Marielle Laetitia SORGE

Hydrogène de France
2 Place Ravezies
33300 Bordeaux
France

Source: World Ports Sustainability Program

The transition towards 'Green Ports': implementation approaches for an effective adoption of the most impactful emission reduction measures in view of port decarbonization

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Thesis tutor: Thomas ZEROUAL

Declaration of honour

I, the undersigned Marielle Laetitia Sorge

Specialization: "Supply Chain Management, Logistics Track"

Student number: 951900081

Title of the thesis: The transition towards 'Green Ports': implementation approaches for an effective adoption of the most impactful emission reduction measures in view of port decarbonization

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Marielle Sorge

Abstract

Over the centuries, ports have become strategic multimodal nodes in international supply chains, distributing immense shares of global trade goods. Besides the related economic growth worldwide, the growing relevance of the maritime sector, and ports specifically, also largely contributes to extensive energy use and deriving greenhouse gas emissions. Due to serious environmental concerns based on manmade global warming, the port industry has been urged in the past years to engage in its own energy transition, a dynamic phenomenon known as 'Green Ports'. Due to lacking current research on the topic, this master thesis will answer the following research question:

The transition towards 'Green Ports': Which implementation approaches can be employed for an effective adoption of the most impactful emission reduction measures in view of port decarbonization?

A systematic literature review has been undertaken through topic-relevant keyword combination with the aim of extracting the most impactful emission reduction measures and their characteristics, which resulted in 44 high-quality secondary scientific publications, out of which 446 primary sources have been used. In order to evaluate the identified measures, a questionnaire has been sent to 714 employees of port and port associations of the European Union, resulting in 56 valid responses. Furthermore, four expert interviews with Sustainability Managers of European ports have been conducted for additional qualitative insights. Finally, the results of the literature review, of the survey and of the interviews have been assembled and compiled for compact recommendations. Hence, practical guidelines for the transposition of emission reduction measures based on priorities, responsibilities, and best practices are delivered to contribute to the support of ports for facilitated decision making and related call to actions in their green transition.

Keywords: green ports, emission reduction, CO2, energy transition, implementation

Résumé

Au fil des siècles, les ports sont devenus des nœuds multimodaux stratégiques dans les chaînes d'approvisionnement internationales, distribuant d'immenses quantités de marchandises dans le commerce international. Outre la croissance économique qui en découle à l'échelle mondiale, l'importance croissante du secteur maritime, et des ports en particulier, contribue aussi largement à la consommation d'énergie et ainsi, à l'émission d'émissions de gaz à effet de serre. En raison des graves préoccupations environnementales liées au réchauffement climatique provoqué par l'humain, l'industrie portuaire a été incitée ces dernières années à s'engager dans sa propre transition énergétique, un phénomène dynamique connu sous le nom de "Green Ports" (ports verts). En raison du manque de recherches actuelles sur le sujet, ce mémoire de fin d'études répondra à la question de recherche suivante :

La transition vers les "ports verts" : Quelles approches de mise en œuvre peuvent être employées pour une adoption efficace des mesures de réduction d'émissions les plus impactantes en vue de la décarbonation des ports ?

Une revue systématique de littérature a été entreprise par le biais d'une combinaison de mots-clés pertinents, dans le but d'extraire les mesures de réduction des émissions les plus efficaces et leurs caractéristiques, ce qui a donné lieu à 44 publications scientifiques secondaires de haute qualité, dont 446 sources primaires ont été utilisées. Afin d'évaluer les mesures identifiées, un questionnaire a été envoyé à 714 employés de ports et d'associations portuaires de l'Union européenne, ce qui a permis d'obtenir 56 réponses valides. En outre, quatre entretiens d'experts avec des responsables de développement durable de ports européens ont été menés pour obtenir des informations qualitatives supplémentaires. Enfin, les résultats de la revue de littérature systématique, de l'enquête et des entretiens ont été rassemblés et compilés en vue de l'élaboration de recommandations compactes. Ainsi, des lignes directrices pratiques pour la transposition des mesures de réduction des émissions basées sur les priorités, les responsabilités et les meilleures pratiques sont fournies afin de contribuer au soutien des ports pour une prise de décision facilitée et appels à actions liées dans leur transition verte.

Mots-clés : ports verts, réduction des émissions, CO2, transition énergétique, implémentation

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A special thank you goes to my colleague and friend Leo Benotteau from HDF Energy, the company where I did my internship simultaneously to writing my master thesis. Leo managed to convince and enthuse me for the topic of port decarbonization within a very short time. Thanks to Leo's initiative and commitment towards me as an intern, he involved me in a project to electrify ships at berth using fuel cells on barge in the port of Rouen, with possible navigation to the ports of Seville or Rotterdam. As part of this project, and due to the increasingly important role of ports for alternative fuels such as hydrogen, Leo has shared his constantly new-found knowledge with me, and has even taken me to a dedicated trade fair in Barcelona, where I could directly get in touch with Port Authorities. Through all these positive actions, Leo did not only help me find the topic of my master thesis, but also supported me thematically at all times and shared relevant contacts for the interviews I conducted. Leo, a thank you is not enough to express how much I value your support.

I also warmly thank my tutor, Thomas Zeroual. First, I would like to emphasise that you were the reason why I decided to choose the SCM specialisation after our joint Supply Chain course in the 3rd semester of my studies, back in 2019. Second, after you thoroughly demonstrated in the course how much the energy sector contributes to man-made global warming, I have since that moment on decided to dedicate my professional career to the energy transition. In this sense, I was all the more pleased to have you as a personal companion for my last study project, in Supply Chain Management, for a topic focusing on decarbonization. I would like to thank you for your valuable guidance, tips, tricks, motivation, and humour.

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List of abbreviations

AGV ..... Automated guided vehicles
ARMG ..... Automated RMG
CAPEX ..... Capital expenditures
CO2 ..... Carbon Dioxide
CSR ..... Corporate social responsibility
EMP ..... Energy management plan
EMS ..... Energy management system
e-RTG ..... Electric RTG
ESI ..... Environmental Ship Index
ESPO ..... European Sea Ports Organisation
ESS ..... Energy storage systems
EU ..... European Union
GHG ..... Greenhouse gas
GW ..... Gigawatts
HFO ..... Heavy fuel oil
IAPH ..... International Association of Ports and Harbors
IAV ..... Intelligent and autonomous vehicles
IMO ..... International Maritime Organization
IPCC ..... Intergovernmental Panel on Climate Change
ISO ..... International Organization of Standadization
KPI ..... Key performance indicator
LED ..... Light-emitting diode
LNG ..... Liquified natural gas
MDO ..... Marine diesel oil
NOx ..... Oxides of Nitrogen
OECD ..... Organisation for Economic Cooperation and Development
OPEX ..... Operating expenses
OPS ..... Onshore power supply
PM_X ..... Particulate Matters
PV ..... Photovoltaic
RES ..... Renewable electricity sources
RM ..... Rail movers
RMG ..... Rail mounted gantry cranes
RTG ..... Rubber tyred gantry cranes
SC ..... Stacking cranes
SLM ..... Smart load management
SO_X ..... Oxides of Sulphur
SWH ..... Solar water heating
TEN-T ..... Trans-European Transport Network
UN ..... United Nations
UNFCCC ..... United Nations Framework Convention on Climate Change
WPCI ..... World Ports Climate Initiative
YT ..... Yard trucks

Introduction

Historically, ports have played an essential role in transporting goods between civilizations, by contributing to the development of national and international trade routes, meanwhile acquiring a central and strategic position along the global logistic supply chains as a multimodal node. Today, ports are of systematic relevance for globalization and resulting economic growth worldwide (Efimova and Gapochka, 2020). In the near future, it is foreseen that ports will foster their role of universal distribution hubs further. In fact, for the period of 1980 to 2016, global container trade went up by 14,94% (UNCTAD, 2017). And in 2018, nearly 80% of global trade by volume and more than 70% by value were carried by ships, which resulted in an estimated increase of 3,8% of global gross domestic product for the 5-year period between 2018 and 2023 (UNCTAD, 2018). With the rising volumes of goods shipped by sea, the operation in ports is expanding, too, which simultaneously makes the maritime sector a major energy consumer compared to other transportation sectors (MAM, 2021).

According to the International Maritime Organization, the shipping sector produced 1016 million tons of carbon dioxide emissions, 11,3 million tons of sulphur oxides and 20,9 million tons of nitrous oxides in 2014 alone, which respectively accounted for 3,1%, 13% and 15% of global air pollution emissions (IMO, 2014). These emissions are supposed to increase by 50% to 250% by 2050, if the current growth continues without effective countermeasures (IMO, 2018b). From all maritime emissions, about 70% happen in the close port environment (Ballini and Bozzo, 2015).

By causing such important greenhouse gas equivalent emissions, the shipping and port sector damages the natural and urban ecological balance and largely drives climate change (Hua et al., 2020). For ports, global warming results in threats like the rise of sea levels or extreme weather conditions (Ng et al., 2013). As for port workers and port city residents, the resulting emissions from ports and shipping are linked to respiratory diseases, cardiovascular diseases, lung cancer and premature mortality (Bailey and Solomon, 2004).

In the past decades, the reduction of carbon emissions caused by the maritime sector has not attracted great attention from policymakers because this transportation mode releases the fewest grams of carbon dioxide per tonne-kilometre of cargo transported (Daniel et al., 2022). However, due to pressing global environmental concerns in recent years, the environmental interest of the port and shipping industry has grown significantly, with sustainable development having emerged as the guiding principle for the long-term development of ports (Ashrafi et al., 2019). To harmonize port economic activities and environmental concerns, the ‘Green Port’ phenomenon has emerged in 2009 during the United Nations Climate Change Conference (Wu and Ji, 2013), which has since lead to changes in business management agendas (Acciaro et al., 2014a).

For the promotion of emission reduction measures in the port and shipping sector, international organizations have issued documents with basic research to start guiding the industry actors (Wang et al., 2023). But constructing green ports is a long, comprehensive, systematic, and complex task (Baily and Solomon, 2004). The current research around the topic of green ports is said to be still in its infancy (Bergqvist and Monios, 2019), while being more relevant than ever (Argyriou et al. 2022). Within the conducted research, only a few studies actually focus on the practical implementation of appropriate measures (Argyriou et al., 2022; Wang et al.,

2023). To address the lack of research and contribute to filling the identified gap of practical employment support, this master thesis will answer the following research question:

The transition towards 'Green Ports': Which implementation approaches can be employed for an effective adoption of the most impactful emission reduction measures in view of port decarbonization?

This question is divided into two categories. On the one hand, it needs to be assessed which impactful emission reduction measures for port decarbonization exist and what their characteristics are. On the other hand, conclusions need to be drawn to provide effective implementation approaches of the identified measures. Hence, the general purpose of this study is to establish practical guidelines for the transposition of emission reduction measures based on priorities, responsibilities, and best practices to contribute to the support of ports in their green transition. The findings of this research project will provide the concerned port stakeholders with a big picture and categorization of the most important emission reduction measures available for facilitated decision making and related actions.

