufficient regulation, and uneven technology adoption, undermine digitalisation's opportunities. (WEF 2018, 28, 66).

The Oxford English Dictionary defines *transformation* as “the action of changing in form, shape, or appearance; metamorphosis” (OED 2021). In the case of digital transformation, an entity evolves through means allowing an expected outcome to occur, ultimately impacting the stakeholders by redefining or creating value (Gong & Ribiere 2021, 12). The World Economic Forum (WEF) estimates that the digital transformation of logistics may unlock value for industry and society worth 4 trillion USD. While digitalisation could disrupt logistics, it can also reduce inefficiencies and increase sustainability. Digitalisation has immense potential to reduce GHG emissions, generating significant environmental, societal and economic impacts. The ambition of digital transformation of logistics should hence be towards a more sustainable society. (WEF 2018, 56-57).

2.2.2 Digital technologies

Today, hi-tech sensors, WI-FI and cutting edge computing are incorporated into billions of objects used in our daily lives. IoT devices are already an integral part of our digital lives and are a key enabler for digitalisation. It is projected that by 2023 there will be 43 billion IoT devices. (Sestino et al. 2020, 1). Gubbi et al. (2013, 4) define IoT as the “Interconnection of sensing and actuating devices that provide the ability to share information across platforms through a unified framework, thereby developing a common operating picture for enabling innovative applications.” IoT devices have computing and communication capabilities that collectively gather data in real-time (Guo et al. 2013, 1). Collecting and analysing such vast amounts of data makes it possible to better understand and predict behaviours and outcomes (Lo & Campos, 2018, 12).

The increased capacity to collect data via IoT devices has led to big data analysis. IoT enables remote ship monitoring and predictive maintenance in the maritime industry where collected sensor data could improve vessels' maintenance and future design. The increased access to real-time vessel data leads to analytics that support vessel operations through increased data on potential vessel problems and predictions for future maintenance needs. Vessel problems are addressed before the fact rather than after the facts leading to improved asset lifespan and cost savings. IoT sensors on vessels and, in turn, data analytics can improve energy efficiency and environmental performance, safety verification, and the monitoring of accidents and environmental risks. (Wang et al. 2015, 3).

Big data differs from standard data in three main ways (Sagiroglu & Sinanc 2013, 42-43):

- high volume – quantity of data
- high variety – heterogeneity of the data, such as structured and unstructured data such as text, images, video and audio
- high velocity – the rate at which data is generated, and the speed at which it should be analysed

From 2018 to 2020, the amount of data created, captured, copied and consumed grew by 80 per cent reaching 59 zettabytes (ZB) – the equivalent of 59 trillion gigabytes. That is roughly 274 exabytes a date globally. (Vopson 2020). Through big data, businesses can create new organisational capabilities and value through optimising decision making and generating new insights (Davenport 2012, 22-24).

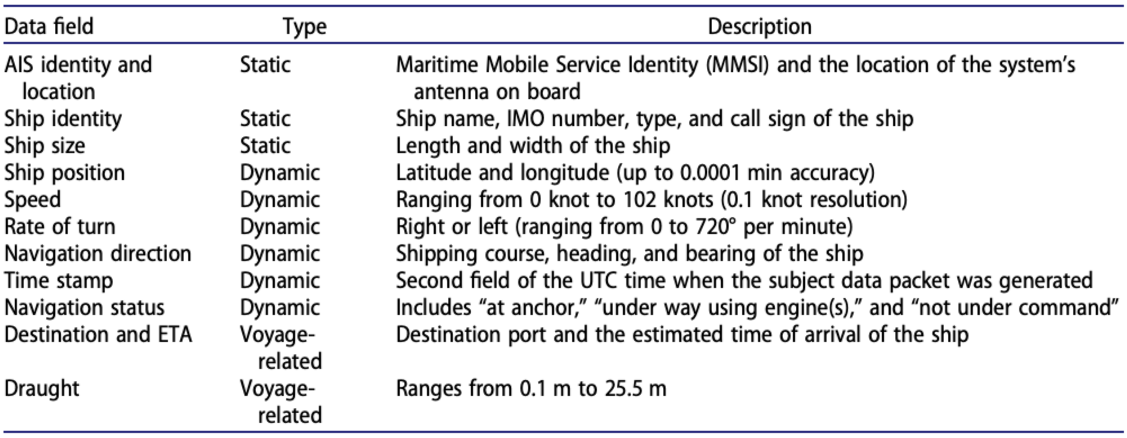
A vast amount of data is generated by vessel navigational systems such as radar, Electronic Chart Display and Information System (ECDIS), auto-pilot system, voyage data recorder (VDR), and other onboard IoT sensors. Navigation strategies can improve energy and fuel efficiency through big data analytics of the data generated by navigational and onboard systems. The dependencies and relationships of fuel consumption, vessel emissions, vessel direction, wind speed, average draft trim, and main engine power are measured and analysed, leading to cost reduction and improved efficiency. Safety is another important outcome and benefit of big data analytics in marine operations. Anomaly detection is possible through machine learning techniques from data gathered of vessel movements. (Mirović et al. 2018, 58-59).

In order to keep and process large amounts of data, it needs to be stored properly. Cloud computing enables network access on-demand to shared computing resources such as networks, software, servers and storage. Cloud users can scale their usage in real-time based on demand with minimal effort or service provider action without requiring to forecast usage or allocate hardware or software resources to cope with their needs. In other words, the cloud user can expand their IT infrastructure without investment in hardware, software and human resources. (Lele 2019, 169). Cloud computing has enabled businesses to increase performance, agility and data storage while lowering infrastructure and software costs, further enhancing collaboration capabilities within organisations (Aljabre 2012, 236).

The emergence of cloud computing has led to new services and value in the maritime industry. For example, KNL Networks is a company that provides secure and affordable solutions using IoT, cloud and platform services for digitalising vessel fleets for ship owners, who can get global access to their vessels' data. Vessel operational data is transmitted through integrating onboard vessel systems with IoT devices to the KNL cloud. Data processing and analysis enable predictive decision-making and could potentially lead to fuel consumption optimisation and emission control. (Rantanen et al. 2019, 11-12).

AI research started in the 1950s; however, it lost focus in 1990. The advent of IoT, big data, cloud computing, and increased computational power has led to AI’s resurgence. (Dornberger et al. 2018, 5-6). In 1956 the Dartmouth Summer Research Project on Artificial Intelligence was based on the conjecture that all aspects of the learning or any other aspect of intelligence can, in principle, be described so that a machine can be made to simulate it and, therefore, intelligent human behaviour could be formalised and reproduced in a machine (Dick 2019, 2). However, today AI is understood as more than just trying to replicate human behaviour. It is the science of creating intelligent machines, especially smart software. This is related to the use of computers to comprehend human intelligence. However, AI does not have to be limited to biological observable methods. (McCarthy 2007, 2).

A core foundation and enabling factor for AI is data. Voluminous amounts of data are generated in the maritime industry, such as voyage, navigational, and Automatic Identification System (AIS) data. AIS was initially developed as a safety measure to avoid ship collisions but was limited to terrestrial receivers. Due to satellites equipped with AIS receivers, it has grown to a global network. By law, the IMO requires all international ships greater than 300 GT and all passenger ships to be fitted with an AIS transmitter. Figure 5 displays the types of data transmitted via AIS.



Data field	Type	Description
AIS identity and location	Static	Maritime Mobile Service Identity (MMSI) and the location of the system’s antenna on board
Ship identity	Static	Ship name, IMO number, type, and call sign of the ship
Ship size	Static	Length and width of the ship
Ship position	Dynamic	Latitude and longitude (up to 0.0001 min accuracy)
Speed	Dynamic	Ranging from 0 knot to 102 knots (0.1 knot resolution)
Rate of turn	Dynamic	Right or left (ranging from 0 to 720° per minute)
Navigation direction	Dynamic	Shipping course, heading, and bearing of the ship
Time stamp	Dynamic	Second field of the UTC time when the subject data packet was generated
Navigation status	Dynamic	Includes “at anchor,” “under way using engine(s),” and “not under command”
Destination and ETA	Voyage-related	Destination port and the estimated time of arrival of the ship
Draught	Voyage-related	Ranges from 0.1 m to 25.5 m

Figure 5: Data transmitted via AIS (Yang et al. 2019, 4)

Some AIS data is transmitted every 10 seconds and can equate to approximately 13 billion records for 5000 ships in one year. The volume of data enables maritime data analytics leading to added value such as "AIS data mining, navigation safety, ship behaviour analysis, environmental evaluation, trade analysis, ship and port performance, and Arctic shipping surveillance." (Yang et al. 2019, 1-5).

Blockchain is a decentralised, distributed database or public ledger of digital transaction records. (Crosby et al. 2016, 8). Created in 2008, it served as the technological foundation for Bitcoin, a cryptocurrency that enabled direct transactions without the need for intermediaries in financial transactions but has since evolved to be applicable and valuable for various uses and industries (Czachorowski et al. 2019, 562-563). For example, blockchain technology can be used for smart contracts, public services, IoT and security services. The key characteristics of blockchain that makes it valuable are (Zheng et al. 2018, 354, 357).:

- decentralisation - the transactions do not need to be validated through a central agency
- persistency - due to transactions being distributed in the entire network, it is nearly impossible to change or falsify
- anonymity - it would be possible to transact without identification
- audibility - all transactions can be audited

In the maritime industry, blockchain is useful in easing the documentation and administrative burden, origin issues, and supporting communication and automation. The Bill of Lading (BoL), a contract of carriage and an essential ownership document in shipping, could be digitised through blockchain, providing an unchangeable chain accessible by all stakeholders in the supply chain within 10 minutes of its creation.

According to maritime law, the consignee must produce the original BoL in order to receive the goods delivered to them. The absence of the BoL before cargo has arrived at the delivery destination could lead to significant delays and losses. The BoL fraud is another factor leading to large losses in international trade. (Czachorowski et al. 2019, 572). Blockchain could mitigate such issues. TradeLens platform, developed by the International Business Machines Corporation (IBM), is the first major blockchain platform in the shipping industry. The core objective of the open and neutral industry-wide platform is digitising the global supply chain by connecting the ecosystem of supply chain actors, enabling collaboration and trust and driving information sharing while reducing paper documents. (Boelsmand & de Voss 2020, 52).

2.3 Sustainability and digitalisation in the maritime industry

Port of call or port call is the intermediate stopover where a ship halts for cargo operations, refuels, resupplies and embarks or disembarks passengers. A vessel needs to call in advance to inform the port about its arrival, which starts a complex process involving a substantial number of actors. Figure 6 illustrates the core events and engaged actors in the port call operations. In addition, processes such as bunkering, maintenance, repair and customs may further entangle the synchronization. (UNCTAD 2020a, 11).

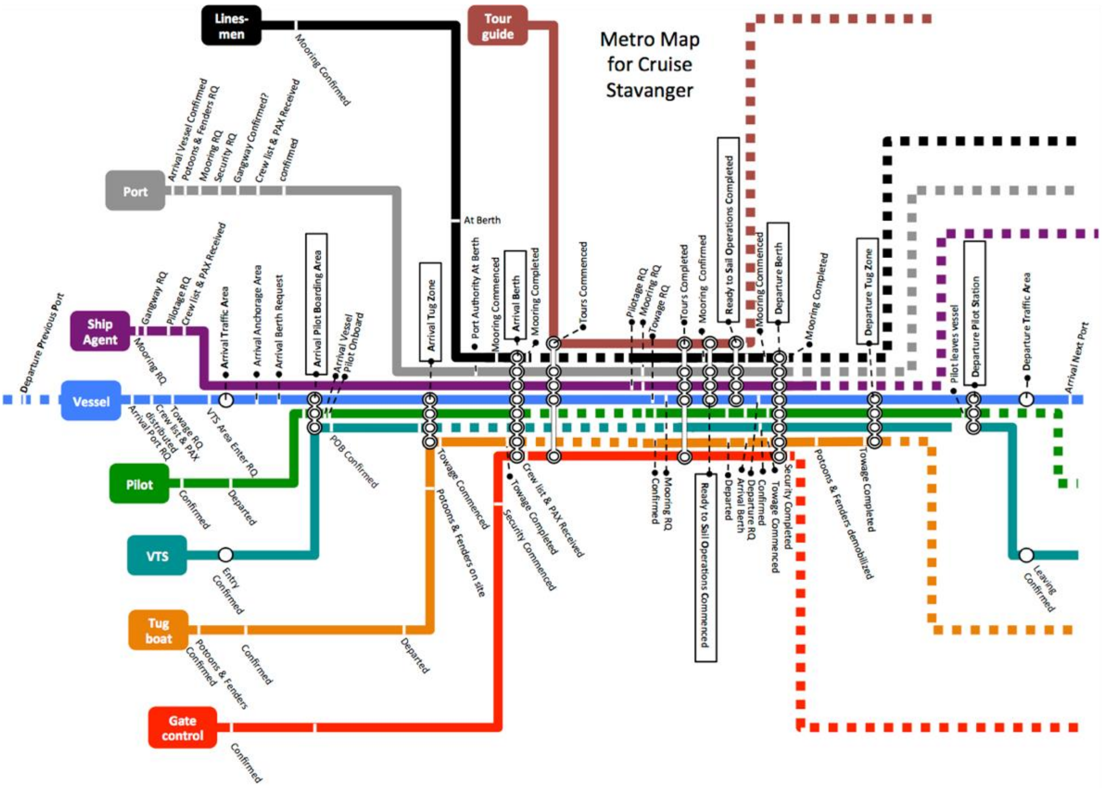


Figure 6: Port Collaborative Decision Making (PortCDM) metro map (Lind et al. 2018)

> *Upon reaching the coastal area, the maritime authority is involved; to enter the port, the port authority needs to give its approval; often there are pilots and tug operators and other supporting nautical services required to bring the ship from the port area to berth; mooring personnel make fast the ship to the berth; terminal operators and stevedores are engaged in loading and unloading; other providers deal with such things as waste and security; and agents are there to ensure that everything goes*

> *according to plan. And the same group of organizations are needed to get the ship ready to depart from berth, leaving the port area, and back to the open sea.(UNCTAD 2020a, 10-11).*

Vessels operate on either a voyage or a time charter basis. In a voyage charter, the charter pays a fixed price for a fixed voyage, while the ship operator carries the risks and expenses for delays or diversions. Whereas time charter is a lease for a certain period, and the charterer carries the risks. The charter parties are incentivised to get from point A to point B as quick as possible. Some ports have limited anchorage space, and together with vessels being served on a first-come-first-served basis at ports, this leads to a *hurry up and wait* situation. The multiplex system, sequenced dependency and siloed data sharing decreases efficiency, visibility and flexibility – leading to long waiting times. (UNCTAD 2020a, 12-14). The average waiting time of a ship to get into port is 5 to 10 per cent of the entire voyage time. During this time, a vessel is either at anchorage or manoeuvring outside the port using its auxiliary engines and boilers, creating emissions. (GEF et al. 2020, 4).

A study conducted by the IMO estimated that the GHG emissions of total shipping in 2018 were 1,076 million tonnes. From that, 1,056 million tonnes were CO2 emissions alone. (IMO 2021a, 1). The IMO agreed to reduce CO2 emissions by at least 40 per cent by 2030 and the total annual GHG emissions by at least 50 per cent by 2050 compared to the 2008 baseline. Achieving these goals will require radical changes to the engine and fuel. (UNCTAD 2020b, 56, 95). Several studies are tackling the issue of emission reduction. For example, real-time data analytics could reduce fuel consumption by 2 to 5 per cent, lowering emissions (Keefe 2014). Better weather routing could result in 1 to 4 per cent CO2 and fuel use reduction. While the most significant fuel and CO2 reduction potential is in reducing vessel speed, up to 10 to 30 per cent. (Wang & Lutsey 2013, 6-18). The concept of JIT arrival enables a voyage optimisation where while the overall length of a voyage does not shorten, the slower steam speed decreases fuel consumption and minimises congestion and waiting time at ports, in both cases reducing the emissions. (GEF et al. 2020, 4-5).

To enable JIT, there are both legal and operational considerations. In 2021, the Baltic and International Marine Council (BIMCO) published a new JIT Arrival Clause for Voyage Charter Parties which tackles the critical aspect permitting JIT; “the obligation on shipowners to proceed with due or utmost despatch and without deviation”. (Hunter

2021a). By removing this obstacle, ships can optimise their speed without breaching voyage charter obligations (Hunter 2021a). As a complement, BIMCO's Port Call Data Exchange Clause 2021, using the IMO's data model framework, promotes a common platform and format for data sharing (Hunter 2021b).

From an operational point of view, the digital concept of Port Collaborative Decision Making (PortCDM) and the unified port call message format S-211, enables data sharing with harmonised messaging format across all actors and a system of records for better situational awareness and decision making. PortCDM is built around four collaboration levels (Lind et al. 2018):

- within the port
- among ship operators and ports
- among different ports actors and / hinterland operators
- between the departing and arriving port

Similarly, nine of the world's leading shipping companies founded the Digital Container Shipping Association (DCSA) to create digital data standards to promote the adoption of interoperable digital solutions. The JIT Port Call programme aims to improve communication between maritime actors, increase operational efficiency, optimise vessel speed, avoid excessive fuel use, enhance schedule reliability, and thereby decrease GHG emissions and lengthy waiting time at anchorage. (DCSA 2021).

Several scholars agree that digitalisation provides the right tools for the needed collaboration and data sharing among maritime actors (Heilig et al. 2017; Lind et al. 2018; Rantanen et al. 2019; GEF et al. 2020; UNCTAD 2020a). Thence digitalisation plays also a crucial role in the maritime industry's sustainability efforts. The sustainability initiatives, such as SDG, WPSP and IMO GHG strategy, which promote low-carbon and zero-carbon shipping and GHG reduction, could significantly benefit from digitalisation in the short term while looking for greener alternatives. (WPSP 2020). Furthermore, using digital technologies, such as AI for predicting cargo flows, IoT for system error monitoring and blockchain to digitise document flow, foster resilience and robustness, and produce economic efficiency and safety gains. (Rantanen et al. 2019, 4-11, 35).

2.4 Synthesis of the theory section

The theoretical framework of this study is divided into three parts. The first part elucidates the concept of sustainability and further introduces the three dimensions of sustainable development: economic, social and environmental. The second part examines digitalisation, the use of digital technologies towards digital transformation. The third part explores the maritime industry, particularly the port operations, and introduces the links into the two parts mentioned above. In the synthesis of the theory section, these three parts are further combined, as together they form the basis for the empirical research.

"Sustainability is about meeting our own needs without compromising the ability of future generations to meet their needs." (Brundtland 1987, 37). The previous literature about sustainable development highlights three intersecting notions. Firstly, sustainable economic development should incorporate the traditional economic growth goals with social values and preserving our natural ecosystem. Secondly, social sustainability is about the welfare of the society – meeting the basic needs. Societies should operate by a new environmental paradigm that is more balanced, emphasising immaterial things, and compassionate, recognising the common good enabling a sustainable society. Thirdly, humans should link the well-being of their own lives to the well-being of other species and nature itself. This way, economic development is limited within the sphere of social welfare and quality of life, which is constrained by the environmental limits within the biosphere – what is good for the environment is fundamentally good for humans. The three dimensions of sustainability form the impact towards what we should strive for.

The maritime industry is one of the biggest facilitators of the international trade and transportation industry. Of global trade, over 80 per cent by volume, corresponding to over 70 per cent when measured in value, are carried by sea and handled by ports worldwide. In 2019, a total of 11.08 billion tons of cargo was shipped internationally. (UNCTAD 2020, 1-37). The increasing volumes in global maritime trade are associated with increasing stresses and adverse effects on the environment. The IMO estimated that the GHG emissions of total shipping in 2018 were 1,076 million tonnes. To comply with the UN 2030 SDGs, the maritime industry has implemented several sustainability targets. The IMO agreed to reduce CO2 emissions by at least 40 per cent by 2030 and the total annual GHG emissions by at least 50 per cent by 2050 compared to the 2008 baseline. WPSP focuses particularly on ports as they are the intermediary point between the sea and the hinterland operations. Ports also impact the local communities the most, employing millions of people and expanding closer to cities.

The sustainability initiatives promote low-carbon and zero-carbon shipping and GHG reduction. While the aim is to find alternative, greener fuels, in practical terms, it will take considerable time and effort for the entire industry to adhere. To bridge the gap in the short term and to capitalise on the current fourth industrial revolution, the maritime industry could benefit from using digitalisation as the means for sustainability. Optimising the port call operations will improve communication between maritime actors and allow data sharing and hence improve decision-making and increase operational efficiency. This, in turn, will lead to enhanced schedule reliability, optimised vessel speed and decreased fuel use and emissions. Therefore, to understand how digitalisation can improve the sustainability of the maritime industry, empirical research is conducted using data analysis of port calls to understand the potential impact JIT arrival has on CO2 emissions.

3 RESEARCH DESIGN

This study aimed to employ a mixed research approach using qualitative and quantitative techniques to address the research problems. The mixed research design was considered because the research problem is unlikely to be adequately addressed using only one method as it requires knowledge of three themes – sustainability, digitalisation and maritime – of which one is not yet fully understood. A new phenomenon, digitalisation, would have traditionally been addressed through a qualitative design. However, previous studies have led to further ambiguities in the topic (a failure) due to *hype* – a human-driven even. After assessing the utility of qualitative methods, it was decided only to use a quantitative method to measure the potential impact of digitalising on shipping emissions.

Maritime can be measured, and sustainability, albeit not universal, can also be measured. Quantifying the causal relationship between the two has well defined secondary data methods to do so. These methods and documented results still contain an estimation error of 20 to 50 per cent (Entec 2010) and therefore have not yet been perfected. Studies covering these themes did not cover them entirely. In many of them, it was not possible due to limited access to funding, limited access to data and lack of computing power. Digitalisation at this very moment cannot be measured, but exploring what effects *represent* digital and its impact on maritime sustainability could provide inside for industry leaders and policymakers.

3.1 Research setting and approach

Sustainability as a research topic continues to grow in popularity amongst researchers and as policymakers and governmental organisations are continually developing standards for industries to maintain, adapt, adjust or adhere to. Meeting the SDGs requires a reduction in negative environmental, social and economic impacts and, similarly, an improvement in the way industries operate on a global platform. The IMO recently released a voluminous fourth GHG study to the public with the aim to provide further scientific reference to decarbonise the shipping industry as the industry is rife with challenges (IMO 2021a).

Although large organisations contribute to the research topic, most of the attention is focused on air pollution. Nevertheless, as new regulations are continually adopted, sustainability is characterised by three dimensions and the following objectives (Asgari et al. 2015):

- the economy – minimising economic costs
- the society – enhancing the quality of living
- the environment – mitigating adverse environmental impacts

Research covering methods to quantify the environmental impacts caused by the maritime industry has been fairly well documented, but the scope remains narrow within a few thematic areas (Jägerbrand et al. 2019, 2). With no summary of the overall environmental impacts presented, Ytreberg et al. (2021) have provided a holistic framework that can be used to develop more coherent and holistic socio-economic assessments.

An emerging topic of interest that has sparked the curiosity of researchers, *digitalisation* or *digital transformation*, has not yet been clearly contextualised or defined, resulting in difficulty for executives to approach the topic, according to Gong and Ribiere (2021), who employed systematic content analysis of 134 literature sources. Digital technology implementation or adoption has been observed in the maritime industry. Fifteen container lines have started collaborating using the blockchain technology platform, TradeLens. Four of these carriers account for over 50 per cent of the maritime market. (Hvolby et al. 2021, 727-728).

The maritime industry is notoriously known for its opaque information sharing business practices owing to redundancies throughout the supply chain. Nevertheless, this sets the tone for the future of digital optimisation, which addresses the maritime industry's inefficiencies with the implementation of JIT arrival, which could result in slower engine speeds and shorter time spent at the port. (Rantanen et al. 2019, 21-22, 27-34). That could likely address the economic needs to allow for industry-wide adoption whilst simultaneously resulting in inefficiencies which should, over the long-term, improve sustainability. (Kiel et al. 2017, 5).

To start, it was necessary to determine the characteristics of a suitable sustainability indicator (Feil et al. 2019, 4). These are illustrated in Table 1:

Table 1: Characteristics of sustainability indicators (Feil et al. 2019, 4)

Essential Characteristics	This Study
the calculation and monitoring period	✓
the limit, i.e., the level of coverage	✓
the unit of measurement	✓
the type of measurement	✓
the unique alphanumeric identification of the indicator	✓
its name, containing its distinctive designation	✓

the definition of essential characteristics and their function	✓
based and referenced on theoretical or pre-developed basis with technical and scientific adequacy	✓

From the above, it is shown that the indicators selected met every criteria. To further predict whether the selected research design is appropriate, the desired qualities shown In Table 2 were reviewed and met.

Table 2: Desired qualities of sustainability measurements (Feil et al. 2019, 4)

Desired Qualities	**This Study**
based on reliable, valid, available, accurate, and accessible information	✓
technically measurable, reproducible, low cost, and easy to apply and evaluate	✓
elaborated, identified, and selected through an open process	✓
simple and significant and an understandable set of indicators with a top-down and bottom-up approach	✓
qualitative and quantitative metrics	✓
usable in time comparisons	✓

This study focuses on the sustainability impacts in the global maritime industry, specifically environmental impacts as measured by emissions resulting from vessel port calls. The analysis of impacts is on a disaggregated basis to the country-level. It follows a secondary data analysis utilising a bottom-up methodology to calculate emission estimations and fuel consumption.

It was identified in the literature that the two main methods used to determine the amount of ship emissions are: top-down methodology or fuel-based approach and bottom-up methodology or activity-based approach (Lee et al., 2020, 3). Miola and Ciuffo (201, 2243) further classified the methodologies into four approaches:

1. Full top-down approach
2. Bottom-up approach in the evaluation of total emissions and top-down in their geographic characterisation,
3. Top-down approach in the evaluation of total emissions and bottom-up in the geographic characterisation and
4. Full bottom-up approach.

This study can be classified as the second approach as listed above because it considers emissions of a single vessel over six months, after which it aggregates the emissions produced by all ships giving total emissions. The total emissions are then geographically characterised based on the ship activities. The top-down methodology uses data on the amount and type of marine fuel sales or fuel consumption and fuel-related emission factors to calculate emissions inventories on the global and national levels. Bottom-up methodologies use information about ship specifications (e.g. type of engine, size of the engine, type of fuel used) and activity (e.g. time spent in port, distance travelled) to calculate the amount of emissions. (Lee et al., 2020, 3).

The following limitations were made:

- Geographic Scope: Covers all 254 countries on a country-level basis. The study only covered the ship operation *at port*.
- Activity Phase: Only *manoeuvring* and *hotelling* phases were covered due to a lack of reliable data and difficulty estimating *at sea* emissions.
- Fleet Classification: The study only included ships with a GT of >1000 tonnes and furthermore restricted to the commercial fleet.

3.2 Data collection

In line with the theme of this study, *digitalisation*, taking advantage of digitalisation, provides researchers with a practical means to collect and evaluate data (Johnston 2013, 619). Accessing vast amounts of information collected by researchers or other external institutions is now possible and is considered the most practical approach to address the research problem. Although the acceptance of secondary data analysis research has been met with opposition and scepticism, it is now becoming a highly effective means of evaluating large volumes of research work. (Johnston 2013, 619-620).

This study follows a secondary data collection method, which was the preferred option for quantifying impact categories given the global scale of the study and the vast and detailed information associated with maritime data. Secondary data is described as “data originally collected for a different purpose and reused for another research question”. (Boeije & Hox 2005, 593). This study used data from the United Nations Conference on Trade and Development statistics (UNCTADstat), a free-to-use dissemination platform, which houses a collection of economic data with a key theme being trade. While AIS data would have been more accurate, it would have required much more computing capacity and finances. Additionally, access to primary data would have been limited due to the significant resources. In this instance, primary data would require analysis of actual emissions captured on vessels requiring a physical presence.

Maritime data is fairly vast, which includes country-level data covering categories such as trade flows, ocean-going merchant fleet origin, port performance and other transport modes such as road. The data for engine and fuel characteristics was sourced from Trozzi (2010), Entec (2002), Entec (2007) and IMO (2021a). The latter also provided the data for emission factors. Figure 7 illustrates the origin of the secondary data.

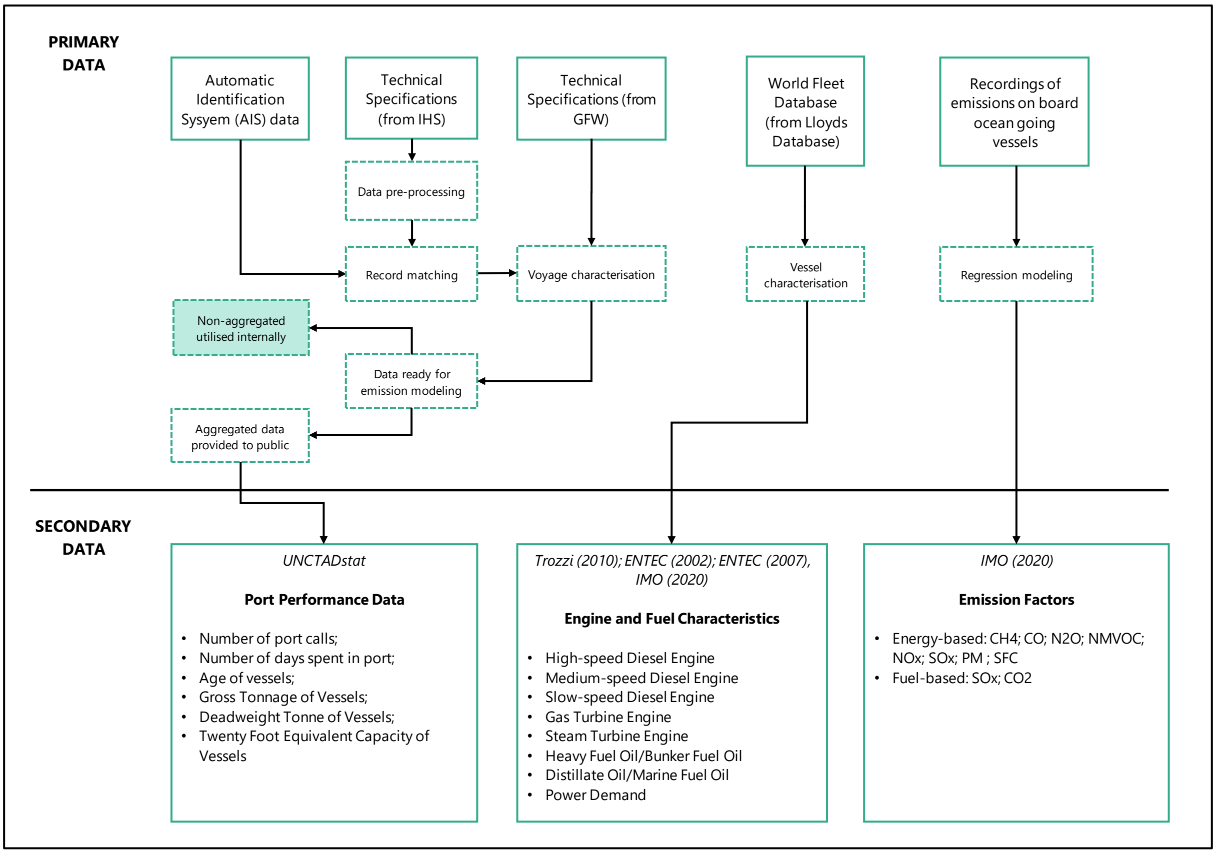


Figure 7: Data origin of the study

The secondary research method employed a data acquisition philosophy that met the required and desired data characteristics previously discussed. In order to conceptualise the research problem, the concept of connectivity became an important theme to synthesise the relationship between two idea’s (Joham et al. 2009, 788-799).