To get to this result, three different methodological approaches are used. In chapter 1, a definition of the 'Green Port' is firstly fostered based on multiple sources. Then, for the explorative research, a systematic literature review of an entire scientific database is conducted which helps identify the most impactful emission reduction measures and their respective characteristics for solid theoretical foundations. The characteristics of the methodology of systematic literature review is presented in chapter 2, whereas the measures are presented in categories by type of application in chapter 3. Based on the results from the explorative approach, empirical research of quantitative and qualitative data is conducted, whose methodologies are explained in chapter 4. For acquiring the quantitative data, a questionnaire has been sent 714 employees of ports and port associations in the European Union to assess their perception for implementation based on their expert knowledge. For acquiring the qualitative information, several interviews with Sustainability Managers working in ports of the European Union have been conducted, and the respondents of the questionnaire have also been asked for additional information with the aim of identifying best practices from directly concerned stakeholders for port operation. The results of the quantitative and qualitative data are described and analysed in chapter 5. Finally, the obtained data from the survey, the interviews and the literature review are compared and compiled for interpretation, which opens the possibility to present solid recommendations in shape of practical guidelines to answer the research question. Also, the limitations of this work and tracks for future research are enlightened at the very end. Both the recommendations and the limitations are presented in chapter 6.

Before deeply diving into the topic, the author would like to highlight that the interest for green ports has been stimulated due to the executed full-time internship at HDF Energy in Bordeaux, simultaneously to writing this master thesis. HDF Energy is a hydrogen-to-power company providing non-intermittent renewable energy to the power grid and cold ironing to ships in ports, meanwhile developing maritime and railway propulsion, all based on their strategic multi megawatt fuel cell. In this context, the author had the opportunity to work on several cold ironing projects in European ports, which enabled to broaden the implementation knowledge for the very specific measure of onshore power supply for ships at berth. Thus, writing this thesis meanwhile acquiring practical insights was very ideal for both the author and HDF Energy.

1. Definition of the 'Green Port'

As of today, there is no universally acknowledged definition of what a green port is and what it exactly entails. The resulting broad definition gives port stakeholders a certain freedom when setting their environmental goals (Argyriou et al., 2022). However, several varying definitions of the 'Green Port' have been found in the literature.

The term 'Green Port' has officially been proposed in 2009 at the United Nations Climate Change Conference in Copenhagen for promoting sustainable practices in ports, but without giving any official definition (UN, 2009). Some years later, Yun et al. (2018) proposed a definition designating a 'Green Port' to referring to a "healthy ecological environment, reasonable utilization of resources, low energy consumption and pollution". The PIANC later defines a 'Green Port' as the "one in which the Port Authority and port users pro-actively and responsibly develop and operate, based on an economic green growth strategy", meanwhile pointing out the following key issues of green port philosophy: environmental quality (soil, water, air and noise), habitat and integrity of ecosystems, energy efficiency and energy transition (from fossil towards renewable), materials and waste management, and climate change mitigation and adaptation (PIANC, 2014). In other definitions, a 'Green Port' is described as having the objective of balancing environmental challenges and economic demand (Bergqvist and Monios, 2019), while striving "to establish sustainable ports by increasing both their economic and environmental competitiveness" (Maritz et al., 2014). For Fao (2014), "a green port involves the integration of environmentally friendly methods of port activities, operation and management".

Additionally, several 'Green Port' definitions also focus on the three-dimensional balance of sustainability criteria (Bergqvist and Monios, 2019; Lam and Notteboom, 2014; Chang and Wang, 2012; Cheon and Deakin, 2010), being economic prosperity, social wellbeing, and environmental quality (Lam and Yap, 2019). In the green port context, the need of ports to be socially responsible for their social environment has specifically been underlined by Wang et al. (2023). Taljaard et al. (2021), however, explains that the "Sustainable Port Development", including social sustainability, builds on the "Green Port Concept", and is therefore not directly related to the initial definition.

Hence, this master thesis will be based on the above-described objective of balancing environmental challenges and economic demand. Since the reduction of emissions is directly contributing to the implementation of green ports (Lam and Notteboom, 2014) and considered the most prominent factor for greening ports (Pettit et al., 2018), a specific focus will be set on emission reduction measures within the 'Green Port' transition.

It is further to be mentioned that for simplicity reasons, the terms "port" and "Port Authority" used in this thesis comprise all entities regulating, managing, and developing port activities, operation, infrastructure, and facilities, for instance Port Authorities, terminal operators, government agencies, or public-private-partnerships, whose allocation of ownership and business tasks vary from port to port.

2. Methodology 1 – systematic literature review

In any research field, it is essential to focus on the existing literature to justify and answer the developed research question. Reviewing the literature can have three main goals: evaluating theory or evidence to check validity (Tranfield et al., 2003), engage in theory development for new conceptual frameworks (Baumeister & Leary, 1997), or giving an overview of a research problematic (Snyder, 2019). In this master thesis, the latter of the three given goals is pursued. By using a concept based on certain guidelines and standards, an academic review can also become a proper research methodology (Snyder, 2019). Hence, instead of randomly picking topic-relevant literature, a systematic literature review has been conducted as first methodology, differentiating the theoretical framework of this master thesis from most other ones.

In the process of a systematic literature review, all empirical sources of a formulated topic and its deriving criteria for eligibility are collected and analysed following a pre-defined protocol (Liberati et al., 2009). In this way, the entire available evidence of a research topic can be revealed, which minimizes bias and provides more reliable findings for later conclusions and decisions (Moher et al., 2015; Oxman et al., 1993; Antman et al., 1992). Davis et al. (2014) referred to the method as being the gold standard among reviews.

Having its origin from the biological and medical research areas (Moher et al., 2015), this method has initially been used to get reliant, transparent, and reproducible trial data. In business research, systematic literature reviews are not yet broadly used but the tendency is increasing (Snyder, 2019). In fact, Tranfield et al. (2003) have adjusted the methodology of systematic literature reviews for social sciences, all by setting principles like transparency, replicability, variety of sources and analysis frameworks. Therefore, the methodology of the following review is inspired by the recommended procedure for structured reviews by Denyer and Tranfield (2009), following the five steps of (1) question formulation, (2) locating studies, (3) study selection and evaluation, (4) analysis and synthesis and (5) reporting and using the results.

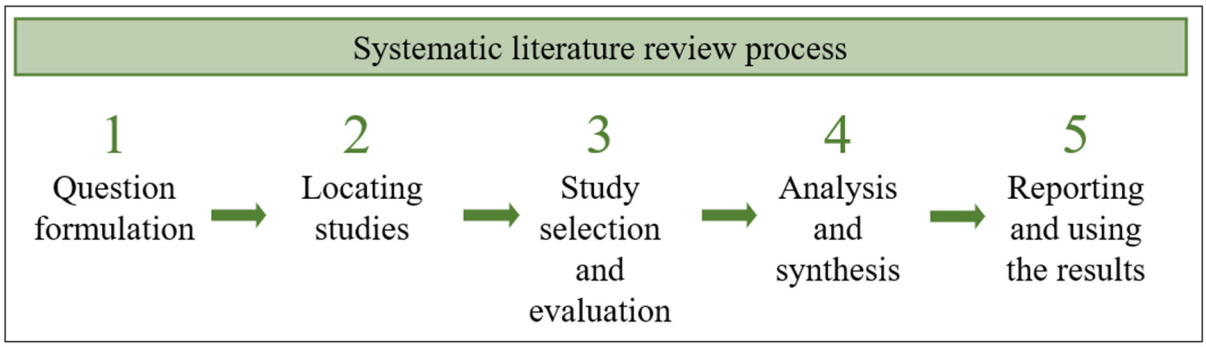

Figure 1: Systematic literature review process. Source: Denyer and Tranfield (2009).

According to the same authors, the results obtained are either to be explained via meta-analysis for quantitative methods, or via textual analysis with a priori coding for qualitative methods. Since the extracted information of the following literature review was both of qualitative and quantitative data, it was difficult to use either of the predefined frameworks. Tranfield et al. (2003) have themselves approved that performing meta-analysis on studies with differing methodological approaches is challenging. In addition, since a master thesis is not comparable with

a doctor thesis or an academic article in terms of timeframe, content and guidelines, the information extracted of the theoretical part of the master thesis focusses on generalization of the chosen topic. In fact, the university guidelines set certain restrictions for solely focusing on one specialized aspect in detail – a topic is required to be covered in its whole. Therefore, the analysis has been undertaken by splitting the topic of green ports into separate thematic chapters. In order to still give an indication of the relevance of a subtheme within the literature, every single source having addressed this subtheme has been indicated behind the phrase. Therefore, some phrases will contain more author sources than others. Furthermore, the relevance of each topic and subtopic has been integrated into the coding evaluation in chapter 6, recommendations.

According to Snyder (2019), systematic literature reviews contribute, among others, to inform policy and the practice. This, for instance, is not the case for other common types of reviews, like semi-systematic reviews for the elaboration of theories (Wong et al., 2013) or integrative reviews for establishment of frameworks and perspectives through literature critique (Torraco, 2005). Hence, the systematic literature review has been decided to be the most accurate methodologic approach to partly answer the research question.

For step (1), question formulation, deep preliminary research has been conducted. The primary need was to assess and understand the scope and relevance of the topic of sustainability in ports. Therefore, the literature has been scanned in different recommended scientific databases, like Google Scholar, Ebsco Host, Wiley, Research Gate and Science Direct. Different, randomly chosen sustainability-related keywords or phrases have been entered into the search engines and resulting abstracts have been skim read. During this exercise, the search term of ‘Green Port’ has been mentioned numerous times, which led the author to put a stronger focus on this specific topic. While browsing the different databases, the related content became more concrete and tangible, as well as the number of articles published. Within the topic of ‘Green Port’, it appeared that not only environmental sustainability was a major research focus, but especially measures to reduce emissions from ports. According to Snyder (2019), systematic literature reviews are not usually suitable or even possible for summarizing a large field of research because of the inexhaustibility of existing state-of-the-field literature. However, by narrowing the focus of the analysed topic down to emission reduction measures for port decarbonization only, instead of including the entire three-dimensional or environmental sustainability, the number of studies has been reduced to a scope which permitted carrying out a systematic literature review. Also, the topic of ‘Green Port’ turned out to still be a rather small research topic as of today. To get to this conclusion, tireless pre-research and testing has been conducted during over two months’ time, an exhaustive but fundamental effort for the subsequent steps of the methodology.

Once the feasibility of the systematic literature review was proven, a review-specific question, which is partly related to the overall research question, could be set up, which is the following:

"The transition towards 'Green Ports': What are the theoretical foundations of the most impactful emission reduction measures for port decarbonization?"