Two themes, *digital* and *sustainable*, both face challenges amongst researchers to accurately measure and define them in a manner that would cause industry or worldwide adoption. A systematic review shows that both face difficulties in integration and collaboration and could benefit from transparency and common indicators. (Tijan et al. 2021, 4-6, 9; Feil et al. 2019, 5, 9-12). The connection between the challenges in both themes warranted further investigation into how sustainability is measured.

3.3 Research method and data analysis

In order to quantify sustainability from the port call process in the context of digitalisation, it was necessary to address the main impacts in the maritime industry. The major impacts are air pollutants, social impacts from air pollutants and economic impacts from shipping.

The secondary data utilised in this study can be grouped into three major groups:

- Activity data (port performance data)
- Engine and fuel characteristics
- Emission factors

3.3.1 Activity data (port performance data)

Once the port performance data was collected, the data was then analysed to check for inconsistencies, double entries and other errors that could result in errors in the final results. Double entries were found in the data, leading to an overestimation of port calls and time spent in port, leading to an overestimation in emissions. An example of this is that certain countries, such as the United States of America, is accounted for thrice due to three characterisations, namely, “United States of America” and “United States of America excluding the Channel Islands” and “United States of America Excluding Puerto Rico and United States Virgin Islands”. These entries were then coded on an *ISO3166-1 (2015)* classification basis.

The format of the raw port performance data arrived in a wide data format, and it was decided to transform the data into a narrow data format, thereby reducing the number of columns and increasing the number of rows. The data also arrived in two separate spreadsheets and therefore had to be consolidated. This produced three spreadsheets with the following number of entries:

- Spreadsheet 1 (SS1): 8 columns x 1,728 rows = 13,824 entries
- Spreadsheet 2 (SS2): 51 columns x 1,728 rows = 88,128 entries
- Spreadsheet 3 (SS3): 12 columns by 10,315 rows = 123,780 entries (excludes helper columns)

Further processing of the data was to characterise the countries by ISO3166-1 (2015) standards into *alpha-2 country code element*, *alpha-3 country code element*, and *num-3 country code element*. The data was further classified in terms of groups of economies based on the M49 standard of the United Nations Statistics Division (UNSD). This led to characterising the data into five main regions, Africa, America, Asia, Europe and Oceania, and then further into sub-regions such as Western Europe, Eastern Europe, etc.

3.3.2 Engine and Fuel Characteristics

The first dataset (i.e. port performance data) did not contain technical information about the vessels at the arrival ports. The vessel data, therefore, was estimated based on technical information on the EEA Technical Report (2019) methodologies and recommendations from Trozzi (2010) and IMO (2021a), and findings from Entec (2002), Entec (2007) to extrapolate:

- Installed power of the main engine (ME) and auxiliary engine (AE)
- Load factors (engine load factor is defined as the engine's actual power output relative to its maximum continuous rating (MCR)) of both ME and AE during different vessel operations
- Engine types per fuel type for vessel arrivals

The installed power of the vessels was estimated utilising a non-linear regression equation developed on the 1997 World Fleet Database and 2010 World Fleet database, shown in Table 3, for what the following equation was used:

$$y = b0\ (x)\ b1$$

Where

x = GT of vessels in the activity data

b0 = equation constant which is based on vessel type and year of vessel construction

b1 = equation coefficient based on vessel type and year of vessel construction

Table 3: Equation used to estimate installed engine power of vessels (Adapted from Trozzi 2010)

Non-linear regression equation inputs	variable	Fleet Age	Liquid Bulk	LPG	LNG	Dry bulk	Dry Break-bulk	Ro-ro	Container	Passenger
Installed Main Engine Power (kW)	b_0	2010	14.76	14.76	14.76	35.91	5.56	164.58	2.92	9.55
		1997	29.82	29.82	29.82	89.57	10.54	35.93	1.33	1.39
	b_1	2010	0.61	0.61	0.61	0.53	0.74	0.44	0.87	0.76
		1997	0.56	0.56	0.56	0.44	0.68	0.59	0.93	0.92

Fleet age was determined based on the data entry year less average age of vessels in the specified arrival data. Figure 8 illustrates the ME power estimated for between the period 2018 to 2020:

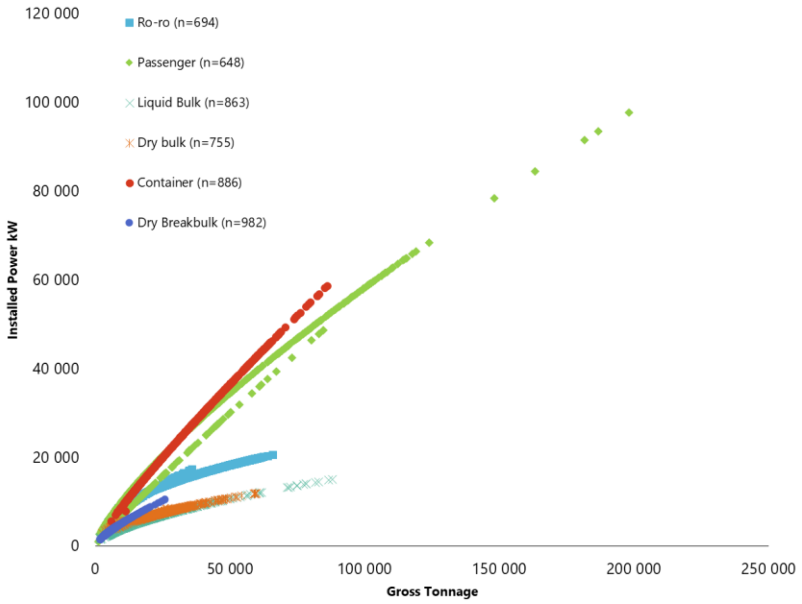


Figure 8: Main engine power

Once the installed power was calculated, the auxiliary engine was calculated based on the ratio of AE to ME power based on relationships studied between vessels (Trozzi, 2010). The ratio for the vessels in the scope of this range was from 0.20 to 0.30. The auxiliary boiler engine (AB) was calculated based on the ME fuel consumption over the study period, to be discussed in the findings section.

The different operating modes also had to be accounted for. A calculation was made for the power that a vessel used during its port operations. (Trozzi, 2010). The energy spent during port activities was calculated using known load factors based on observed historical fleet data. The key assumptions that drive the emission factors used are the vessel's engine and fuel specifications. This was done using representative engine, and fuel types of vessels in the port calls (EEA Technical Report 2019, 14).

3.3.3 Emission factors

Once the vessel engine categories were defined in the dataset, the respective emission factors could be applied to the algorithm in the model. Calculations of specific fuel consumption (SFC) required knowledge of the age of the vessels' engine and was characterised based on the age classification methodology by IMO (2021a, 50):

- Generation 1: Any engine built before 1984
- Generation 2: Any engine built between 1984 and 2000
- Generation 3: Any engine built after 2000

Therefore, the age of the vessel was factored into the algorithm before calculating SFC.

This study followed a hybrid approach utilising both a bottom-up (energy-based) and top-down emission (fuel-based) methodology. The formula used to calculate the quantity of the emissions (Ei) is as follows (Bacalja et al., 2020, 7):

$$Ei = [(PME \times LFME \times TOME \times EFME) + (PAE \times LFAE \times EFAE)] \times TPA$$

Where,

PME = Main Engine Installed Power (in kW)

PAE = Auxiliary Engine Installed Power (in kW)

LFME = Load Factor of Main Engine (in %)

TOME = Time of Main Operating (in %)

LFAE = Load Factor of Auxiliary Engine (in %)

EFME = Emission Factor for Main Engine (in g/kW)

EFAE = Emission Factor for Auxiliary Engine (in g/kW)

TPA = Time Spent during Port Activity (in hours)

To summarise the data analysis, Table 4 provides an apprehensible compilation of the steps, objectives, how they were approached and the corresponding variable in the above-mentioned formula. The full detailed list of the emission factors applied can be found in the Appendices.

Table 4: Emission data analysis

Steps	Objective	How?	Variable
1	Estimate engine capacity	Non-linear regression based on historical fleet data	PME
2	Estimate auxiliary engine capacity	Known ratio's between main and auxiliary engine	PAE
3	Estimate load percentage used during port call	Known load factors based on historical fleet data	LFME, LFAE, TOME
4	Determine time spent during vessel operation modes	Using average time spent manoeuvring and hoteling at port	TPA
5	Select emission factors to determine amount of pollutants emitted	Using known engine and fuel types of vessels in the port calls	EFME, EFAE
6	Calculate total amount of pollutants per port call	Use given time spent at port and multiply the power used in Step 4 for each iteration	E=[(PME x LFME x TOME x EFME) + (PAE x LFAE x EFAE)] x TPA

3.4 Evaluation of the research quality

This subchapter will focus on the trustworthiness and ethics of the study by using Lincoln and Guba (1985) criteria, where trustworthiness can be assessed through four categories: credibility, transferability, dependability and conformability or internal and external validity, reliability and objectivity, depending on whether it is applied to the qualitative (former) or quantitative method (later).

Credibility refers to the *internal validity*, how well the findings correspond to reality. This can be achieved through a prolonged period of engagement, persistent observation and triangulation. (Lincoln & Guba 1985, 296-307). The researcher's familiarity with the topic, gathering of sufficient data, and ability to use multiple perspectives to overcome biases all improve the credibility of the research. (Eriksson & Kovalainen 2008, 294). In this study, prolonged period engagement was fulfilled by the researcher familiarising herself in-depth with the studied phenomenon for over a year. Overall, 100 000 data points were processed. This amount and variety of analysed data constitute persistent observation. To achieve triangulation, the researcher used different sources of data and more than one theory, sustainability and digital transformation theory.

Transferability refers to the *external validity*, how well can the findings be generalised in similar settings. For this, the researcher is required to show a connection between their findings and previous studies. They should also provide a detailed description of the research context and underlying assumptions, enabling the reader to transfer the study across different types of persons, settings, and times and make their own transferability judgments. (Lincoln & Guba 1985, 290-291, 316; Eriksson & Kovalainen 2008, 294). In this study, the research setting, approach and method are thoroughly described. The findings showed similar results to previous research and literature, further supporting the transferability of this study. It was found that all scenarios supported the previous findings of port optimisation having a positive effect on sustainable development.

Dependability refers to the *reliability*, how well the research process is documented (Lincoln & Guba 1985, 300). This is concerned with logic, traceability and how each step of the research process is conducted (Eriksson & Kovalainen 2008, 294). Reliability has been used synonymously with rigour – being accurate, confirmable and transparent during the research process. One way to ensure rigour is to use both qualitative and quantitative methods in a single study (Andrew & Halcomb 2009, 121). To strengthen the dependability, the research process was described as clearly as possible to allow the reader to follow the line of thought and the interpretations of the researcher. The data used in the analysis has been systematically and unambiguously coded. The terms used throughout the study have been selected for their prevalence in the field.

Confirmability refers to the *objectivity*, how intersubjective and neutral is the study from the researcher's personal constructions. (Lincoln & Guba 1985, 300, 324). Therefore, findings and interpretations of the study should be strictly linked to the data collected in ways that are easily understood and replicated by others. (Eriksson & Kovalainen 2008, 294). As this study used freely available data without anonymising it, others can easily replicate the findings. The data analysis process is described in detail, and the links between data and interpretations have been illustrated in figures and tables, which improve the comprehensibility of the narrative.

In addition to evaluating the trustworthiness of the study, it is important to discuss the moral philosophy. Research ethics cover the entire research process, how it is conducted and reported. The researcher should consider not only the data collection process but also quoting other authors and writing and publishing the report. (Eriksson & Kovalainen 2008, 64-77). This study used unrestricted data from freely available databases. Therefore, there were no major concerns to anonymise or keep the data confidential. Still, the data was stored and analysed with integrity and objectively, not to bring harm to any subject. Fellow researchers and their work have been respected by proper referencing of the intellectual origins. To avoid plagiarism, the originality of this study has been checked, and citations have been used to clearly distinguish authorship.

4 FINDINGS AND DISCUSSION

This chapter presents the findings of the study divided into two subchapters: 4.1. secondary data results, which shows the findings of secondary data processed, and 4.2. future scenarios, which shows possible scenarios if digitalisation and JIT are implemented. Subchapter 4.3. concludes with a summary of the main findings.

4.1 Secondary data results

Table 5 illustrates the descriptive statistics for the processed port performance data over the study period 2018 to 2020.

Table 5: Descriptive statistics of the processed data

	Port Calls	Time in Port	Age of Vessel	GT a	GT b	DWT a	DWT b	TEU a	TEU b
Unit	#	days	years	kt	kt	kt	kt	#	#
Mean	2 229	1.76	15.6	26	77	26	88	2 704	9 127
Min	3	0.02	3.0	1	2	2	3	286	515
IQR1	72	0.90	11.0	9	33	9	31	1 444	2 690
Median	206	1.27	14.0	19	60	17	57	2 326	5 762
IQR3	824	2.08	18.0	33	108	38	105	3 753	14 500
Max	285 175	17.90	49.0	198	237	166	442	7 813	23 964
Std Dev	11 186	1.53	6.5	25	57	24	84	1 513	7 333
Obs.	5 556	4 214	5 556	5 556	5 556	4 022	4 022	886	886

The time in *port data* is positively skewed, with the mean larger than the median. Meaning a larger proportion of vessels spend less time in port than the average of time spent. The number of *port calls* per country shows a much larger average over its median, illustrating the effect of many smaller ports in the dataset, with larger ports representing the majority of the shipping activity.

A box-and-whisker plot was compiled for each vessel category and is shown in Figure 9. The *Time at berth (in days)* figure shows that the vessels spend between 1 and 2 days at the port with outliers on the longer end. There was no time in the data for Ro-ro and passenger vessels. However, estimations were made. The data for time spent at port shows that LPG, LNG, liquid bulk and container vessels spend, on average, less than two days at port, while dry bulk and dry breakbulk vessels have on average a wider distribution for time spent at the port with total time spent ranging from 1 day to 2 days. In addition, the whiskers indicate some outliers in the data, with maximum time spent at port for each vessel category ranging from 8 days to 14 days. The very narrow box for LNG indicates that the data is concentrated at one day; this could illustrate that LNG vessels do not have much time spent at the port.

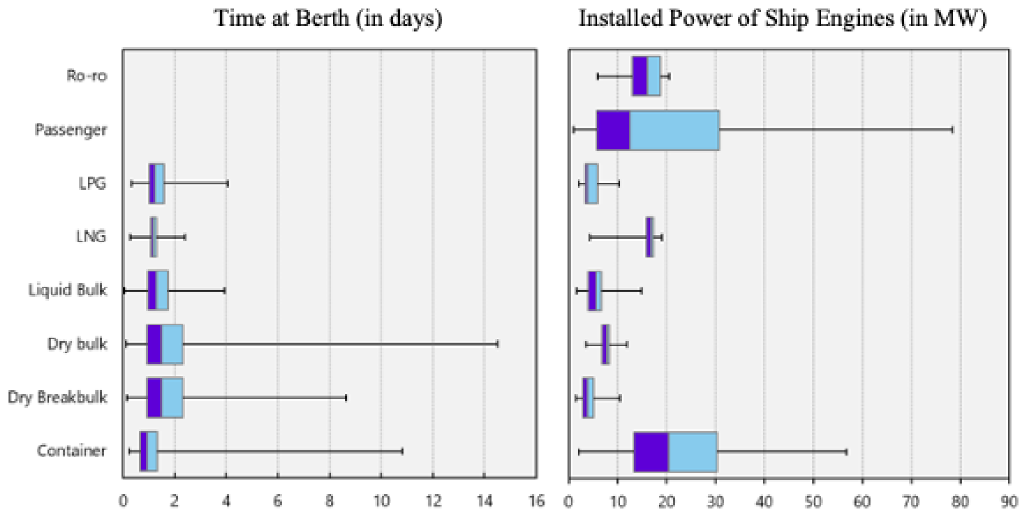


Figure 9: Box and whisker plot of time at port and installed power

The *Installed Power of Ship Engines* (main engine power + auxiliary engine power (in MW-hours = 1000 kW-hours) shows that Ro-ro vessels generally have between 10 to 20 MW with less common observations having <10 MW. The wide box representing passenger vessels shows the interquartile range is between 5 and 30 MW, with 50 per cent of the observed vessels having a power range of between 12 and 30 MW with a small number of very large powered vessels, up to the 80MW power rating. Most LPG and liquid bulk vessels had installed power of less than 5 MW, while LNG power data was concentrated around the 20 MW mark. Container vessels had power concentrated between 15 and 30 MW with a range extending to almost 60MW. That would mean the 20 foot carrying capacity for the 15 to 30 MW is 1000 to 5000 TEU's.

Figure 10 displays the total amount of CO2 emissions for the years 2019 and 2020 ranked for the top 30 emitting countries. For the majority of the countries, the tonnes of CO2 emitted from vessels was lower for the year 2020 against the previous year or nearly similar except for China. This could likely result from the slowdown due to the COVID-19 pandemic (Millefiori et al. 2021, 5, 10).

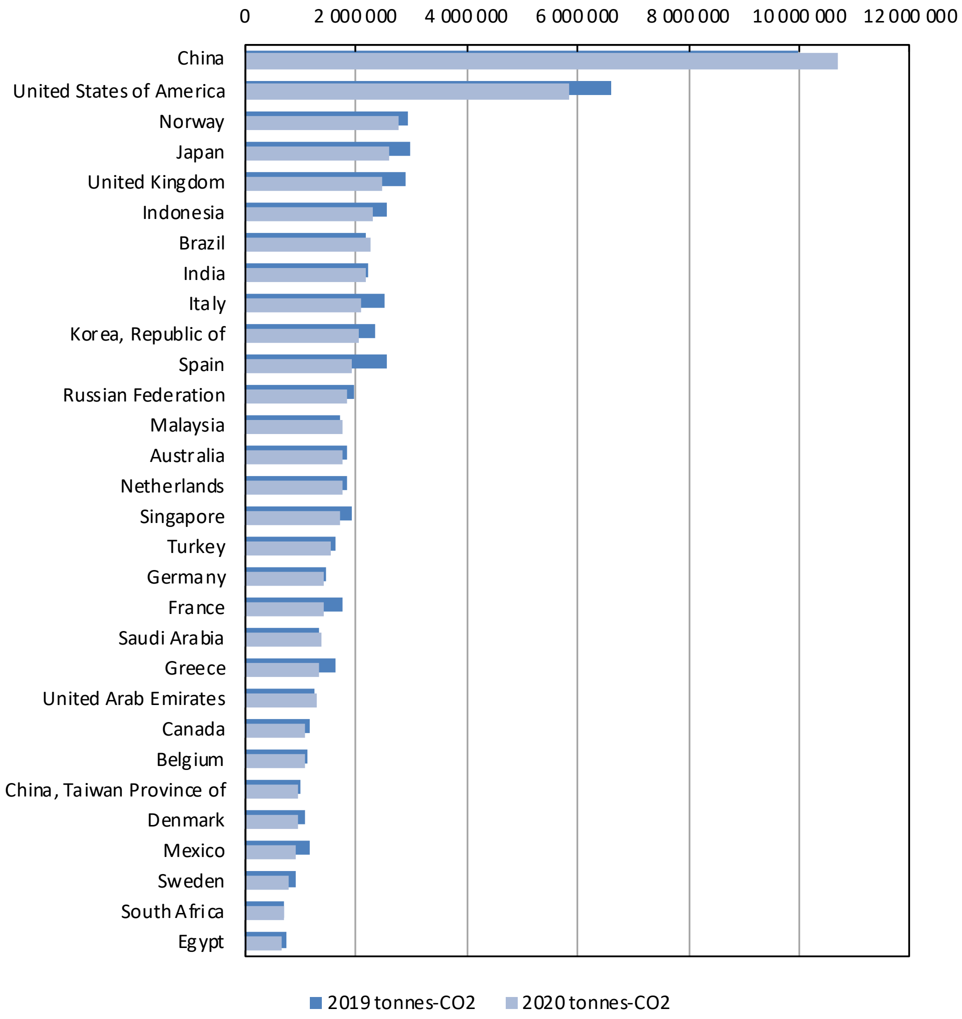


Figure 10: CO2 emissions for the Top 30 countries based on port activity

Figure 11 illustrates the amount of emissions of CO2 and SOx calculated as well as the fuel consumption of each vessel for global port calls in 2020.

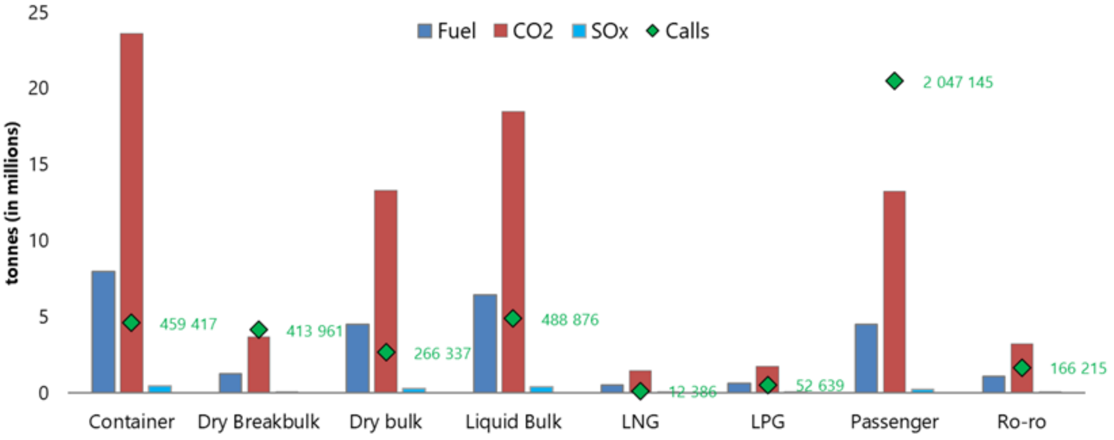


Figure 11: CO2, SOx and SFC consumption in 2020

Focusing on the CO2 emission calculations, the countries with the largest trade volumes for 2020 were ranked, and the top 30 countries were inserted into the scatter plot, Figure 12.

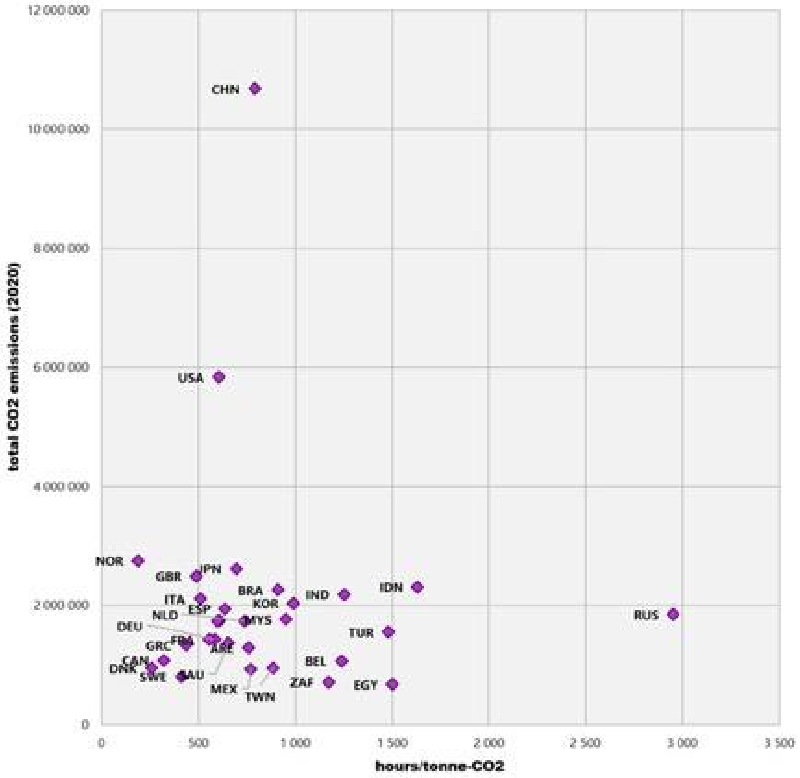


Figure 12: Top 30 ports relationship between hours/tonne-CO2 and total CO2-emissions

An interesting finding from the results is that majority of the countries fall into the total CO2 emission bracket of between 0 and 4,000,000 tonnes of CO2 per annum. There were only three outliers, Russia, the USA and China. In terms of efficiency, measured in this case as hours per tonne-CO2, illustrates that Russia's ports are inefficient, as the hours spent at the port are largely driven by operations where vessels are waiting – running at low engine loads and therefore emitting lower CO2 for every tonne of CO2 produced. China is by far the largest polluter of CO2, nearly emitting twice the amount of pollutants of the USA.

The results of the emission factors determined for the study period can be seen in Table 6.

Table 6: Emission factors for study period (in tonnes)

	Energy-based approach (bottom-up)	Fuel-based approach (Top-down)	
Date	SFC	CO2	SOx
Jun-18	13 467 092	39 292 664	431 989
Dec-18	14 058 411	41 023 432	450 890
Jun-19	14 118 747	41 191 953	453 176
Dec-19	14 887 696	43 434 214	478 851
Jun-20	13 136 859	38 300 246	422 706
Dec-20	13 745 768	40 391 563	444 246
Grand Total	83 414 573	243 634 072	2 681 857

The emission, SFC, CO2 and SOx, calculated from the port calls, represented less than 10 per cent of the total shipping emissions estimated by the IMO (2021a). The value found was in line with other literature for CO2 amount for port activities to CO2 from total shipping activities.

4.2 Future scenarios

This study employs an ordinary least squares (OLS) regression method to predict future maritime activity based on a causal relationship between one independent variable, World Real Gross Domestic Product (Real GDP) and dependent variable marine seaborne trade (MST) or port throughput for the World and five geographical groups namely Africa, America, Asia, Europe and Oceania. MST for each geographical group is calculated as the sum of *Cargo Unloaded* and *Cargo Loaded*. World MST is the sum of each geographical group's MST.

$$MST_{World} = \sum_{k} \left(MST_{Africa} + MST_{America} + MST_{Asia} + MST_{Europe} + MST_{Oceania} \right)$$

Where,
MST = marine seaborne trade or port throughput in million tonnes
k = direction of cargo at port (unloaded or loaded) in million tonnes

Using data from OECD (2018) as a source of actual and projected World Real GDP and data from UNCTADstat as a source of MST, it was possible to analyse the historical relation between GDP and MST. In order to determine whether Real GDP is an adequate predictor of MST, an OLS regression was executed. The results showed an $R^2 = 0.98992$, illustrating a strong correlation between the two variables with a p-value of 1.8x10-24, showing that the relation is statistically significant.

Once the linear relation was established to be strong and accurate, linear regression models for each geographical group were analysed against World Real GDP. Correlation analysis of the variables analysed shows a strong relationship between the variables indicated by a correlation of > 0.8. The predictor variable shows a strong correlation with the dependent variables indicating the causal relationship exists for geographical variables as well. Due to the strong relation between MST and GDP, linear regression models were developed for each geographical group to predict trade activity with specificity to regions.

The regression models show statistical significance with p-values for all categories below 0.05, meaning that GDP would be a good predictor of MTS 95% of the time. The regression models were then regressed against the projected Real GDP up until 2050, illustrated in Figure 13.

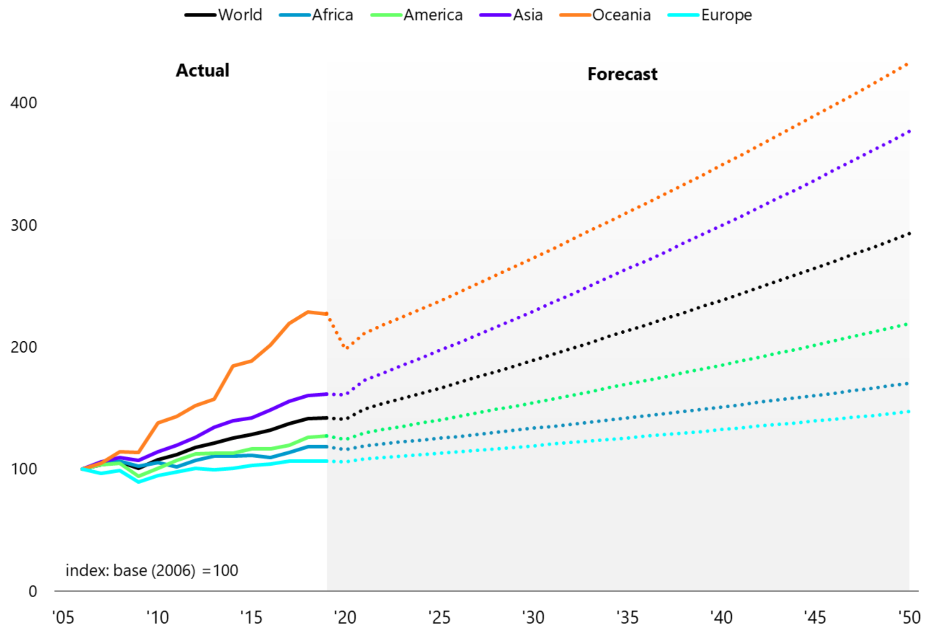


Figure 13: Total Trade Projections to 2050

Once the shipping activity could be projected based on future economic activity, five scenarios were inputted into the dataset to examine and quantify the potential impact of digitalisation on CO2 emissions. The potential impact of digitalisation on sustainability was estimated by assuming a 20 per cent reduction in waiting time, based on commercial pilots of a digital platform implementation at the Port of Rotterdam. (Port of Rotterdam 2021). This assumption was used due to the lack on empirical research of how digitalisation reduces waiting time in ports and, therefore, sustainability. This assumption was applied to the quantitative analysis to show the potential impact of such a digital platform if applied on a global scale and in other selected scenarios.