In the next step, (2) locating studies, the methodology reverts to the described procedures in (1). The exact steps of the review protocol are visualized below:

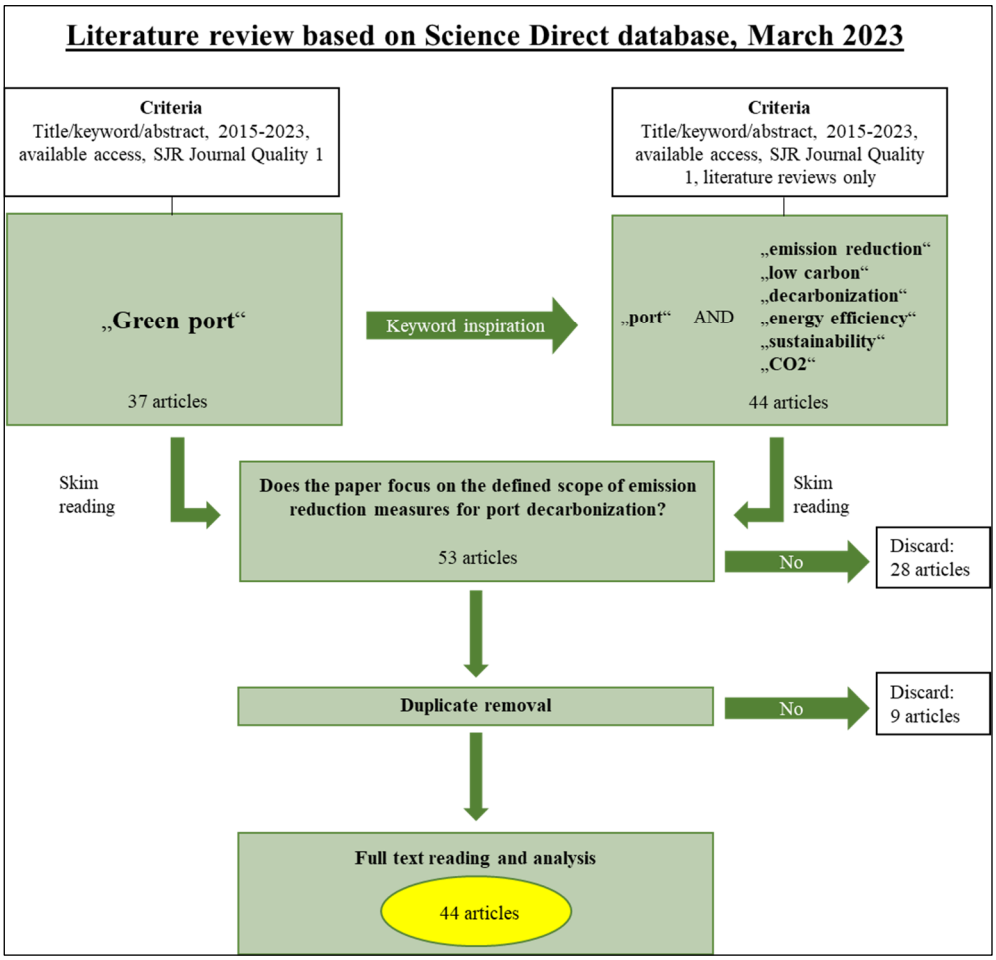

Figure 2: Visualization of the review protocol. Source: own illustration.

Firstly, it has been decided to solely use the database Science Direct for article collection. Science Direct is "the world's leading platform for peer-reviewed scientific literature" (Science Direct, 2023), in the fields of Physical Sciences and Engineering, Life Sciences, Health Sciences and Social Sciences and Humanities. According to Seuring and Gold (2012), peer-reviewed journals are in fact an essential communication channel of researchers. Science Direct has also been recommended by several professors of the author's two universities. Furthermore, Science Direct was the database with most publications for the chosen search terms, included most topic-related journals in the category of Supply Chain Management and had the highest access quote through the institutional login. In fact, Ebsco Host, Wiley, and Research Gate did offer a scarce amount of 'Green Port'-related articles, and the available ones have already been covered by Science Direct. As for Google Scholar, the content of the found literature was too often related to completely other fields or of poor quality.

Secondly, the search keywords have been fixed, comprising a single search area, but in different approaches. The main keyword is 'Green Port', in quotes, which translates into the search of this very specific term within the database. By reading through the resulting literature, this first

search term served as further keyword inspiration with focus on the established guiding question. The additional and even more specific keywords used are “port”, respectively combined with “emission reduction”, “low carbon”, “decarbonization”, “energy efficiency”, “sustainability”, and “CO2”, all as well in quotes.

In the step (3), study selection and evaluation, additional criteria for a filter model have been added. It has been decided to only search for the keywords in the “Title, keyword, abstract” section to avoid formal hits of the topic. Also, the time frame of 2015 to 2023 was set up, limiting the number of articles further. Since the transition towards decarbonization has especially been sped up in the years following the 2015 Paris Agreement for limitation of global warming, the timeframe seems plausible. Another fundamental criterion is the available access to the literature through institutional login of the author’s both universities, HWR Berlin and ESCE Paris. According to Tranfield et al. (2003) and Wong et al. (2013), the quality of the selected literature is of crucial importance for the overall value of the outcoming systematic literature review. Therefore, only publications with 2022 SCImago Journal Ranking - Quality 1 have been included into the review. SCImago Journal Ranking evaluates the quality of worldwide scholarly journals by assessing their number of citations received as well as the prestige of the journals having cited the sources (SJR, 2022). A last criterion has further been added for the combined keyword selection inspired by the overall one of ‘Green Port’. Since the aim of the systematic literature review was to summarize the state-of-the field, only pre-written summaries of literature reviews have been included in the final collection process. The resulting own literature review is thus based both on single articles and literature reviews, most focusing on different specialized subtopics.

By using this strictly set filter model, 37 articles have been found for the search string ‘Green Port’ and 44 articles for the combination of the keyword “port” with the 6 topic-related keywords, which results in 81 articles in total as of the reference date 31st of March 2023. The process of the review continued with skim reading these 81 articles, by focusing on whether the content focusses on the previously defined scope of emission reduction measures for port decarbonization. 28 articles did not match this condition, either because they focused on other environmental topics within ports excluding emission reduction, or because they were purely technical or engineering with focus on construction, or because they were related to ports in the medical sciences. The remaining 53 articles have then been scanned for duplicates. 9 further articles have subsequently been discarded. Finally, 44 articles remained for in depth full text reading and analysis. The results of the steps (2) and (3) are documented in an extraction sheet, in annex 1. With the described process of selecting articles, the following systematic literature review provides the necessary logic, validity, quality, and possibility of reproducibility, by covering all the relevant data around the ‘Green Port’ topic for port decarbonization.

Step (4), analysis and synthesis, will follow in chapter 3, by summarizing all found emission reduction measures in ports and inductively categorizing them into separate chapters. As mentioned above, the analysis of the literature will be done by compilation of the various topics to meet the master thesis requirements for topic generalization. For the results, the primary sources

used in the 44 analysed articles will be cited, which resulted in 446 single sources for the theoretical findings. An overview of the subtopics extracted from the review and comprising the emission reduction measures for port decarbonization is visualized below:

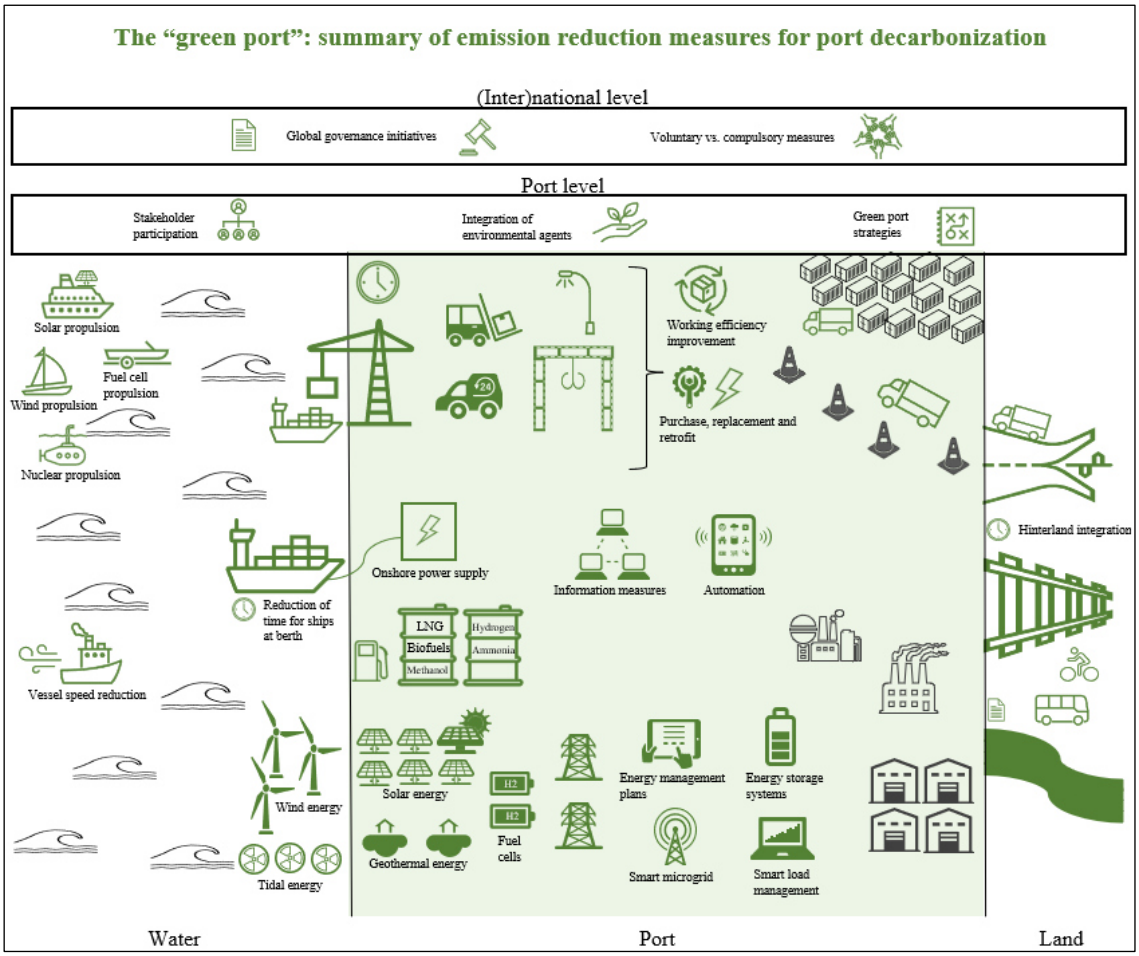

Figure 3: Summary of emission reduction measures for port decarbonization. Source: own illustration.

Step (5), reporting and using the results, will then be carried out in combination with the results of the field research findings, in chapter 6.