There are two main ways to measure the climate impact cost: *damage cost* and *damage avoidance cost*. The impact cost of the scenarios was measured utilising the damage cost, for which the current median estimate of the SCC per ton is 50 USD. (Howard & Sylvan 2015, 3, 23). In addition, for Scenario 4, the EU climate change avoidance cost was utilised as the metric to compare to the preferred method used by the European Commission. The avoidance cost is the marginal cost of reaching a specific level of GHG emission reduction. The base cost for CO2 was EUR 100 for the years up to 2030, thereafter EUR 269 was applied (European Commission 2019).

Five scenarios were chosen based on providing a global picture, representation of countries with the highest potential to implement digitalisation and the potential of a political and economic union of the EU. Due to the novelty of JIT and digitalisation, there is limited academic research calculating the waiting time in ports. Therefore, in this study, the reduction of waiting time of 20 per cent in port has been used based on the commercial pilot of PortXchange in Rotterdam (Port of Rotterdam 2021). Scenario 1 demonstrates no change in waiting time. This scenario is then compared to the following:

- Scenario 2 – Global change in port efficiency
- Scenario 3 – GDP Top 30 countries (The World Bank 2021b) implement change
- Scenario 4 – EU member countries (27) (European Union 2021) implement change
- Scenario 5 – Global Competitiveness Index for Port Infrastructure Top 30 countries (The World Bank 2021a) implement change

4.2.1 Global change in port efficiency and reduction in waiting time

The first and second scenarios are compared in Figure 14, showing an increasing reduction of CO2 emissions as time passes. If port efficiency is improved globally, the CO2 reduction potential could be 1.0 billion USD per year and around 20 million tonnes of CO2 emissions by 2050. This scenario represents a global view to illustrate the scale.

However, this may not be viable to implement on a global scale due to development maturity. To address this, more realistic scenarios are depicted based on the ability to implement digitalisation and JIT shipping effectively and at scale.

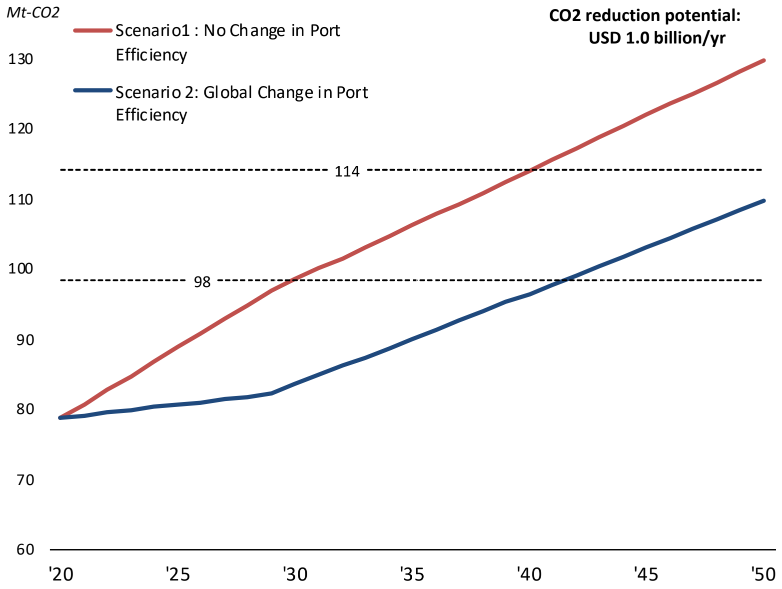


Figure 14: No change vs global change in port efficiency

Table 7 breaks down the difference between Scenarios 1 and 2. Firstly, it shows the possible CO2 emission gap for the next 30 years, which increases over time. Secondly, the profit/loss of emissions is demonstrated using the current median estimate of the SCC per ton = 50 USD (Howard & Sylvan 2015, 3, 23). The profit or cost savings of optimising port call operations could already by 2030 reach around 0.8 billion USD.

Table 7: CO2 emission and social cost difference of Scenarios 1 and 2

	CO2 Emissions (Million tonnes)			Profit/Loss from Climate Change Avoidance Costs (USD billions)		
	Scenario 1	Scenario 2	Diff %	Scenario 1	Scenario 2	Diff $
'20	78.7	78.7	0.00	$3.9	$3.9	$0.00
'30	96.9	82.2	-15.15	$4.9	$4.1	$0.80
'40	112.4	95.2	-15.31	$5.6	$4.8	$0.86
'50	128.2	108.4	-15.43	$6.4	$5.4	$0.99

4.2.2 CO2 impact from reduction in waiting time in the largest 30 countries by GDP

The first and third scenarios are compared in Figure 15, showing an increasing reduction of CO2 emissions as time passes. If port efficiency is improved in the GDP top 30 countries, the CO2 reduction potential could be 0.68 billion USD per year and close to 13.6 million tonnes of CO2 emissions by 2050. In this case, economic and financial capability is used as a criterion to forecast the CO2 emissions.

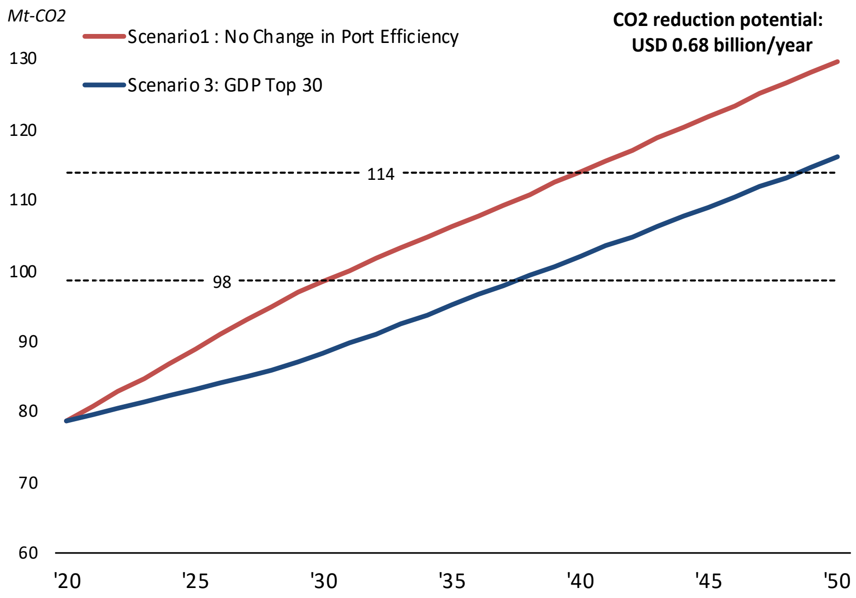


Figure 15: No change vs GDP top 30

Table 8 breaks down the difference between Scenarios 1 and 3.

Table 8: CO2 emission and social cost difference of Scenarios 1 and 3

	CO2 Emissions (Million tonnes)			Profit/Loss from Climate Change Avoidance Costs (USD billions)		
	Scenario 1	Scenario 2	Diff %	Scenario 1	Scenario 2	Diff $
'20	78.7	78.7	0.00	$3.9	$3.9	$0.00
'30	96.9	86.9	-10.37	$4.9	$4.3	$0.60
'40	112.4	100.6	-10.49	$5.6	$5.0	$0.59
'50	128.2	114.6	-10.57	$6.4	$5.7	$0.67

Based on the current median estimate of the SCC per ton = 50 USD (Howard & Sylvan 2015, 3, 23), the profit grew steeply, surpassing 0.6 billion USD, in 2030.

4.2.3 CO2 impact from reduction in waiting in all EU-member states

The first and fourth scenarios are compared in Figure 16, showing a slight reduction of CO2 emissions as time passes. If port efficiency is improved in EU member states, the CO2 reduction potential could be 0.2 billion USD per year and a slight reduction of 2.0 million tonnes of CO2 emissions by 2050. EU is used as a criterion to forecast the impact of port optimisation to provide EU policymakers with the potential impact investment in EU maritime digitalisation could have on the global community.

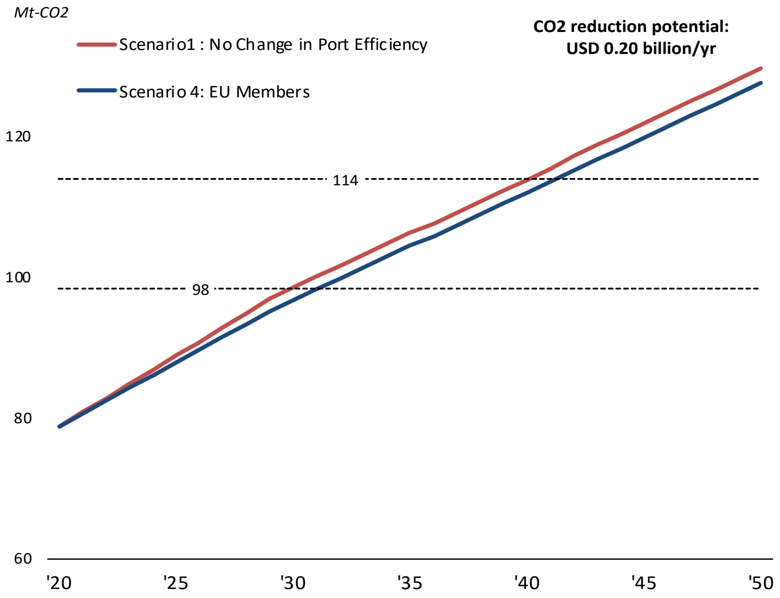


Figure 16: No change vs EU Member countries

Table 9 breaks down the difference between Scenarios 1 and 4. Firstly, it shows the possible CO2 emission gap for the next 30 years, which increases over time. Secondly, the profit/loss of emissions is demonstrated using the EU climate change avoidance costs. The base cost for CO2 was EUR 100 for the years up to 2030, thereafter EUR 269 was applied (European Commission 2019).

Table 9: CO2 emission and social cost difference of Scenarios 1 and 4 in EUR

	CO2 Emissions (Million tonnes)			Profit/Loss from Climate Change Avoidance Costs (EUR billions)		
	Scenario 1	Scenario 2	Diff %	Scenario 1	Scenario 2	Diff €
'20	78.7	78.7	0.00	€7.9	€7.9	€0.00
'30	96.9	95.2	-1.81	€9.7	€9.5	€0.18
'40	112.4	110.6	-1.65	€30.2	€29.7	€0.50
'50	128.2	126.2	-1.53	€47.3	€46.6	€0.72

For consistency, the calculation was made also in using the current median estimate of the SCC per ton = 50 USD (Howard & Sylvan 2015, 3, 23) illustrated in Table 10.

Table 10: CO2 emission and social cost difference of Scenarios 1 and 4 in USD

	CO2 Emissions (Million tonnes)			Profit/Loss from Climate Change Avoidance Costs (USD billions)		
	Scenario 1	Scenario 2	Diff %	Scenario 1	Scenario 2	Diff €
'20	78.7	78.7	0.00	$3.9	$3.9	$0.00
'30	96.9	95.2	-1.81	$4.9	$4.8	$0.10
'40	112.4	110.6	-1.65	$5.6	$5.5	$0.09
'50	128.2	126.2	-1.53	$6.4	$6.3	$0.10

The difference between EUR and USD tables can be especially seen after 2030, as the USD prediction stays consistent while the EUR prediction rises by 169€ per tonne. Table 10 shows how drastically the cost of CO2 emissions rises. The change between the year 2030 and 2040 is 20.5 billion EUR.

4.2.4 CO2 impact from reduction in waiting by most competitive countries as ranked by the Global Competitiveness Index for Port Infrastructure

The first and fifth scenarios are compared in Figure 17, showing a slight increase in the reduction of CO2 emissions as time passes. If port efficiency is improved in GCI port infrastructure top 30 countries, the CO2 reduction potential could be 0.37 billion USD per year and close to 7.5 million tonnes of CO2 emissions by 2050. In this case, country infrastructure capability is used as a criterion to forecast the potential savings of implementing JIT shipping through digitalisation.

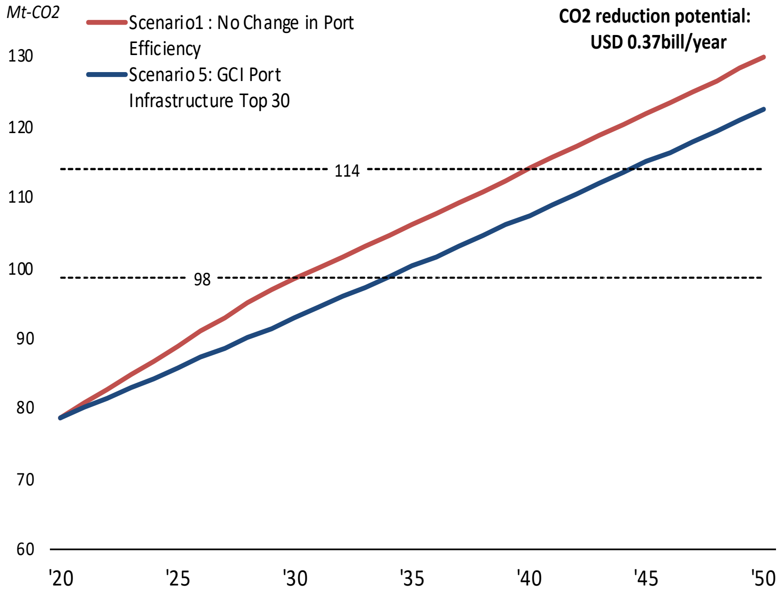


Figure 17: No change vs Top 30 GCI port infrastructure

Table 11 breaks down the difference between Scenarios 1 and 5.

Table 11: CO2 emission and social cost difference of Scenario 1 and 5

	CO2 Emissions (Million tonnes)			Profit/Loss from Climate Change Avoidance Costs (USD billions)		
	Scenario 1	Scenario 2	Diff %	Scenario 1	Scenario 2	Diff €
'20	78.7	78.7	0.00	$3.9	$3.9	$0.00
'30	96.9	91.4	-5.70	$4.9	$4.6	$0.28
'40	112.4	106.0	-5.71	$5.6	$5.3	$0.32
'50	128.2	120.8	-5.73	$6.4	$6.0	$0.37

Based on the current median estimate of the SCC per ton = 50 USD (Howard & Sylvan 2015, 3, 23) the profit grew steadily, around 0.7 billion USD every 10 years.

4.3 Summary of the main findings

Figure 18 illustrates all five scenarios combined, showing a reduction of CO2 emissions as time passes. The CO2 reduction potential could be 0.2 to 3.2 billion USD per year, depending on which scenario implemented. The most significant reduction is between Scenarios 1 and 2. That is understandable as it compares each country. An interesting finding is that a bigger impact from the change would be if the GDP top 30 countries would implement change than if the Top 30 GCI port infrastructure countries would do so. This could be explained by the latter already being more efficient in their port operations.

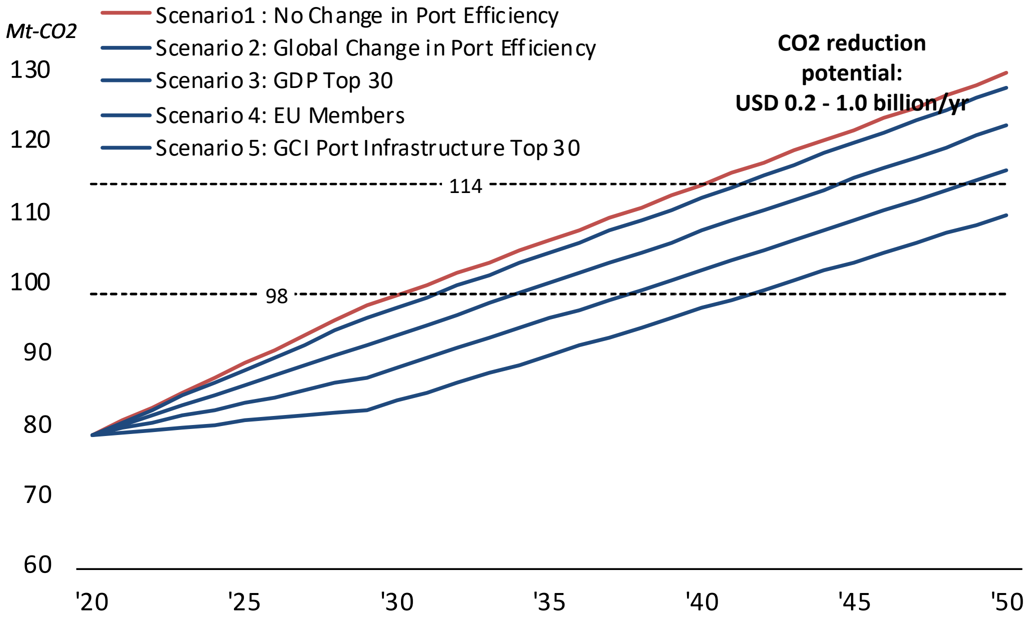


Figure 18: All five scenarios combined

Chapter 4 focused on the findings of the study. Firstly, Chapter 4.1. analysed the secondary data: the number of port calls, time in port, age of vessels and the installed power of ship engines were calculated. One interesting finding was that for the years 2019 and 2020, the majority of top 30 CO2 emitting countries the tonnes of CO2 emitted from vessels was lower for the year 2020 against the previous year or nearly similar, which could be a result of the slowdown due to the COVID-19 pandemic (Millefiori et al. 2021, 5, 10). Secondly, Chapter 4.2. showed five different scenarios, Scenario 1 if digitalisation and JIT are not implemented and the following four scenarios, if digitalisation and JIT are implemented in different settings. This was done to demonstrate how optimising port operations could impact the CO2 emissions and thereby sustainability. The global CO2 emission reduction potential could be 15.4 annually by 2050. The implications of the research findings and the limitations faced are examined further in Chapter 5.

5 CONCLUSIONS

"*Ports are the connecting nodes of global trade and world economy. There is no way that we can move this world towards sustainability without ports*."

(*Christiana Figueres, 2018*)

5.1 Theoretical contribution

This study has several theoretical contributions. The prior theory indicates digitalisation to be a critical enabling factor in ensuring the transition to a sustainable maritime sector. While the global fleet base is slow to renew, the issues with communication and collaboration could be improved relatively faster. A key outcome of the digital transformation process is the optimisation of maritime operations in the port environment (Gong & Ribiere 2021, 7-12). The findings of the study are in line with this. Implementing a JIT shipping and decreasing port waiting time by 20 per cent would potentially reduce CO2 emission and increase cost savings through all four projected scenarios.

The prior studies estimated that 17 per cent of the shipping's total annual CO2 emissions could be reduced with better planning (Valeur 2019). Scenario 1, demonstrating a global implementation of JIT, showed a potential annual reduction of 20 million tonnes in CO2 emissions globally by 2050, translating to a 15.4 per cent reduction. While change on a global scale may not be viable to implement due to development maturity, as half of the world population still lacks internet access (Schwab 2016, 11-17), more realistic scenarios were depicted based on the ability to implement digitalisation and JIT shipping effectively and at scale. From the leading 30 GDP countries, 12 are also the top 30 leaders in the global competitiveness of port infrastructure. Leveraging their current economic state and digital infrastructure would be beneficial, as Scenarios 3 and 5 show an annual CO2 reduction of 10.6 per cent and 5.7 per cent, respectively, compared to Scenario 1 in 2050.

Sustainability can be defined as economic, social and environmental. The well-being of the environment correlates with both social and economic well-being, as economic development is limited within the sphere of social welfare and quality of life, which is constrained by the environmental limits within the biosphere – what is good for the environment is fundamentally good for humans. (Caldwell 1990, 5-7, 183). In fact, the reduction in SOx emissions should result in health benefits, especially for populations living close to ports and coasts. (IMO 2020). The study showed that from 2018 to 2020, the total amount of SOx emissions in port calls was 2.68 million. Based on this study, in 2020 alone, the SOx emissions were around 0,4 million tonnes per port call.

Furthermore, the reduction in GHG emissions leads to cost savings. By using the current median estimate of the SCC per ton = 50 USD (Howard & Sylvan 2015, 3, 23), the study showed that a potential economic saving could be 0.2 to 1.0 billion USD depending on the chosen scenario. The EU uses a climate change avoidance cost to calculate the impact cost of CO2 emissions. The avoidance cost is the marginal cost of reaching a specific level of GHG emission reduction. The base cost for CO2 is EUR 100 for the years up to 2030 and thereafter EUR 269 (European Commission 2019). This method increases the cost of CO2 emissions by a whopping 20.5 billion EUR from the year 2030 to 2040. Based on Holden et al. (2014, 131) argument, the primary objective of the EU investing in port optimisation would be facilitating sustainable economic development goals rather than just the traditional economic growth goals.

Due to the novelty of the JIT concept and digitalisation in the maritime industry, a limited theory simulates the potential effects JIT could have on a global scale. Commercial proof of concepts of solutions by PortXchange enabling JIT shipping in Rotterdam and the national single window implementation in Singapore has reduced waiting time by 20 per cent (Port of Rotterdam 2021; Tijan et al. 2019, 8). This reduction could have significant implications on global sustainability. By transposing this reduction in waiting time in ports on a global scale, the study provided policymakers and executives with the external cost associated with not implementing JIT shipping. Bringing these potential costs to the fore is a powerful tool for decision-makers to motivate investment in port digitalisation to avoid such costs and implications.

5.2 Practical implications

The study's practical implications are mostly directed to the government level, which is both the policymakers and the financial contributor to state well-being. Even though the IMO has set CO2 regulations and the Baltic and International Marine Council contributes by removing legislative obstacles, change towards sustainability is slow. While the end goal is to become carbon neutral in the long run by changing into green fuels, converting the entire industry will take a long time. Port optimisation is a parallel solution to reducing GHG’s and could be implemented in short to medium term compared to alternative fuel adoption. The ideal scenario would, of course, be a global implementation of digital port call optimisation. Unfortunately, this is impossible for various reasons, such as not all countries nor ports have access to this kind of change. However, even if 30 countries that would potentially have the means for change would optimise port calls, the reduction in emissions and profit gain would be significant.

The top 30 countries by GDP include the USA, China, Japan, Germany and Korea. If only these top 30 countries would optimise their port calls, the potential reduction in CO2 emissions is not far from a change globally. As even the 30th ranked country, Israel's GDP was 401.9 billion USD (The World Bank 2021b); these countries could have the necessary economic means for digitalisation. The reduction in CO2 emissions would have a potential social cost savings of 2.21 billion USD annually. This is the potential opportunity cost of investing in the digital optimisation of port calls. Governments should emphasise sustainable development by investing in digitalisation to benefit the economy, society and the environment.

From the leading 30 GDP countries, 12 are also the top 30 leaders in the global competitiveness of port infrastructure. Optimising their port calls could take the least effort for these countries, as they might already be well equipped. By leveraging their current infrastructure, ports can implement changes quicker and enhance their competitiveness further, especially as the potential cost of change could reach 1.21 billion USD annually. It would also make logical sense for the countries to invest in developing their digital infrastructure to become even more competitive on the global scale.

The European Maritime Safety Agency (EMSA) and the European Environment Agency (EEA) published a report that examines the EU maritime sector's impact on the environment. The study found that even if the maritime transport's CO2 emissions have decreased in the last decade, they are projected to increase again by 2030 and 2050. (EMSA & EEA 2021, 41). This does not fall in line with the EU sustainability objectives and should thus be addressed sooner rather than later. The EU provides grants and subsidies to improve infrastructure and protect the environment (European Commission 2021). By providing this funding's to member states digitalising their port infrastructure, the EU could reduce CO2 emissions and improve its sustainability goals.

To tackle the global issue of climate change, governments and international organisations need to act swiftly. It is essential to keep in mind that the maritime sector is an integral part of world trade with complex infrastructure. While the global fleet base is slow to renew, the issues with communication and collaboration could be improved relatively faster. The decision-makers should not only set rules and regulations to pivot the maritime industry towards sustainability but also invest and incentivise the maritime actors to optimise their operations that directly lead to the sustainable development of the industry.

5.3 Limitations

While the maritime industry may be understood as vast waterborne commerce, this study focused solely on port operations. Connecting the hinterland and the sea, ports are the bottleneck of the chain with a tremendous throughput of vessels, trains, trucks and people. Although the shipping industry produces an enormous amount of waste and impact on the environment, such as discharges to the sea and noise from port areas, the study addressed fuel consumption and GHG emissions, particularly CO2. These have been the central concern of the maritime industry to achieve sustainability goals.

In addition, the study had some limitations on data. The secondary data utilised to derive the various emissions was in a country-level aggregated format meaning the calculations were based on port-performance consolidated to the country level. For countries with a large number of port calls (i.e. China), there would be no visibility of outliers. Nevertheless, as Table 12 demonstrates, based on previous research by Entec (2002), the final weighted average time spent in port of this study had very similar figures.

Table 12: Weighted average time spent in port

Time spent in port (hours)	This Study						Entec (2002)	
	2018-S1	2018-S2	2019-S1	2019-S2	2020-S1	2020-S2		
Container	18.2	18.8	18.4	18.3	18.3	19.2	15.3	Container
Dry Breakbulk	29.1	28.3	28.7	28.4	30.6	29.4	22.5	General Cargo
Dry bulk	54.0	50.6	51.9	49.9	53.1	51.9	47.0	Bulk Dry
							53.0	Bulk Dry / Oil
Liquid Bulk	22.7	22.7	22.6	22.6	23.4	23.2	18.8	Chemical Oil
							39.3	Other Liquids
LNG	26.8	27.1	27.0	28.2	26.6	27.1	25.0	Liquefied Gas
LPG	24.0	25.5	25.0	24.4	25.4	25.6	25.0	Liquefied Gas
Passenger	14.8	14.8	14.8	14.8	14.8	14.8	n.a.	Estimated hours
Ro-ro	16.0	16.0	16.0	16.0	16.0	16.0	n.a.	Estimated hours

Coverage of vessels in this study versus identified by the total fleet in the Fourth IMO GHG Study (2021a), which illustrated that the ships for which complete data was available in the UNCTADstat database for ship activity covers about 62 per cent (45,135) of the total fleet categories Type 1 and Type 2. Port performance data only included ships with a GT of >1000 tonnes. Furthermore, the types of ships included in the analysis were restricted to the commercial fleet, which corresponds to around 59 per cent (43,011) of ships. A further limitation that could have impacted the results is that two of the studied vessel types, passenger and roll-on/roll-off ships, had no actual data for time spent in port. Excluding these two vessels from the analysis would result in a reduction of the fleet to 53 per cent (39,011). Nevertheless, based on the inventory estimations, the total CO2 emissions for both points would have accounted for 811 million tonnes of CO2 emissions or 77 per cent of total ocean-going CO2. (IMO 2021a, 446-448).

5.4 Further research opportunities

The limitations considered above create appealing possibilities for future studies. This study utilised secondary data as it was available free of charge and in a more compact format. Future studies could use more accurate AIS data. Furthermore, the study was based on a country-level aggregated format and looked at the no global change versus four other scenarios. In comparison, future studies could focus profoundly on a port call basis and look at either port or countrywide. An interesting finding was that in terms of efficiency, measured in this case as hours per tonne-CO2, Russia's ports are inefficient, and China is by far the largest polluter of CO2. These could provide possibilities for more specific future research.

The maritime industry is merely one of many industries with which the research question could be answered. In the same way, the environmental impact may not be the best measure regarding the maritime industry, i.e. economic measures could be a more robust indicator; therefore, it can be inferred that the results would be more conclusive. In January 2020, the IMO adopted the IMO 2020 rule, limiting the sulphur oxide (SOx) content in the fuel oil used not to exceed 0.5 per cent mass by mass (m/m). The reduction should result in health and environmental benefits, especially for populations living close to ports and coasts. (IMO 2020) An interesting study could be on social impacts of the IMO 2020 cap and how the SOx reduction affects health, i.e. respiratory, cardiovascular and lung disease.

6 SUMMARY

The maritime industry is growing in size and volume; over 80 per cent of world trade by volume is carried by sea, port throughput and handling capacity are expanding, and the vessels are getting bigger in number and size. The increasing volumes in global maritime trade are associated with accumulating stresses and adverse effects on the environment. To pivot the industry towards global SDGs, organisations and policymakers are implementing several measures, including stricter regulations and renewed legislations. While the end goal of achieving carbon neutrality remains problematic and slow-going, several short-term solutions could be implemented. This study aimed to explore how digitalisation can support the sustainable development of the maritime industry, focusing primarily on enhancing port efficiency. The purpose of the study was divided into two sub-questions: what are the sustainability impacts of the maritime industry, and how could digitalising port calls impact shipping emissions?

The theoretical framework of the study consisted of three large concepts. Firstly, sustainability and its three pillars – economic, social and environmental – were discussed. Secondly, digital transformation and digital technologies were explored. Thirdly, the complexity of the maritime industry, particularly the port operations, were described. The chapter was concluded by synthesising the theoretical framework tying up the maritime industry's sustainability efforts with digitalisation. The research method used in this study was quantitative, as the research problem is best addressed by processing numerical data.