3. Synthesis of the systematic literature review

This chapter comprises the findings of the theoretical foundations extracted from the systematic literature review. The analysis is presented as a synthesizing summary, divided into chapters and subchapters.

3.1. The leading role of port governance

This part will focus on the development of environmental policy and regulatory framework.

3.1.1. Development of environmental policy and regulatory framework

This subchapter zooms on global governance initiatives and comparison between voluntary and compulsory measures.

3.1.1.1. Global governance initiatives

Since the publication of a report from the Intergovernmental Panel on Climate Change (IPCC) which proves observations of increased atmospheric and ocean currents since 1950, global movements for decarbonization and environmental protection against climate change have been initiated (Howell et al., 2017). The first initiatives have been introduced by the IPCC in 1988 and by the United Nations Framework Convention on Climate Change (UNFCCC) in 1994 (Talberg et al., 2013; IPCC, 2011). Two major political momentums have further been celebrated in 2005, when more than 192 countries signed the Kyoto and ten years later in 2015, when 195 countries signed the Paris Agreement (Reynolds et al., 2017; Dutton, 2015). Also in 2015, the United Nations (UN) adopted 17 Sustainable Development Goals under the 2030 Agenda, a global framework for international cooperation for economic, social, environmental, and governance elements (Argyriou et al., 2022). This general international dynamic to fight global warming has also resulted in port specific ambitions, especially through international institutions. It has, for instance, been proven that port policy is strongly and directly influencing green port implementation (Munim et al., 2022).

In 1973, the International Maritime Organization (IMO) has adopted the International Convention for the Prevention of Pollution from Ships (MARPOL), which regulates the prevention of marine pollution, greenhouse gas emissions as well as energy savings, including the port environment (Castellano et al. 2020). Later, in 2005, the Maritime Environmental Protection Committee (MEPC) made the proposition of imposing a carbon emission tax on ports (IMO, 2005). In 2008, the International Association of Ports and Harbors (IAPH) and IMO published a report for specific ship-to-port measures in the short, middle, and long term, calling for encouragement of related port technologies, especially clean onshore power (Wang et al., 2023). Then, in 2010, the World Ports Climate Initiative (WPCI) published both details of environmental impacts in marine ports and related reduction measures, as well as a document called ‘Carbon Footprint of Ports’, targeting the development and improvement of greenhouse gas (GHG) emissions of ports (WPCI, 2010). A similar document was published in 2011 by the Organisation for Economic Cooperation and Development (OECD), pointing out the role of ports regarding environmental impacts (OECD, 2011).

After the introduction of emission and pollution reduction measures from international shipping, especially Carbon Dioxide (CO2), Oxides of Nitrogen (NOx), Oxides of Sulphur (SO_X) and Particulate Matters (PM_X) in 2011 (IMO, 2011) and 2013 (IPCC, 2013), the IMO published in April 2018 its ‘Initial Strategy’ which aims a reduction of GHG emissions from ships and ports by at least 50% by 2050 in comparison to 2008, including an assessment document called “Port Emissions Toolbox” (IMO, 2018a; IMO, 2018b). To fulfil the strategy, the related resolution MEPC.323 has further been adopted in 2019, leading “Member States to encourage voluntary cooperation between the port and the shipping sectors to contribute to reducing GHG from ships“, by promoting regulatory, technical, operational and economic action (IMO, 2019).

In the European Union (EU), with the continent-specific climate objectives and roadmaps under the European Green Deal from 2019 and the European Climate Law from, the European Commission introduced sector specific policies with the introduction of the 'Fit for 55' package in July 2021. The project related to the FuelEU Maritime initiative include for instance the increased use of renewable or low-carbon fuels and requirements for onshore power supply (OPS) for ships at berth (EC, 2021a; EC, 2021b; EC, 2019). Before the adoption of the EU Green Deal, the European Sea Ports Organisation (ESPO) already supported European ports in the adoption of green practice programs (ESPO, 2016).

In Europe as well as on a global scale, however, there are large observable differences from country to country and from port to port in regard to the adoption of environmental measures, which is directly related to the local geographical, economic, regulatory and political context (Sornn-Friese and Poulsen, 2016; Lam and Notteboom, 2014). In this sense, Tseng and Pilcher (2019) found that the literature is broadly calling for more intervention from international organizations regarding international guidelines and regulations, as well as increased demand for responsibility by governments.

3.1.1.2. Voluntary vs. compulsory measures

Introducing green port practices can be based on either compulsory or voluntary measures to encourage ports to use environmentally friendly operation (Tseng und Pilcher 2019). The compulsory measures can be divided into positive rewarding and negative punishment measures. In spite of the rewarding measures, the literature mentioned economic governmental subsidies and funding programs, tax rate reduction and port fee discount, and for the punishment measures, air pollution pricing, the imposition of fines and forced suspension of business have been suggested (Xu et al., 2021; Wang et al., 2020; Tseng und Pilcher 2019; Radu and Grandidier, 2012; EU, 2003). However, the listed punishment measures should be controlled within a reasonable scope to avoid further negative influences (Xu et al., 2021).

3.1.2. Fundamentals for green port management

Besides port policy and regulation, it has been proven that it is also the port management which drives the development of green ports the most, meanwhile still considered as being the least competitive attractiveness factor of ports today (Munim et al., 2022). However, port authorities are increasingly pressured to greening their ports, not only in view of growing their environmental and economic competitiveness, but also for safeguarding their 'license to operate' (Roh et al., 2016; Lam and Van der Voorde, 2012). Further, the literature suggests to ports that setting environmental parameters enables green port evaluation and in result, better governance practices (Hua et al., 2020). Therefore, it is fundamental to firstly understand the complexity of ports in the given context.

3.1.2.1. Stakeholder participation

One of the most complex managerial tasks for greening ports is the engagement of all port stakeholders. Following to Kahane et al. (2013), the term stakeholders refers to "an individual,

a group, or an organization affected by the proposed changes, such as shipping companies, store owners, local industry, local organizations, and social and academic institutions such as schools and universities". This definition underlines the extent to which the reduction of emissions exceeds the responsibilities of port authority operations (Munim et al., 2020). In fact, various types of stakeholders own, manage, and maintain the ports, differing in size, surroundings, activities and interests (Buckwell et al., 2020; Almutairi et al., 2019; Ha et al., 2019). Also, ports can be either publicly regulated, privately owned or operate under a hybrid public and private custody (Buckwell et al., 2020; Dooms, 2019). Furthermore, the integration of citizen participation for climate action in ports is gaining more attraction, especially in the European Union (Spandagos et al., 2012).

Cooperation between all these named stakeholders is a complex task, especially in regard to finding common goals (Cheon, 2017; Le et al., 2014). But at the same time, coordination is essential for green port implementation to succeed (Lin et al., 2022; Homsombat et al., 2013).

3.1.2.2. Integration of environmental agents

Integrating the human factor into the transition to green ports is fundamental for port operators to really understand the potential environmental risks, pollution reduction measures and corporate social responsibility (CSR) actions planned to fully support the green port project (Campisi et al., 2022; Heij and Knapp, 2012; Mellin and Rydhed, 2011; Petrosillo et al., 2009). One way to integrate the human factor is through the integration of sense-agents into the change process, who will take the key role of giving the port employees a meaning to the environmental reform, materialize the reform plan into action and create a 'going green' identity (van der Heijden et al., 2012; Dunphy et al., 2007). Further, the implementation of environmental multi-disciplinary teams as appropriate and integrated approach of port management is suggested in the literature, to encourage participation and motivation towards port greenification (Pavlic et al., 2014), while transparently disclosing information (Xia et al., 2022). Another fundamental component within the environmental governance system of ports is the engagement of so-called climate change managers, environmental managers, and energy managers (Pavlic et al., 2014; Ng et al., 2013). In addition, the literature also mentioned the implementation of national umbrella organizations to fulfil the need for coordination and uniformity in the promotion of the green port concept (Homsombat et al., 2013), especially because the vision of ports and the one's from government officials differ largely (Tseng and Pilcher 2019).

3.1.2.3. Green port strategies

Another important managerial task of port authorities is the demonstration of port's contribution regarding their environmental efforts. According to Xia et al. (2022), "the report is an epitome of the green management concept and the effectiveness of green measures", demonstrating the taken responsibilities (Wang et al., 2023). Lam and Li (2019) conducted a benchmarking of worldwide green marketing initiatives in major ports and found numerous best practices. Firstly, to reflect the environmental commitment of the port management, it is recommended to specify the latter in the mission statement, vision, or organizational goals, which leads to differentiation from competitors. Secondly, the responsible bodies for environmental measures

need to be integrated into the port's structure, for example into the organizational chart. Thirdly, the environmental functions need to be clear, such as sections dedicated to climate and sustainability, separate annual and environmental reports, or plans or development initiatives, published for example in reports, news releases, publications, or the port's websites. In general, it is necessary for environmental measures to be in line with the overall port strategy. In this regard, it is essential for the green marketing efforts to be representative and transparent, to avoid greenwashing and thus credibility in the customers and policymakers' eyes.

Another, indirectly related proposed measure, is to let go of today's mainly used private governance model, which stand for monopolistic behaviour, port speculation and missing interest in the long-term perspective of port development. Instead, the landlord model is recommended to be introduced, opening the opportunity to push private operators to implement green practices (Munim et al., 2020).

3.2. The functional role of port operation measures

This part will focus on onshore power supply, energy efficiency for port equipment and fleet transformation, and smart resources and automation.

3.2.1. Onshore power supply

Most ships consist of two separate types of engines, being the main engine, used for propulsion, and auxiliary engines, used for hoteling activities such as power system maintenance, lightning and refrigerating. During docking time, the propulsion engines are usually turned off, but the auxiliary engines keep turning to provide the necessary onboard power supply, while burning diesel, heavy fuel or liquified natural gas (LNG) and thus emitting emissions (Iris and Lam, 2019). With the aim of reducing these emissions, the technology of onshore power supply, or shore power or cold ironing, consists in plugging a vessel to the dock by supplying electric power from the shore side to switch off the auxiliary engines (Anh et al., 2022; Yu et al., 2022). Simplified, the containerized equipment of an onshore power supply system is linked to a regional substation, which converts high-frequency and transforms the high-voltage electric input power from the grid into an alternating current with specific voltages and frequencies. Through a cable and further equipment, named shore-ship connecting system, the requirements of both the onshore power supply interface and the ship's power receiving interface are matched. Then, with the installed ship-borne power receiving system, including cable winch, transformer, and relevant management system, the power distribution onboard of the ship is regulated (Chen et al., 2019).

The pioneer in applying shore power is the Swedish port of Gothenburg, whose move in the year 2000 started attracting greater attention for the technology throughout the industry and initiated several major European ports to follow their example, with the result of shore power becoming an integral component of European port modernization from 2010 on (Liu et al., 2020; Zhang et al., 2015).