The results of the study are in line with previous research, indicated that optimising the port operations and reducing waiting time could have significant impacts on CO2 emissions. Lowering the CO2 emissions leads to the sustainable development of the environment and economic and social sustainability as the cost savings have the potential to reach billions of USD and have positive effects on social well-being. While change on a global scale may not be viable to implement due to development maturity, more realistic scenarios were depicted based on the ability to implement digitalisation and JIT shipping effectively and at scale. If port efficiency would be improved in the GDP top 30 countries, the CO2 reduction could be just ten years behind global implementation figures. Twelve of these countries are also in the top 30 of the Global Competitiveness Index for Port Infrastructure. By leveraging their current digital infrastructure and economic capabilities, these countries alone could produce significant sustainability impacts while remaining competitive.

In conclusion, governments and international organisations need to act swiftly to tackle the global issue of climate change. It is essential to keep in mind that the maritime sector is an integral part of world trade with complex infrastructure. While the global fleet base is slow to renew, the issues with communication and collaboration could be improved relatively faster. The decision-makers should not only set rules and regulations to pivot the maritime industry towards sustainability but also invest and incentivise the maritime actors to optimise their operations that directly lead to the sustainable development of the industry.

REFERENCES

Akcam, B.K. – Guney, S. – Cresswell, A.M. (2019) Research design and major issues in developing dynamic theories by secondary analysis of qualitative data. *Systems*, 7(3), p.40.

Aljabre, A. (2012) Cloud computing for increased business value. *International Journal of Business and social science*, 3(1).

Andersson, K. – Brynolf, S. – Lindgren, J. F. – Wilewska-Bien, M. (Eds.). (2016) *Shipping and the environment: Improving environmental performance in marine transportation.* Springer Berlin Heidelberg.

Andrew, S. – Halcomb, E. J. (2009) *Mixed methods research for nursing and the health sciences*. John Wiley & Sons Ltd. Chichester.

Arndt, H. W. (1981) Economic development: a semantic history. *Economic development and cultural change*, 29(3), 457-466.

Asgari, N. – Hassani, A. – Jones, D. – Nguye, H. H. (2015) Sustainability ranking of the UK major ports: Methodology and case study. *Transportation Research Part E: Logistics and Transportation Review*, 78, 19-39.

Bacalja, B. – Krčum, M. – Slišković, M. (2020). A Line Ship Emissions while Manoeuvring and Hotelling—A Case Study of Port Split. *Journal of Marine Science and Engineering*, *8*(11), 953.

Barbier, E. B. (1987) The concept of sustainable economic development. *Environmental conservation*, 14(2), 101-110.

Bernhofen, D. M. – El-Sahli, Z. – Kneller, R. (2016) Estimating the effects of the container revolution on world trade. *Journal of International Economics*, 98, 36-50.

Boeije, H. R. – Hox, J. J. (2005) Data collection, primary vs. secondary. *Encyclopedia of social measurement*, 1, 593-599.

Boelsmand, A. S. – de Voss, N. A. (2020) *Blockchain openness – exploring platform strategy and openness for blockchain platforms through the case of TradeLens*. Master's thesis. Copenhagen Business School, Copenhagen.

Bossel, H. (1999) *Indicators for sustainable development: theory, method, applications.* International Institute for Sustainable Development, Winnipeg.

BRS Group (2020) Shipping and shipbuilding markets 2020. <https://it4resources.interactiv-doc.fr/catalogues/revue2020_finale_flipbook_optimise_couv_668/galeries/brs_review_2020.pdf>, retrieved 15.05.2021.

Brundtland, G. (1987) *Report of the World Commission on Environment and Development: Our Common Future*. United Nations General Assembly document A/42/427.

Business Finland (2020) Smart ports and maritime logistics from Finland. <https://www.corealis.eu/wp-content/uploads/2020/08/bf_smartportsfromfinland_lores_010720.pdf>, retrieved 15.05.2021.

Caldwell, L. K. (1990) *Between two worlds: science, the environmental movement and policy choice* (No. 1). Cambridge University Press.

Cohen, M. A. (2010) A Taxonomy of oil spill costs – What are the likely costs of the Deepwater Horizon spill?. Resources for the Future, Washington.

Corbett, J. J. – Winebrake, J. (2008). The impacts of globalisation on international maritime transport activity. In *Global forum on transport and environment in a globalising world*, (Vol. 31, p. 31).

Crosby, M. – Pattanayak, P. – Verma, S. – Kalyanaraman, V. (2016) Blockchain technology: Beyond bitcoin. *Applied Innovation*, 2(6-10), 71.

Czachorowski, K. – Solesvik, M. – Kondratenko, Y. (2019) The application of blockchain technology in the maritime industry. In Green IT Engineering: Social, *Business and Industrial Applications* (pp. 561-577). Springer, Cham.

Davenport, T. H. – Barth, P. – Bean, R. (2012) How 'big data' is different. *MIT Sloan Management Review*, (Vol. 54, No. 1).

Dick, S. (2019) Artificial Intelligence. *Harvard Data Science Review*, 1(1).

Dornberger, R. – Inglese, T. – Korkut, S. – Zhong, V.J. (2018) Digitalization: Yesterday, today and tomorrow. In *Business Information Systems and Technology 4.0.* (pp. 1-11). Springer, Cham.

EEA Technical Report (2019) EMEP/EEA air pollutant emission inventory guidebook 2019. Technical guidance to prepare national emission inventories. EEA, Copenhagen.

Entec (2002) Quantification of emissions from ships associated with ship movements between ports in the European community. Final Report 0617702121. Entec UK Limited, Norwich.

Entec (2007) Ship emissions inventory – Mediterranean Sea. CONCAWE Final Report, Entec UK Limited, London, England.

Entec (2010) UK ships emission inventory. Entec UK Limited, London.

Eriksson, P. – Kovalainen, A. (2008) *Qualitative methods in business research*. Sage Publications Ltd., London.

European Commission (2019) Handbook on the external costs of transport, version 2019 (No. 18.4 K83. 131). Brussels.

European Commission (2021) Before you apply: EU funding for beginners. <https://ec.europa.eu/info/funding-tenders/how-apply/you-apply-eu-funding-beginners_en>, retrieved 30.9.2021.

European Maritime Safety Agency, EMSA - European Environment Agency, EEA (2021) European Maritime Transport Environmental Report 2021. EMSA. Luxembourg.

European Union (2021) The 27 member countries of the EU. <https://europa.eu/european-union/about-eu/countries_en>, retrieved 30.08.2021.

Feil, A. – Schreiber, D. – Haetinger, C. – Strasburg, V. – Barkert, C. (2019) Sustainability indicators for industrial organizations: Systematic review of literature. Sustainability, 11(3), p.854.

Global Enabling Sustainability Initiative, GeSI – Deloitte (2019) Digital with Purpose: Delivering a SMARTer2030. Summary. <https://gesi.org/research/download/36>, retrieved 25.9.2021.

Global Environment Facility, GEF – the United Nations Development Programme, UNDP – the International Maritime Organization, IMO – Global Maritime Energy Efficiency Partnerships, GloMEEP – Project and members of the Global Industry Alliance, GIA (2020) Just In Time Arrival Guide – Barriers and Potential Solutions. GloMEEP Project Coordination Unit, London.

Gong, C. – Ribiere, V. (2021) Developing a unified definition of digital transformation. *Technovation*, 102, 102217.

Gubbi, J. – Buyya, R., Marusic, S. – Palaniswami, M. (2013) Internet of Things (IoT): A vision, architectural elements, and future directions. *Future generation computer systems*, 29(7), 1645-1660.

Guo, B. – Zhang, D. – Wang, Z. – Yu, Z. – Zhou, X. (2013) Opportunistic IoT: Exploring the harmonious interaction between human and the internet of things. *Journal of Network and Computer Applications*, 36(6), 1531-1539.

Haukioja, T. (2007) *Sustainable development and economic growth in the market economy*. Publication of the Turku School of Economics. Series A-6:2007.

Holden, E. – Linnerud, K. – Banister, D. (2014) Sustainable development: Our common future revisited. *Global environmental change*, 26, 130-139.

Howard, P. – Sylvan, D. (2015) *Expert consensus on the economics of climate change.* Institute for Policy Integrity, New York University School of Law, New York.

Hunter, G. (2021a) New BIMCO clause encourages bulk sector to embrace just in time arrival concept. <https://www.bimco.org/news/contracts-and-clauses/20210215-new-bimco-clause-encourages-bulk-sector-to-embrace-just-in-time-arrival-concept>, retrieved 20.9.2021.

Hunter, G. (2021b) New BIMCO clause promotes harmonised ship-shore data exchange. <https://www.bimco.org/news/contracts-and-clauses/20210413-new-bimco-clause-promotes-harmonised-ship-shore-data-exchanget>, retrieved 20.9.2021.

Hvolby, H. H. – Steger-Jensen, K. – Bech, A. – Vestergaard, S. – Svensson, C. – Neagoe, M. (2021) Information exchange and block chains in short sea maritime supply chains. *Procedia Computer Science*, 181, 722-729.

International Chamber of Shipping, ICS (2021) New BIMCO/ICS Seafarer Workforce Report warns of serious potential officer shortage. <https://www.ics-shipping.org/press-release/new-bimco-ics-seafarer-workforce-report-warns-of-serious-potential-officer-shortage/>, retrieved 8.9.2021.

International Maritime Organization, IMO (2020) IMO 2020 – Cutting sulphur oxide emissions. <https://www.imo.org/en/MediaCentre/HotTopics/Pages/Sulphur-2020.aspx>, retrieved 26.9.2021.

International Maritime Organization, IMO (2021a) *Fourth IMO GHG Study* 2020. International Maritime Organization, London.

International Maritime Organization, IMO (2021b) Women in maritime. <https://www.imo.org/en/OurWork/TechnicalCooperation/Pages/WomenIn-Maritime.aspx>, retrieved 8.9.2021.

Jägerbrand, A. K. – Brutemark, A. – Svedén, J. B. – Gren, M. (2019) A review on the environmental impacts of shipping on aquatic and nearshore ecosystems. *Science of the Total Environment*, 695, 133637.

Jakobsen, E.W. – Juliebø, S. – Haugland, L.M. – Baustad, H. – Osman, M.S. – Sewraz, D. – Villemin, A. (2019) *The leading maritime capitals of the world 2019.* Menon Economics and DNV GL Publication.

Joham, C. – Metcalfe, M. – Sastrowardoyo, S. (2009) Project conceptualization using pragmatic methods. *International Journal of Project Management*, 27(8), pp.787–794.

Johnston, M. (2013) Secondary data analysis: A method of which the time has come. *Qualitative and quantitative methods in libraries*, 3(3), 619-626.

Keefe, P. (2014) Optimize performance via data analytics. Maritime Logistics Professional Q1/2014. <https://www.maritimeprofessional.com/news/optimize-performance-data-analytics-245836>, retrieved 19.9.2021.

Kiel, D. – Müller, J. M. – Arnold, C. – Voigt, K. I. (2020) Sustainable industrial value creation: Benefits and challenges of industry 4.0. In *Digital Disruptive Innovation* (pp. 231-270).

Lee, E. S. – Nam, H. S. – Song, D. W. (2012) Defining maritime logistics and its value. In *Maritime logistics: a complete guide to effective shipping and port management*, eds. Song, D. W. – Panayides, P., 9-21. Kogan Page, London.

Lee, H. – Park, D. – Choo, S. – Pham, H.T. (2020) Estimation of the Non-Greenhouse Gas Emissions Inventory from Ships in the Port of Incheon. *Sustainability*, 12(19), p.8231.

Lele, A. (2019) Cloud computing. In *Disruptive technologies for the militaries and security* (pp. 167-185). Springer, Singapore.

Lincoln, Y. S. – Guba, E. G. (1985) *Naturalistic inquiry*. Sage Publications, Newbury Park.

Lind, M. – Andersen, T. – Bergmann, M. – Watson, R. T. – Haraldson, S. – Karlsson, M. – Michaelides, M. – Gimenez, J. – Ward, R. – Bjørn-Andersen, N. – Gonzales, A. Holmgren, B. – Zerem, A. – Rauer, F. – Sahlberg, H. – Lindberg, J. (2018) The maturity level framework for PortCDM. *Sea Traffic Manage., Norrköping, Sweden, Tech. Rep, 13.*

Lloyd's List (2020) One Hundred Ports 2020. One Hundred Ports: A simpler time. Informa UK Ltd. <https://lloydslist.maritimeintelligence.informa.com/one-hundred-container-ports-2020/Digital%20edition%20ebook>, retrieved 10.06.2021

Lo, F. Y. – Campos, N. (2018) Blending Internet-of-Things (IoT) solutions into relationship marketing strategies. *Technological Forecasting and Social Change*, 137, 10-18.

McCarthy, J. (2007) *What is artificial intelligence?*. Computer Science Department, Stanford University, Stanford.

Milbrath, L. W. (1984) A proposed value structure for a sustainable society. *Environmentalist*, 4(2), 113-124.

Millefiori, L.M. – Braca, P. – Zissis, D. – Spiliopoulos, G. – Marano, S. – Willett, P.K. – Carniel, S. (2021) COVID-19 impact on global maritime mobility. Scientific reports, 11(1), 1-16.

Miola, A. – Ciuffo, B. (2011) Estimating air emissions from ships: Meta-analysis of modelling approaches and available data sources. *Atmospheric environment*, *45*(13), 2242-2251.

Mirović, M. – Miličević, M. – Obradović, I. (2018) Big data in the maritime industry. *NAŠE MORE: znanstveni časopis za more i pomorstvo*, 65(1), 56-62.

OceanEconomics (2021) How the shipping sector is decarbonising <https://ocean.economist.com/innovation/articles/how-the-shipping-sector-is-decarbonising>, retrieved 23.9.2021.

OECD (2021) GDP long-term forecast. <https://data.oecd.org/gdp/gdp-long-term-forecast.htm>, retrieved 28.8.2021.

Oxford English Dictionary, OED (2021). Transformation, n. <https://www-oed-com.ezproxy.utu.fi/view/Entry/204743?redirectedFrom=transformation#eid>, retrieved 18.9.2021.

Port of Rotterdam (2021) PortXchange. <https://www.portofrotterdam.com/en/services/online-tools/portxchange>, retrieved 27.9.2021.

PSA News release (2019) PSA begins a new chapter in Singapore with TUAS port, building an ecosystem to synergise port operations & co-create supply chain orchestration. <https://www.singaporepsa.com/-/media/Feature/PDF/News-And-Media/2019/nr191003.pdf>, retrieved 2.3.2021.

Purvis, B. – Mao, Y. – Robinson, D. (2019) Three pillars of sustainability: in search of conceptual origins. *Sustainability science*, 14(3), 681-695.

Rantanen, A – Berg, N. – Kanto, E. (2019) *Digitalization as a tool to reduce GHG emissions in maritime transport*. Traficom Research Reports 28/2019, Finland.

Rossman, G.B. – Wilson, B.L. (1985) Numbers and words. *Evaluation Review*, 9(5), pp.627–643.

Sagiroglu, S. – Sinanc, D. (2013) Big data: A review. In *2013 international conference on collaboration technologies and systems (CTS)* (pp. 42-47). IEEE.

Schwab, K. (2016) *The fourth industrial revolution*. Penguin Random House LLC, New York.

Sestino, A. – Prete, M. I. – Piper, L. – Guido, G. (2020) Internet of Things and Big Data as enablers for business digitalization strategies. *Technovation*, 102173.

Short, R. E. – Cox, D. T. – Tan, Y. L. – Bethel, A. – Eales, J. F. – Garside, R. (2021) Review of the evidence for oceans and human health relationships in Europe: A systematic map. *Environment International*, 146, 106275.

Steurer, R. – Langer, M. E. – Konrad, A. – Martinuzzi, A. (2005) Corporations, stakeholders and sustainable development I: a theoretical exploration of business–society relations. *Journal of business ethics*, 61(3), 263-281.

The World Bank (2021a) GCI 4.0: Global Competitiveness Index 4.0, Rank. <https://tcdata360.worldbank.org/indicators/h36ef8a78?country=BRA&indicator=41289&viz=line_chart&years=2007,2017>, retrieved 16.9.2021.

The World Bank (2021b) GDP Current US$. <https://data.worldbank.org/indicator/NY.GDP.MKTP.CD?most_recent_value_desc=true>, retrieved 30.8.2021.

Tijan, E. – Agatić, A. – Jović, M. – Aksentijević, S. (2019) Maritime national single window – A prerequisite for sustainable seaport business. *Sustainability*, 11(17), 4570.

Tijan, E. – Jović, M. – Aksentijević, S. – Pucihar, A. (2021) Digital transformation in the maritime transport sector. *Technological Forecasting and Social Change*, 170, p.120879.

Trozzi, C. (2010) Emission estimate methodology for maritime navigation. Techne consulting report ETC. EF, 10.

United Nations Conference on Trade and Development, UNCTAD (2018) Review of maritime transport 2018. <https://unctad.org/webflyer/review-maritime-transport-2018>, retrieved 29.8.2021.

United Nations Conference on Trade and Development, UNCTAD (2019) *Key statistics and trends in international trade 2018* (No. UNCTAD/DITC/TAB/2019/2).

United Nations Conference on Trade and Development, UNCTAD (2020a) *Digitalizing the port call process* (UNCTAD/DTL/TLB/2019/2).

United Nations Conference on Trade and Development, UNCTAD (2020b) *Review of maritime transport 2020* (No. UNCTAD/RMT/2020).

United Nations Conference on Trade and Development statistics, UNCTADstat (2021) Data center. <https://unctadstat.unctad.org/wds/ReportFolders/reportFolders.aspx?sCS_ChosenLang=en>, retrieved 28.8.2021.

United Nations Educational, Scientific and Cultural Organization, UNESCO (2020) The science we need for the ocean we want: *The United Nations Decade of Ocean Science for Sustainable Development (2021-2030)*. Paris. 2020. 20 pp. (English). IOC Brochure 2020-4 (IOC/BRO/2020/4).

United Nations, UN (2015) *Resolution adopted by the General Assembly on 19 September 2016.* A/RES/71/1, 3 October 2016 (The New York Declaration).

Valeur, S. (2019) Waiting time in ports costs shipping billions of dollars annually. <https://shippingwatch.com/Ports/article11550328.ece>, retrieved 23.3.2021.

Vopson, M.M. (2020) The world's data explained: how much we're producing and where it's all stored. <https://www.weforum.org/agenda/2021/05/world-data-produced-stored-global-gb-tb-zb/>, retrieved 26.9.2021.

Voss, J. P. – Kemp, R. (2006) Sustainability and reflexive governance: introduction. In *Reflexive governance for sustainable development*, eds. Voss, J. P. – Bauknecht, D. – Kemp, R., 3-28. Edward Elgar, Cheltenham.

Walker, B. – Salt, D. (2012) *Resilience thinking: sustaining ecosystems and people in a changing world.* Island press, Washington.

Walker, T. R. – Adebambo, O. – Del Aguila Feijoo M. C. – Elhaimer, E. – Hossain, T. – Edwards, S. J. – Morrison ,C.E. – Romo, J. – Sharma, N. – Taylor, S. – Zomorodi, S. (2019) Environmental effects of marine transportation. In *World seas: An environmental evaluation* (pp. 505-530). Academic Press.

Wang, H. – Lutsey, N. (2013) Long-term potential for increased shipping efficiency through the adoption of industry-leading practices. *The International Council on Clean Transportation*, Washington.

World Economic Forum, WEF (2018) Digital Transformation Initiative. Executive summary. <http://reports.weforum.org/digital-transformation/wp-content/blogs.dir/94/mp/files/pages/files/dti-executive-summary-20180510.pdf>, retrieved 18.9.2021.

World Port Sustainability Program, WPSP (2020) World Ports Sustainability report 2020. <https://sustainableworldports.org/wp-content/uploads/WORLD-PORTS-SUSTAINABILITY-REPORT-2020-FIN.pdf>, retrieved 20.5.2021.

Yang, D. – Wu, L. – Wang, S. – Jia, H. – Li, K. X. (2019) How big data enriches maritime research – A critical review of Automatic Identification System (AIS) data applications. *Transport Reviews*, 39(6), 755-773.

Ytreberg, E. – Åström, S. – Fridell, E. (2021) Valuating environmental impacts from ship emissions – The marine perspective. *Journal of Environmental Management*, 282, 111958.

Zheng, Z. – Xie, S. – Dai, H. N. – Chen, X. – Wang, H. (2018) Blockchain challenges and opportunities: A survey. International Journal of Web and Grid Services, 14(4), 352-375.

APPENDICES

Appendix 1. Supplementary data

Table 13: CO2 Emissions (Adapted from IMO 2021a)

CO2 Emissions Per Year	2012	2013	2014	2015	2016	2017	2018
Group1	**860.6**	**850**	**850.2**	**874.4**	**909.8**	**945**	**935.4**
Bulk carrier	183	178	177	184	192	198	193
Chemical tanker	64	67	69	74	79	82	82
Container	221	214	210	212	221	232	232
Cruise	25	25	25	26	27	28	30
Ferry-pax only	9	9	10	10	11	11	11
Ferry-RoPax	36	35	36	36	37	38	37
General cargo	66	64	64	62	63	63	58
Liquefied gas tanker	55	56	58	58	60	66	71
Oil tanker	140	140	140	149	157	162	159
Other liquids tankers	2	2	2	2	2	2	2
Refrigerated bulk	17	16	16	16	15	15	14
Ro-Ro	18	18	18	19	20	21	21
Vehicle	26	25	25	25	25	26	26
Miscellaneous - fishing				**41.7**	**43.4**	**39.8**	**40**
Miscellaneous - fishing				42	43	40	40
Miscellaneous - other				**1.5**	**1.5**	**1.2**	**1.3**
Miscellaneous - other				2	2	1	1
Miscellaneous - fishing	**37.8**	**38.3**	**40.2**				
Miscellaneous - fishing	38	38	40				
Miscellaneous - other	**1.5**	**1.5**	**1.5**				
Miscellaneous - other	2	2	2				
Offshore	**19**	**20.2**	**22.4**	**21.4**	**19.6**	**19.9**	**20.5**
Offshore	19	20	22	21	20	20	21
Service - other	**11.6**	**12**	**12.4**	**13.2**	**13.1**	**13.8**	**14.1**
Service - other	12	12	12	13	13	14	14
Service - tug	**29**	**32.2**	**34.3**	**35.3**	**35.6**	**39.4**	**40.3**
Service - tug	29	32	34	35	36	39	40
Yacht	**2.2**	**2.6**	**3.1**	**3.5**	**3.6**	**4.5**	**4.9**
Yacht	2	3	3	4	4	5	5
Grand Total	**961.7**	**956.8**	**964.1**	**991**	**1026.6**	**1063.6**	**1056.5**

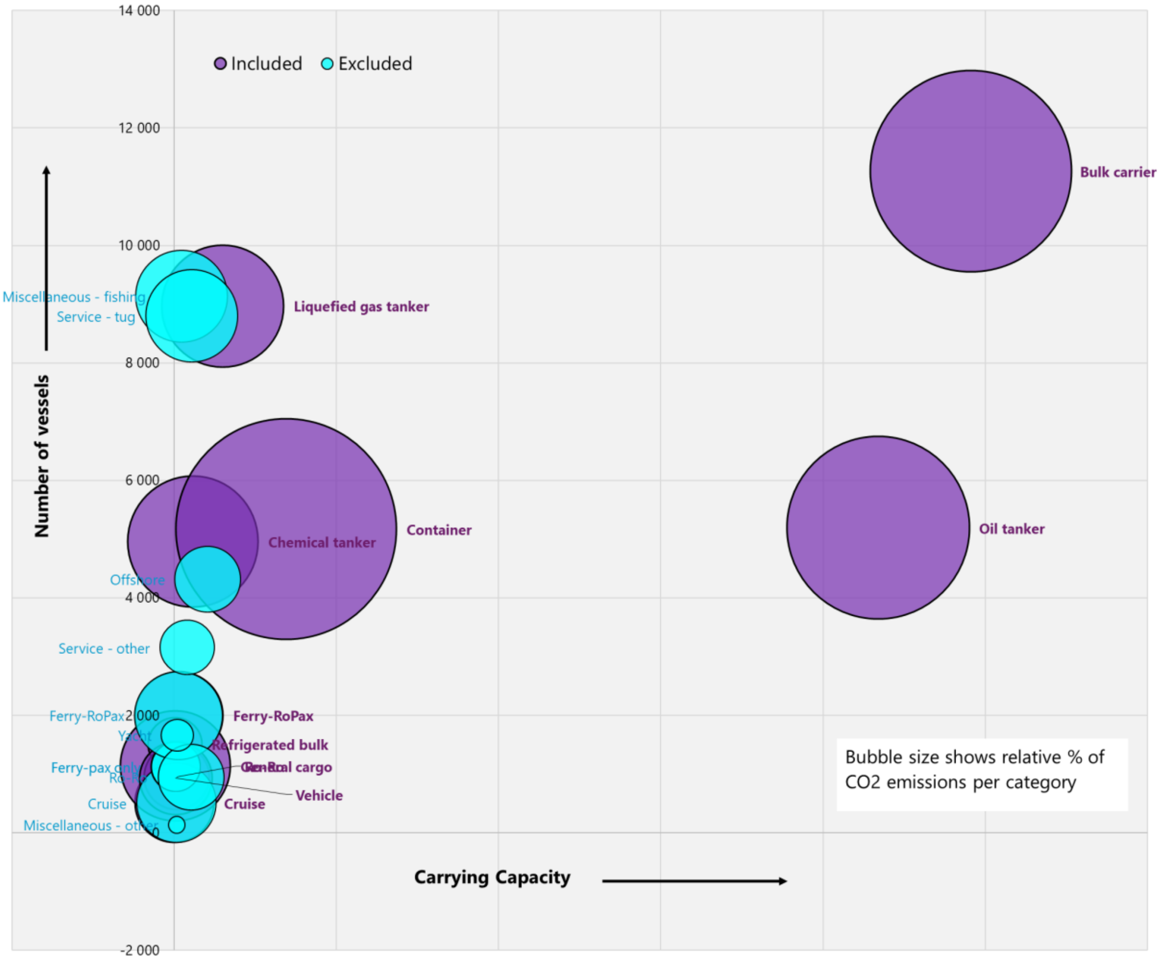


Figure 19: Relative percentage of CO2 emission per vessel category

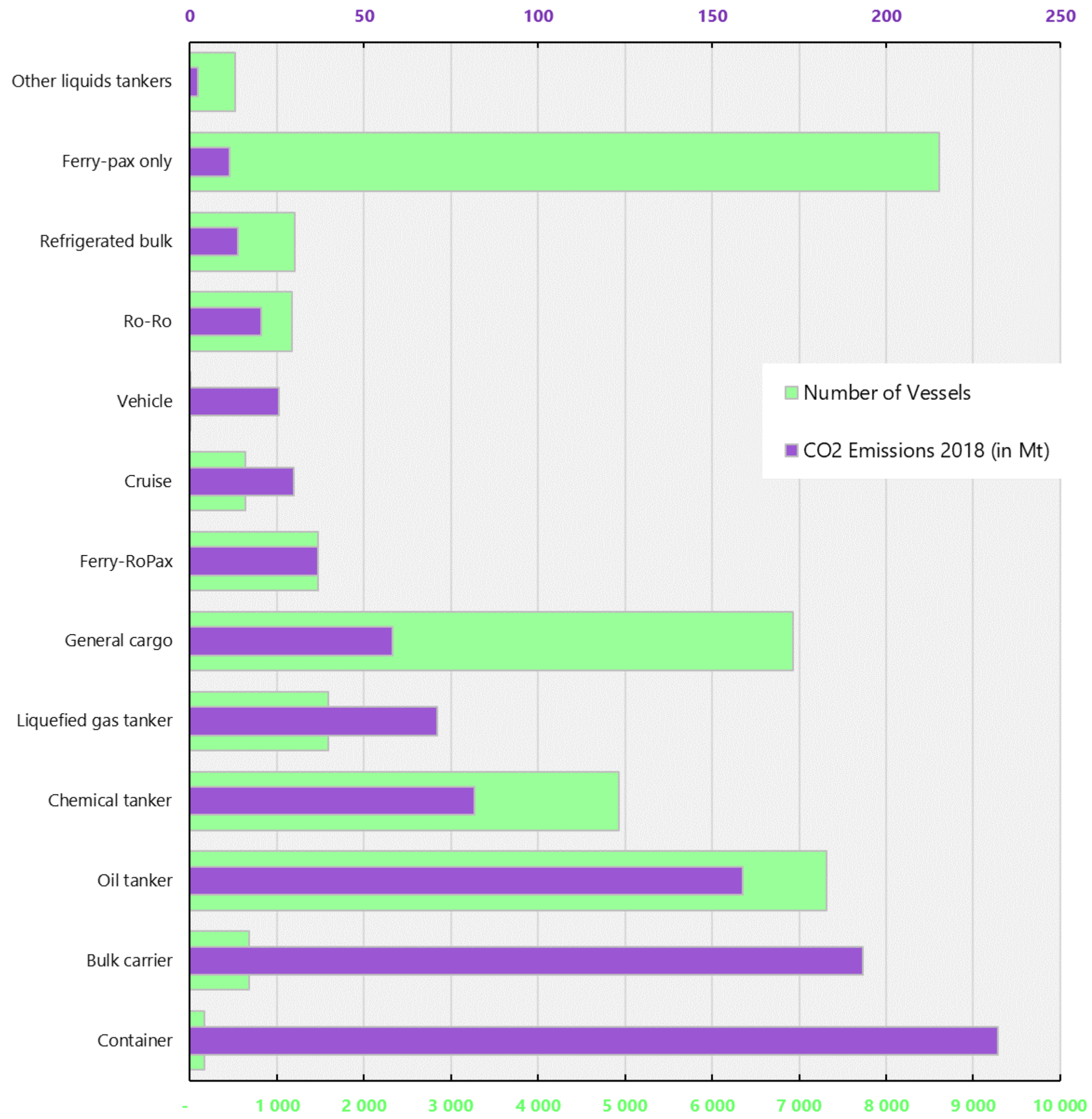


Figure 20: Summarised Data Fleet Coverage (Adapted from IMO 2021a)