However, even though electricity consumption does not release direct carbon equivalent emissions, shore power cannot be considered a zero-emission technology (Sciberras et al., 2016). In

fact, since the source of emission is transferred to the source of power generation, the indirect life-cycle emissions need to be considered, too, including emissions from energy extraction, transportation, consumption and generating stations (Peng et al., 2021). Yun et al. (2018) and Peng (2016) both found out that when using thermal power plants as power source and having large transmission distances, the indirect carbon emissions from the shore power technology turn out to be higher than using the conventional method of diesel-, fuel- or LNG-powered auxiliary engines. To give an approximation, the CO2 abatement potential amounts 99.5% in Norway due to the main source of hydroelectric power, 85% in France where nuclear power is the main electricity source, and only 9.4% in the USA with a major use of natural gas and coal as electricity sources (Hall, 2010).

Numerous studies using OPS have been identified in the literature, demonstrating the enormous greenhouse gas emission reduction potential:

Port of reference	Emission reduction potential	Source
Port of Oslo	63–78%	López-Aparicio et al. (2017)
Port of San Pedro Bay	53%	SPBP (2017)
Port of Osaka	66%	Styhre et al. (2017)
Port of Gothenburg	61%	Styhre et al. (2017)
Port of Long Beach	18%	Styhre et al. (2017)
Port of Sydney	8%	Styhre et al. (2017)
Port of Shenzhen	20%	Yang et al. (2017)
Ports of Antwerp and Genoa	50%	Acciaro et al. (2014b)
Port of Kaohsiung	57%	Chang and Wang (2012)

Table 1: Emission reduction potential of OPS. Sources: as indicated.

Furthermore, SOx-reductions of 46% and 30-60% and NOx-reductions of 92% and 40-60% were calculated, respectively (Zis et al., 2014; Hall, 2010). Based on these numbers, the use of alternative power for cold ironing application is considered one of the most impactful solutions to reduce emissions in ports (Hoang et al., 2022). However, it is also to be mentioned that the reduction potential varies strongly depending on factors such as ship handling time, regional policies and the calculation method used (Iris and Lam, 2019; Díaz-Ruiz-Navamuel et al. 2018; Zis et al., 2014). Furthermore, onshore power reduces vibrations and acoustic noise, providing health and living benefits for port workers and port city residents (Styhre et al., 2017; Borkowski and Tarnapowicz, 2012).

Other advantages for the use of this technology are its feasibility in the short term due to the component availability and experience on the market, the comparatively fast international legislation and promotion, the low cost of shore power compliancy for newly built ships and the lower price of electricity compared to fuel power (Daniel et al., 2022).

But the adoption of shore side electricity also accounts several barriers. Besides policy and regulatory issues, it is in a first place the high initial investment cost which slows the implementation down, be it regarding port and berth infrastructure construction or updating, installing of ship-use power receiving facilities, or retrofitting costs for ships (Wang et al., 2023; Schwartz et al., 2020; Chen et al., 2019; Dai et al., 2019; Radwan et al., 2019; Innes and Monios, 2018; Tseng and Pilcher, 2015; Arduino et al., 2011). Besides, the operation and maintenance costs of OPS systems are also considerable, represented by the cost of manpower, regularly inspecting and testing equipment replacement and repair, but mainly influenced by the fluctuating price of electricity provided by the grid (Yu et al., 2022; Xu et al., 2021; Peng et al., 2019; Radwan et al., 2019; Innes and Monios, 2018; Zis et al., 2014; Bao and Jiang, 2010).

Besides, by using direct power supply from the grid, there is a risk of grid overload due to the huge additional power consumption (Radwan et al., 2019; Tseng and Pilcher, 2015; Khersonsky et al., 2005). Therefore, additional peak levelling technologies are recommended to ensure system reliability during peak hours (Daniel et al., 2022; Tsekouras and Kanellos, 2016), for example fuel cells, turbines, or LNG on barge (Coppola and Quaranta, 2014; Battistelli et al., 2012).

The allocated power capacity configuration of shore power facilities is another important issue (Wang et al., 2018), which is directly linked to the size of a ship as well as to the inter-arrival time of ships (Peng et al., 2019). Adapting and matching the electrical supply voltage and frequency is a further important barrier for OPS due to lacking unified interface standards, varying regarding the size of ships and port or national grids around the world (Daniel et al. 2022), (Radwan et al., 2019; Tseng and Pilcher, 2015; Vaishnav et al., 2015). Finally, determining accident responsibility is an urgent matter (Chen et al., 2019), as well as taking possible public resistance of OPS into account (Daniel et al. 2022).

3.2.2. Energy efficiency for port equipment and fleet transformation

The operational equipment in and between terminals also widely contributes to emissions in ports, with quay cranes being the second highest emission source in ports after ships, yard cranes on the third position and trucks on the fourth (Yun et al., 2018). However, the research on the impact of energy and thus emission saving is comparatively limited (Wang et al., 2018). In fact, operational performance is today still considered more important than environmental performance (Dong et al. 2019). However, by introducing environmental criteria into the performance evaluation of port equipment, even greater efficiency scores can be obtained (Castellano et al. 2020). The two main strategies for rendering port equipment more environmentally friendly are working efficiency improvement and new equipment purchase, replacement or retrofit (Yun et al., 2018).

3.2.2.1. Working efficiency improvement

The term “efficiency” of energy consumption refers to minimizing waste for port operation (Alamoush et al., 2020). Energy saving is considered as one of the green port indicators and has been rated by ESPO as second highest priority after air pollutants in the EU priorities, leading to a steep increase of energy efficiency programs in European ports (ESPO, 2018; Chen and Pak, 2017). In the section of port equipment working efficiency improvement, the focus relies on scheduling optimization, and it has been found by Yun et al. (2018) that reasonability is the key component for an optimal trade-off between timesaving and energy saving. Since a large proportion of emissions is related to ships at berth as described above, the improvement of operation around the berthed ships can contribute to reducing emissions, even though the increase in working efficiency of the equipment itself only has a small direct impact considering its proportion within total port emissions. Examples are speeding up the handling efficiency of quay and yard cranes, as well as speeding up internal trucks:

Equipment	Increase in speed	Carbon emission reduction for ships at berth	Carbon emission reduction of total port emissions
Quay cranes	from 20 to 52 TEU/h	- 10.41%	- 1.55%
Yard cranes	from 30 to 50 TEU/h	- 14.37%	- 3.62%
Internal trucks	from 15 to 30 km/h	- 21.17%	- 1.46%

Table 2: Emission reduction potential of port equipment. Source: Yun et al. (2018).

Furthermore, since most cranes operate with an alternative current drive, a conversion to direct current technology using a proper current factor is very likely to reduce emissions from port operation, too, as well as using the hoist-down movement for cranes which permits to recover large parts of energy (Zhao et al., 2014; Tran, 2012), which could instead be stored for later use (Iris und Lam, 2019).

3.2.2.2. Purchase, replacement and retrofit

The replacement of port equipment can be achieved in three different ways: purchase of new equipment, replacement of old equipment by cleaner and more efficient one or retrofit of old engines (Wang et al., 2023; Alamoush et al., 2020). Especially the soaring diesel prices in recent times, increasing terminal operation costs and stricter air pollution regulations force ports to replacing their operation equipment (Yang, 2017).

The most common type of equipment replacement in the literature focusses on the electrification of operation equipment. For the context, rail mounted gantry cranes (RMG) and rubber tyred gantry cranes (RTG) are especially used for stacking containers in ports, while yard trucks (YT) and automated guided vehicles (AGV) are responsible for the horizontal handling of containers – stacking cranes (SC) and rail movers (RM) are usually able to perform both (Carlo et al., 2014). The RTG's are found to be particularly appropriate candidates for electric retrofit or replacement (Hoang et al., 2022; Ding et al. 2021; Alasali et al., 2018; E-Harbours Electric, 2012), meanwhile having high emission reduction potential (Lin et al., 2022).

When retrofitting RTG cranes into electric RTG cranes (e-RTG), they are usually powered by either a bus bar, a touch wire, electric cables, or a rechargeable battery system (PLA, 2016; Yang and Chang, 2013; Obata et al., 2010; PLB, 2008). Traditional RTGs can also be replaced by RMGs or automated RMGs (ARMG). Even though this type of replacement does affect port operation efficiency and operation cost during the process, RMG's prove to have greater working efficiency once installed and cause lower carbon emissions (Lin et al., 2022). The ranking between the four discussed types of cranes regarding emission reduction is as follows: E-RTG < ARMG < RMG < RTG (Hoang et al., 2022).

Besides, equipment such as forklifts, rail movers, yard trucks, stacking cranes and automated guided vehicles also use swappable and portable "battery electric" systems, a widely used technology (Hoang et al., 2022; Dhupia et al., 2011). In addition, hydrogen-powered fuel cells are considered an emerging technology for port operation equipment (Curtin and Gangi, 2014). While benefitting from easier and more rapid recharge as well as lower space requirements than batteries, this technology is not commercially viable today (Kinnon et al., 2021). Furthermore, hybridization is another way of introducing electrification into port operation, divided into fuel-electric hybrids (engine and battery), rechargeable plug-in electric hybrids and diesel-hydraulic hybrid (CARB/EPA, 2015). While operating a hybrid RTG, for example, the diesel engine is

switched off, meanwhile the necessary power is delivered by a specially designed electric collector (Ding et al. 2021).

In order to store potential energy for the use of electric port operation equipment, batteries, flywheels and supercapacitors have proven to be energy efficient solutions (Antonelli et al., 2017; Niu et al., 2017; Tan and Yap, 2017; Greencranes, 2012; Flynn et al., 2008; Kim and Sul, 2006).

The emission reduction potential for switching from RTG to e-RTG as the most studied equipment type is summarized in the table below:

Emission reduction potential	Energy usage savings	Noise reduction	Sources
/	- 82%	- 50%	Vlahopoulos and Bouhouras (2022)
/	- 20% to 84%	/	Luque et al. (2016)
- 40%	- 10%-30%	- 40%	Vujicic et al. (2013)
- 67.79%	- 86.6%	/	Yang and Chang (2013)
/	- 80%	/	Jinru (2011)

Table 3: Emission reduction potential of crane electrification. Sources: as indicated.

Just as in the section above, the emission reduction potential is even greater when considering the overall life-cycle emission assessment and using renewable energy sources (Davarzani et al., 2016; Lirn et al., 2013).

Resulting benefits of port operation equipment electrification are decreasing operating costs of - 50%-70% based on Vujicic et al. (2013), decreasing maintenance and repairing costs of -30% based on Yang and Chang (2013) and decreasing human errors due to standardized performance (Sifakis und Tsoutsos, 2021). On the downside, critical barriers for equipment replacement or retrofit are high initial capital costs and labour expenditure reductions (Yang, 2017).

3.2.2.3. Further equipment improvement measures

Among port activities, lightning consumes about 3-5% of total energy use (Acciaro et al., 2014a), since it serves various applications like port storage facilities, administration buildings and outdoor terminal high mast lightning (Iris und Lam, 2019). Therefore, it is recommended to modernize the lightning equipment by replacing todays mainly used high-pressure sodium lamps with energy-efficient light-emitting diode lamps (LED) (Sifakis and Tsoutsos, 2021). The use of LED lamps saved 70–90% of energy in the Port of Venice, saved 300,000 euros of electricity cost in the ECT Delta terminal in the Netherlands and could save 1000 tons of CO2 per year in the Port of Rotterdam (Van Duin et al., 2017; Hippinen and Federley, 2014).

Furthermore, to minimize cooling demand and heat loss in port buildings, greening the roofs, painting walls in white, cleaning lamps, cold storage insulation and curtains are recommended measures (Alamoush et al., 2020).

To reduce port's dust pollution coming from mainly cargo (un)loading and transportation processes, sprinkler systems, dust-proof nets and thatch covers are proposed and applied measures (Wang et al., 2023).

3.2.3. Smart resources and automation

This section comprises information and automation measures.

3.2.3.1. Information measures

Besides the green port, there has been an evolution of the smart port, which partly focusses on emission reduction as well. A smart port is "a system of port transportation and activity based on modern knowledge platform that enables multiple and diverse information services for port stakeholders based on the collection, processing, release, exchange, review, and use of relevant information" (Siror et al., 2011). Additionally, according to (Buiza et al., 2015), a smart port is "emphasising especially operational and energy efficiency, productivity, and the environmental impact aspect". The use of advanced technologies in ports began around the year 2000 and is evolving ever since (Jiang et al., 2013). In a smart port, innovative industry 4.0 technologies like Internet of Things, Big Data, Artificial Intelligence and 3D printing connect with surrounding objects, building smart infrastructure by allowing the exchange of data between all entities, which leads to logistics and transportation improvements (Accenture and SIPG, 2016; Ferretti et al., 2016), and thus increases efficiency and effectiveness while reducing costs, time, labour and the lifespan of machines (Alzahrani et al., 2021), which leads to long-term growth (Pagano et al., 2022). Information measures contribute to emission reduction in ports, on ships and for hinterland transportation (Christodoulou et al., 2019; Gonzalez-Aregall et al., 2018; Woo et al., 2018; Lam and Notteboom, 2014; Acciaro et al., 2014b; Gelareh et al., 2013).

The information measures can be divided into three categories: emission and energy inventory, monitoring, and reporting. Data collection is a necessary first step to identify pollution sources (Dabra et al., 2009; Peris-Mora et al., 2005). Monitoring, especially air pollution, then helps improving port environment grasping activities with external effects on the port calculating the cost of GHG emissions and raising the green image of the port (Kang and Kim, 2017; Tichavska and Tovar, 2015a; Tichavska and Tovar, 2015b; Lam and Notteboom, 2014; Darbra et al., 2009). The main monitoring activities include air monitoring, weather data monitoring and trace gas concentration monitoring. (Sdoukopoulos et al., 2019; Gonzalez-Aregall et al., 2018; Wiacek et al., 2018; Puig et al., 2017). Since port emission reporting is not yet a mandatory activity, only a few ports actually report their emissions. The list of the above-mentioned industry 4.0 technologies can for instance monitor logistics flows, fuel consumption and smart operation, or facilitate communications between terminals (Ozturk et al., 2018).

3.2.3.2. Automation

With increasing electrification of equipment, conversion to automated systems is enabled, which also significantly contributes to energy and emission savings (Sifakis and Tsoutsos, 2021). According to the literature, 1% of worldwide terminals were fully automated in 2019 (WMU and ITF, 2019) and 2% were semi-automated, slightly forecasting the trend of automation in next generation ports (Iris and Lam, 2019). A state-of-the-art report by PEMA (2016) concluded that gate automation, scheduling yard trucks and container tracking are today's uses of port automation. Typical resulting tasks are, for instance, minimization of traffic congestion into port areas, reduction of container shambles, optimization of travel distances, improvement

of lifting procedures and reduction of extra container shuffles and weight imbalances (Lee et al., 2015; Martín-Soberon et al., 2014). Examples of used technologies in the context of port automation are automatic shut-down and start-up systems, automated mooring systems, double loading cycles of quay cranes, twin-lift or tandem-lift operations in gantry cranes, variable speed generator for RTGs, eco-driving, route optimisation, acceleration techniques for port vehicles, intelligent and autonomous vehicles (IAVs), waterborne autonomous guided vessels and drones and robots for warehouses (Sifakis and Tsoutsos, 2021; Tan et al., 2018; Zheng et al., 2017; Accenture and SIPG, 2016; Lee et al., 2015; Yang, 2015; Hippinen and Federley, 2014; Gelareh et al., 2013; IAPH, 2007). With rising electrification, digitalization and automation of port operation, the issues of safety and security gain greater attention and port resilience must be guaranteed (Zhen et al., 2022).

3.3. The supplementary role of ship-to-port and port-to-land interfaces

Emissions from ships in ports only account for a small portion of total shipping emissions but do represent the main emission source of port emissions, which approximately range between 55% and 77% (He et al., 2021). Furthermore, trucks entering ports to transport the goods to their final destination is another immense emission source. Therefore, it is of great significance to focus on the annexing ship and land interfaces regarding emission reduction, too.

3.3.1. Energy efficiency for ships in ports

This subchapter adressed vessel speed reduction and reduction of time for ships at berth.

3.3.1.1. Vessel speed reduction

The emissions from ships in port waterway channels accounts for about 68% of total ship emissions in ports (Yun et al., 2018). With operational speed reduction of vessels approaching ports, fuel consumption and hence emissions can significantly be reduced (Alamoush et al., 2020; IMO, 2009a). Yun et al. (2018) observed that when vessel speed exceeds the 10 knots, the reduction of speed in waterways can cut down carbon emissions, whereas when the vessel speed is lower than 10 knots, the reduction of speed in waterways will instead increase carbon emissions by a small quantity. In fact, already in 2011, Cariou (2011) called the 10 knots line “the most energy efficient speed”.

Different calculations of emission reduction impacts by using vessel speed reduction are summarized in the table below:

Speed reduction	Carbon emission reduction from ships in waterway channels	Carbon emission reduction of total ship emission in container terminal	Carbon emission reduction from the whole container terminal	Fuel consumption reduction	Source
-20%	- 7%	/	/	- 40%	Bergqvist and Monios (2019)
From 24 knots to 8 knots	- 48.4%	- 37.5%	- 32.9%	/	Yun et al. (2018)
From 24.5 knots to 12 knots	- 41%	/	/	/	Chang and Jhang (2016)
From 22-27.5 knots to 15-21 knots	- 8–20%	/	/	/	Zis et al. (2014)

Table 4: Emission reduction potential of vessel speed reduction. Sources: as indicated.

Furthermore, by combining vessel speed reduction of 20 knots with onshore power supply, CO2 emissions can even be reduced by 71% to 91%, as calculated for the Port of Kaohsiung-Taiwan (Chang and Wang, 2012).

One related measure is the use of a so-called virtual arrival time, which can manage vessel's speed regarding the current and upcoming situation of port's berth schedule (Du et al., 2015). This technique is already well-established and has proven reliable and safe expertise (Sifakis and Tsoutsos, 2021).

However, a drawback of the application of vessel speed reduction is the associated implication of increased number of ships in service to cover the same demand (Daniel et al., 2022). Nonetheless, emission reductions could still be considerable, especially when applying speed reduction over the entire vessel journey, since speed and engine power are closely related (Taskar and Andersen, 2020; Wang et al., 2016; Lindstad and Eskeland, 2015; Faber et al., 2012).

Vessel speed reduction remains a well discussed and recommended topic for port emission reduction (Bergqvist and Monios, 2019; Styhre and Winnes, 2019; Poulsen et al., 2018; Tsai et al., 2018; Ahl et al., 2017; Qin et al., 2017; Styhre et al., 2017; Chang and Jhang, 2016; Winnes et al., 2015; Chiu et al., 2014; Gibbs et al., 2014; Zis et al., 2014; Lirn et al., 2013; Chang and Wang, 2012; Kontovas and Psaraftis, 2011; Corbett et al., 2009).

3.3.1.2. Reduction of time for ships at berth

The reduction of time for ships at berth by carrying out the same amount of transport work is another method to decrease time and fuel use, and thus port emissions, even though the total terminal impact is relatively small (Yun et al., 2018; Heng et al., 2015). When reducing berthing time, it needs to be considered that the berthing time varies from the ship size, and usually amounts up to several days for bulk and container ships, but only several hours for short-sea shipping ferries (Peng et al., 2021). In contrast, it opens the opportunity of reducing ship sailing speed at sea (Johnson and Styhre, 2015).

A summary of emission and fuel reduction potential is listed below:

Berthing time reduction	Carbon emission reduction from ships at berth	Carbon emission reduction from the whole container terminal	Fuel consumption reduction	Source
From 6 hours to 2 hours	- 22.1%	- 6.0%	/	Yun et al. (2018)
By 1 to 4 hours	/	/	- 2%–8%	Johnson and Styhre (2015)
By 30% Increase of 30%	- 37% + 30.7%	/	/	Moon and Woo (2014)

Table 5: Emission reduction potential of ship's berthing time. Sources: as indicated.

In theory, reducing ships berthing time appears to be an easily applicable measure. In practice, however, numerous factors need to be calculated and integrated by port authorities, such as terminal opening hours, stevedore operations, berth availability, efficiency of container handling equipment, production efficiency and cost reduction, berth layout, allocation, quay crane assignment, tidal constraints, customer satisfaction, emission tax rates and vessel waiting time (Jos et al., 2019; Ma et al., 2019; Styhre and Winnes, 2019; Wang et al., 2019; Kovac et al., 2018; Lin et al., 2018; Wang et al., 2018; Ernst et al., 2017; Umang et al., 2017; Xiang et al., 2017; Han et al., 2015; Winnes et al., 2015).

In order to implement the reduction of ships berthing time and simultaneously ship's arrival speed, Kontovas and Psaraftis (2011) propose to replace the currently widely used first-come-first-serve model by an arrival booking scheme like guaranteed berth on arrival and booking by rendezvous, which have revealed to contribute to emission saving due to reduced ship waiting times. Furthermore, the time spent in terminals can be reduced by implementation of information measures such as information communication technologies, electronic data interchange, single window, port community system, and vessel traffic management, as well as streamlined ship clearance and standardized documents (Styhre and Winnes, 2019; Poulsen et al., 2018; IMO, 2015; ESPO, 2012). Furthermore, automatic mooring systems largely help reducing mooring operation time by more than 1.5 hours (Sifakis and Tsoutsos, 2021), with emission reduction potential of about 76.78% (Piris et al., 2018). All these options, however, require the collaboration with numerous maritime stakeholders (Gibbs et al., 2014).

3.3.2. The use of alternative fuels

Since ship fuels like marine diesel oil (MDO) or heavy fuel oil (HFO) are poor in quality with high viscosity, high density as well as high ash and sulfur content, (Zhan et al., 2019; Zetterdahl et al., 2016), their resulting emissions are tremendous. In fact, approximately 20 million tonnes of NOx, 10 million tonnes of SOx and 1 million tonnes of PM are emitted only by marine diesel engines every year (IMO, 2014).

So far, the price attractiveness of these fossil fuels was the main driver for their widely used application (IMO, 2009b; IMO, 2008). However, considering stricter environmental regulations, it is fundamental to seek for alternative renewable fuels to meet the growing shipping demand (Ni et al., 2020). In this context, ports need to build the corresponding infrastructure, including charging piles, storage facilities and pipelines. However, especially the high investment costs and technological immaturity are today's main barriers for the large-scale implementation of alternative fuels (Wang et al., 2023). In the following section, we will discuss the main alternative fuel sources LNG, biofuels, methanol, hydrogen and ammonia.

3.3.2.1. LNG

Liquified natural gas plays a superordinated role for the decarbonization of shipping and is also the current most mature option of all alternative fuels (Daniel et al., 2022; DNV, 2019; IMO, 2016). LNG can be used as a fuel for ship propulsion (Xu and Yang, 2020), especially for large ships (Ni et al., 2020), or for inland operations (Sifakis and Tsoutsos, 2021). The potential for emission reduction of LNG from the literature is as follows:

Application	CO2 reduction	NOx reduction	SOx reduction	PM reduction	Source
From diesel and HFO engine fuel to LNG	Yes	Yes	Yes	Yes	Daniel et al. (2022); Xu et al. (2021); Aneziris et al. (2020); Yun et al. (2018); Anderson et al. (2015); Li et al. (2015); IMO (2009c); IMO (2009d)
From ordinary low-sulfur engine fuel to LNG	- 23.8%–25.9%	/	/	/	Luo (2018)
From traditional fuel to LNG	- 5%–30%	/	/	/	Bouman et al. (2017)
From HFO engine to LNG	- 11%	- 86%	- 98%	- 96%	Elgohary et al. (2014)
From diesel oil engine to dual fuel (LNG/diesel)	- 10%	- 72%	- 91%	- 85%	Banawan et al. (2009)

Table 6: Emission reduction potential of LNG. Sources: as indicated.

LNG counts several advantages over other alternative fuels, which are mainly technological advances, cost effectiveness, higher energy density and higher thermal efficiency (Hoang et al., 2022; Ni et al., 2020; Ammar, 2019b; Thomson et al., 2015; Banawan et al., 2009).

The disadvantages of LNG are flammability, methane leakage, spacious infrastructures for storage and bunkering, imperfect technical specifications, insufficient price competitiveness, reduced market and supply issues, uncertainty of operational risk and regulation (Peng et al., 2022; Alamoush et al., 2020; Iannaccone et al., 2020; Ni et al., 2020; Xu and Yang, 2020; Hwang et al., 2019; Ushakov et al., 2019; Fernández et al., 2017; Schinas and Butler, 2016; Burel et al., 2013; Bengtsson et al., 2011). All these obstacles make the use of LNG commercially limited today (Kumar et al., 2011).

3.3.2.2. Biofuels

Biofuels are another climate-friendly option in comparison to fossil fuels (Gaurav et al., 2017). Biofuels include a wide range of production sources, such as biomass (algae, cyanobacteria) (Hanssen et al., 2014) or renewable harbour wastes (Misra et al., 2017) and end-products, for example biodiesel and bioethanol (Bengtsson et al., 2012; Righi et al., 2011). Biofuels are mainly suitable for small and medium-sized ships, as well as certain port operation equipment (Ni et al., 2020).

The calculated emission reduction potentials of biofuels identified in the literature are listed below:

Application	CO2 reduction	NOx reduction	SOx reduction	PM reduction	Source
Mixed biodiesel (ship)	- 70.0% – 80.0%	/	/	/	Bouman et al. (2017)
Low-speed diesel engine with 7% and 20% biodiesel blend (ship)	- 28–64%	- 26–72%	-30-70%	/	Nikolic et al. (2017)
Diesel-biodiesel blend (ship)	+ 10%	- 4%	/	/	Gysel et al. (2014)
Diesel to biodiesel and crude vegetable oil (ship)	- 19.0% - 38.0%	/	/	/	Eide et al. (2013)
Algae biodiesel engine (ship)	/	/	/	-25%	Khan et al. (2012)
100% biodiesel (ship)	No, increase	Yes	/	/	Roskilly et al. (2008)
Diesel with 30% biodiesel blend (port equipment)	- 30%	/	/	/	Geerlings and van Duin (2011)

Table 7: Emission reduction potential of biofuels. Sources: as indicated.

The main advantages are renewability, compatibility of existing engines, low toxicity, availability and diversity of raw materials for production, high energy density, simplicity in handling and storing and reduced total cost of ownership once scaled up (Olçer et al., 2021; Pitpoint clean fuels, 2021; Dharma et al., 2016; Johari et al., 2015; Lapuerta et al., 2005).

The disadvantages of biofuels include complex use characteristics, low technological maturity (instability, corrosiveness), current limited availability, high processing and maintenance costs (fuel tank and filter cleaning), lack of adequate safety instructions, operational experience, and incapable infrastructure (Wang et al., 2023; Ni et al., 2020; Svanberg et al., 2018; Eide et al., 2013; Mander et al., 2012).

3.3.2.3. Methanol

Methanol is another emerging clean fuel whose production relies on a broad range of sources, including biomass but also natural gas and coal (Yao et al., 2017). Below are presented the identified emission reduction potentials:

Application	CO2 reduction	NOx reduction	SOx reduction	PM reduction	Source
Methanol-diesel dual fuel engine		- 75%	- 75%	- 75%	Ammar (2019a)
Methanol-diesel dual fuel engine at low speed		lower	zero	almost zero	Zincir et al. (2019)

Table 8: Emission reduction potential of methanol. Sources: as indicated.

The amount of emission quantifying studies for methanol is restricted. However, an additional study pointed out that the environmental performance of methanol is only improved when using natural gas or biomass (Brynolf et al., 2014). Other studies, on the contrary, underlined that when considering the entire life-cycle perspective of methanol, its GHG reduction potential is higher than the one of conventional fuels (Gilbert et al., 2018; Brynolf et al., 2014).

Focussing on methanol's advantages, the technical feasibility, supply chain availability and low-load methane leakage can be named, whereas methanol's immiscibility with diesel and safety of storage and high costs are considered the main application barriers (Ni et al., 2020; Ammar, 2019a; Balcombe et al., 2019; Svanberg et al., 2018; APEC, 2014; Brynolf et al., 2014).

3.3.2.4. Hydrogen

Hydrogen is also considered an alternative fuel capable of replacing today's fossil fuel of ships and port application (Wang et al., 2023), especially when using renewable energy as production source (IEA, 2020). However, hydrogen fuelled marine engines are still rare today, which is mainly because when hydrogen exceeds the 25% blending ratio, the diesel engine needs to be modified (Bui et al., 2021; Fathom.world, 2019). Hence, hydrogen is currently only added as a supplement component to other fuels such as diesel, LNG or biodiesel (Zhou et al., 2014; Köse and Ciniviz, 2013; Saravanan and Nagarajan, 2008). Nevertheless, research is focusing on establishing this energy carrier further, especially because of green hydrogen's characteristic of emitting near-zero GHG and air pollutants at combustion (CO2, NOx, SO2, PMs, etc.), (Daniel et al., 2022; Hoang et al., 2022; Chang et al., 2019; Bicer and Dincer, 2018; Castellani et al., 2018; Chang et al., 2016; Pereira et al., 2014; Wang et al., 2013; Arteconi et al., 2010).

Beside the high environmental friendliness, safety, bunker capability, adaptability, commercial effect, the social aspect, technical feasibility and cost-effectiveness are advantages of the green molecule, or obstacles to be overcome in the near future (Hansson et al., 2019; Deniz and Zincir, 2016; Salvi and Subramanian, 2015; Barreto et al., 2003).

Some factors which will be hard to overcome even in the long term are the low energy density volume the need of bringing the hydrogen down to -252,9 C for obtaining a liquid state the lack of proper storage infrastructure and the considerable water sums for its green production (Wang et al., 2023; Daniel et al., 2022; Hoang et al., 2022).

3.3.2.5. Ammonia

Ammonia is a hydrogen carrier with similar environmental characteristics. It can be blended with diesel, hydrogen and methanol (Rehmatulla et al., 2017; Valera-Medina et al., 2017; Westlye et al., 2013; Boretti, 2012; Reiter and Kong, 2011; Reiter and Kong, 2008). Due to its higher energy density, the storage of ammonia is facilitated (-33.4 C) (Daniel et al., 2022). Also, there is an existing ammonia infrastructure in place due to its established use for fertilizer production (Daniel et al., 2022; Lan et al., 2012; Klerke et al., 2008).

Still, there is only limited storage space available in ports and the large-scale distribution is currently problematic. In addition, today's ammonia production will not be able to supply the maritime sector (Daniel et al., 2022), which is why its use in ports lies far in the future.

3.3.3. Renewable electricity for ship propulsion

The direct use of renewable or eco-friendly electricity sources for (co-assisted) ship propulsion has also been studied in the literature, with fuel savings and deriving emission reduction potential for ports. Hence, solar, wind, fuel cell and nuclear propulsion will be analysed.

3.3.3.1. Solar propulsion

Solar energy is mainly used through the installation of photovoltaic (PV) systems on a ship's upper deck to provide additional electricity for the electric equipment on (Hoang et al., 2022). Observed energy and emission saving potential is listed below:

Application	CO2 emissions reduction	Fuel saving	Energy efficiency	Source
Solar arrays onboard a Ro-Ro marine vessel (total journey)	/	- 7.38%	- 7.76%	Karatug and Durmusoglu (2020)
Solar/diesel hybrid electric ship in ports	- 0.86% – - 4.88%	- 1.58% – - 1.78%	/	Yuan et al. (2018)
Solar-wind hybrid system (total journey)	/	- 10 – - 40%	/	FathomShipping (2012)

Table 9: Emission reduction potential of solar-assisted ship propulsion. Sources: as indicated.

It has been underlined, though, that additional data is necessary for analysing the real emission reduction potential of PV arrays on ships (Hoang et al., 2022).

The main drawback of the technology is that solar energy is facing high intermittency due to its dependency on weather conditions (Hoang et al., 2022). Therefore, solar power will never fully-power ships, but only be capable of generating auxiliary power demand (Pfenninger and Staffell, 2016; Carlton et al., 2013). In fact, a study from Bouman et al. (2017) concluded that solar energy generation on marine vessels will lie between 0.2% and 12%. To intensify the percentage, the integration of energy systems including storage is considered a viable option, as well as increasing the efficiency of the panels (Wang et al., 2023; Hoang et al., 2022; Salem and Seddiek, 2016; Teeter and Cleary, 2014; Glykas et al., 2010).

3.3.3.2. Wind propulsion

Like in ancient times, wind-assisted propulsion is becoming increasingly popular again for lowering emissions from ships. The used sails can be of conventional or modern style, like Flettner rotors, kites or spinnakers, soft sails, wing sails, and wind turbines (Mofor et al., 2015; Carlton et al., 2013). Several reduction potentials have been calculated in the literature:

Application	Fuel saving	Source
Flettner Rotor-Sail system on a cargo ship	22.9%	Lu and Ringsberg (2019)
SkySails system	50%	SkySails (2019)
Foldable eConowind's sail unit	25%	IWSA (2018)
Single Flettner rotor	2–24%	Traut et al. (2014)
Towing kite	1–32%	Traut et al. (2014)

Table 10: Fuel saving of wind-assisted ship propulsion. Sources: as indicated.

Just like solar power, wind-assisted propulsion will not be able to power entire ships, but they can generate additional propulsion thrust, especially in high seas (Staffell and Pfenninger, 2016). According to (Qiu et al., 2015), the replaced engine power can amount between 15% and 25%. The most effective values are usually obtained under slow-speed conditions (>16 knots) and on smaller sized vessels (3000–10, 000 tons) (Smith et al., 2016; Smith et al., 2013). The intermittency aspect also accounts for wind energy (Daniel et al., 2022), which is one of the reasons why wind-assisted propulsion is still in a nascent development (Carlton et al., 2013). However, future increasing fuel prices might motivate ship owners to use such technology (Tilling et al., 2020).

3.3.3.3. Fuel cell propulsion

Electricity from fuel cells is generated by converting chemical energy, which leads to a significant reduction of CO2, NOx, SOx and PM emissions (Inal and Deniz, 2020; Van Biert et al., 2016). Fuel cells can either be used for direct marine vessel propulsion (especially smaller ships) or for port equipment, however, their application, remains scarce to date (Hoang et al., 2022; Kinnon et al., 2021; Pagliaro, 2020; Bicer and Dincer, 2018; Sharaf and Orhan, 2014).

The main advantage of fuel cells is the emission-free functioning since the only directly emitted by-product is water (Klebanoff et al., 2021). Furthermore, noise and vibrations are reduced to a minimum, which also has positive impact for surrounding marine ecosystems (Ghenai et al., 2019). Quick start-up, high power density and lower working temperature are other advantages of fuel cells (Huang et al., 2021), making them able to compete with diesel propulsion generators in the maritime industry. Nevertheless, reliability, lifetime, tolerance to salty sea air, possible supply issues on long journeys, explosion risk, limited technology maturity level and the low investment return with current costs are some of the common bottlenecks for current fuel cell integration (Kumar et al., 2023; Sifakis and Tsoutsos, 2021; Iris and Lam, 2019; Alaswad, 2016).

3.3.3.4. Nuclear propulsion

Nuclear power for marine propulsion is only used for applications of certain warships, submarines, aircraft carriers and icebreakers (Khlopkin and Zotov, 1997). This technology does in

fact have the potential of eliminating CO2 emissions and air pollution (Kontovas, 2014), but the high negative impacts like nuclear wastes, social acceptance, political acceptance, nuclear weapons creation, environmental catastrophes, safety, and operational costs impede the wider adoption of this energy source (Daniel et al., 2022).

3.3.4. Hinterland integration

Using green hinterland technologies significantly contributes to green port development, too, since CO2 emissions from port hinterland transportation exceed the emissions of port operation itself, excluding ships (Alamoush et al., 2020; Du et al., 2019; Gonzalez-Aregall et al., 2018; Kavakeb et al., 2015; Lirn et al., 2013; Bergqvist and Egels-Zanden, 2012). Therefore, authors claim that ports have a part of responsibility of reducing the negative externalities linked to their operation (Gonzalez-Aregall et al., 2018; Marta et al., 2018).

The first typical type of measure is truck emission reduction, including truck replacement or retirement, repowering or retrofit of engines (Alamoush et al., 2020). Polluting trucks can also be banned from terminals, or simply excluded on a voluntary basis (Clott and Hartman, 2013; Norsworthy and Craft, 2013). Second, truck congestion reduction outside gates and terminals can be achieved by implementing truck appointment systems, a measure which has proven significant emission reductions (Schulte et al., 2017; Chen et al., 2013; Guan and Liu, 2009; Giuliano and O'Brien, 2007). Automated gate processing systems or extended off peak terminal and gate hours are other congestion reduction measures, as well as trucks empty return coupled with loaded pickups (IMO, 2018b; Accenture and SIPG, 2016; APEC, 2014). And third, modal shift or modal split improvement is a further emission reduction measure of port's hinterland, translated by the move of cargo to rail, barges or short sea shipping (IMO, 2018b; IAPH, 2007). All measures are drastically reducing CO2 emissions, and rail cargo reduces them even more than truck cargo improvement (Mamatok and Jin, 2016; You et al., 2010).

Furthermore, several ports in Europe and North America have encouraged their employees to use public transportation or bicycles to reduce local air pollution (I2S2, 2013).

3.4. The powerful role of green electricity measures

This chapter focusses on renewable electricity sources and energy management systems.

3.4.1. Renewable electricity sources

Since numerous ports around the world are exploiting renewable energy resources, the percentage of energy from renewable resource is considered a typical key performance indicator (KPI) for green and sustainable port evaluation (Buiza et al., 2015; STP, 2015; Acciaro et al., 2014). In the following section, the main renewable power sources solar, wind, tidal, geothermal and fuel cells will be discussed.

3.4.1.1. Solar energy

Solar energy has known a steep increase in worldwide energy production between 2001 and 2018 (IRENA, 2018). In several assessments for renewable energy opportunity in ports, photovoltaics ended up having the highest applicability rate (PLB, 2016), especially because it is a cost-effective, mature, and clean solution (Sifakis and Tsoutsos, 2021). In fact, numerous studies approved that solar panels are an ideal energy production technology with low carbon emissions, also for port operation (Kotrikla et al., 2017; Lee Lam et al., 2017; Yarova et al., 2017; Baldenegro, 2013). The two different types of solar energy application are solar water heating (SWH) and photovoltaic (PV) (Fossile et al., 2020; Xiao et al., 2020; Balbaa and El-Amary, 2019; Mitzinneck and Besharov, 2018; Augustine and McGavisk, 2016; Interreg IVB North Sea Region Programme, 2012).

SWH accounts more for high-temperature industrial processes, whereas PV converts the directly radiated light into electricity, with monocrystalline solar cells being the most efficient panel type (Hess et al., 2011; Labouret and Villoz, 2010; Hagopian et al., 2007). Between further decreasing installation costs, competitive maintenance costs, robustness to weather conditions and broad installation potential, PV panels are a genuine energy production option to be considered by ports (Alzahrani et al., 2021; Branker et al., 2011; Chow, 2010). Unexploited areas like empty pieces of land or the rooftops of ship or container docks, buildings, warehouses and cruise terminals are ideal installation surfaces for PV (Sifakis and Tsoutsos, 2021; Song and Poh, 2017; Boile et al., 2016; Vincent, 2014; E-Harbours Electric, 2012). Depending on criteria such as port size, average solar irradiation and electrification status, certain researchers also concluded that using PV panels does have the necessary potential to meet the power demand of port authorities (Alzahrani et al., 2020; Alzahrani et al., 2019; Balbaa et al., 2019; Lam et al., 2017; Misra et al., 2017). Furthermore, PV has been proved to contribute to efficient and effective port sustainability, which is directly linked to higher competitiveness in the global market (Fossile et al., 2018; Kang et al., 2018). But still, studies about the exact carbon mission reduction potential of solar energy is scarce.

3.4.1.2. Wind energy

Another promising, sometimes complementary energy source is wind energy, created due to large-scale air mass movements based on differences in the atmospheric pressure and earth rotation, whereby the wind is transformed into electricity by using a tower, a turbine, a yaw mechanism, a speed control unit, a drive train system, and an electrical generator (Dincer, 2018; Tong, 2010). Since port areas are often exposed to high-speed wind, their location is ideal for using wind as energy source (Li et al., 2018; Weiss et al., 2018; Kotrikla et al., 2017; Yarova et al., 2017; Spiropoulou et al., 2015; Solari et al., 2012). The turbines can be installed at onshore and offshore sites, but offshore sites are more effective and stable (Cavvazi and Dutton, 2016). In order to determine the ideal location for wind turbine installation, parameters such as wind speed, geological structure of the site, transmission networks and the required material and mineral sources need to be evaluated (Blazauskas et al., 2015). Also, the wind energy can help meeting local port site power demand (Gutierrez-Romero et al., 2019; Wang et al., 2019). Wind energy is considered more energy-efficient than solar energy, while producing zero direct

carbon equivalent emissions and supporting social and environmental objectives of ports (Fossile et al., 2020; Peake, 2018). On the reverse side, high initial investment costs, high operating costs, need of regular maintenance, noise generation, low social acceptance by surrounding communities, space availability and exceeding of port grid capacity make wind energy a less preferred solution (Chen et al., 2021; Alamoush et al., 2020; Fossile et al., 2020; Peake, 2018; Cesari and Gaudiosi, 1999). For the latter two criteria, various ports have opted for a so-called wind power purchase agreement with wind farm developers, buying a portion of their produced green wind energy, while also considering wind energy storage options (Li et al., 2019; PIANC, 2019; Christoforaki and Tsoutsos, 2017; Blazauskas et al., 2015). The direct emission reduction potential analysis of wind energy for ports remains limited, too (Alzahrani et al., 2021).

3.4.1.3. Tidal energy

A further considered method of renewable energy for port decarbonization is marine energy, especially from wave circulation and tidal movement, but also from salinity, and ocean temperature differences (Alamoush et al., 2020; Foteinis et al., 2018; EC, 2014; Rourke et al, 2010). Wave and tidal energy have both been studied by comparatively only a few researchers, but some studies have in fact demonstrated their potential to meet ports power demand with the necessary installation capacity and ocean strength (Lazaroiu and Roscia, 2017; Ramos et al., 2014; Alvarez et al., 2013).

The advantages and disadvantages of wave and tidal energy are very similar. Regarding the advantages, predictability of current and more easy grid connection can be named, as for the disadvantages, installation costs, regular maintenance, low reliability, immature (but growing) technology, seasonal variation and time consummation are common factors (Alzahrani et al., 2021; Alamoush et al., 2020; Espina-Valdes et al., 2019; Li et al., 2018; Hiranandani, 2014; Tang et al., 2014; de la Lanza Espino et al., 2010; Rourke et al., 2009). In any case, feasibility studies before implementation are inevitable (Cascajo et al., 2019; Li et al., 2018).

3.4.1.4. Geothermal energy

Geothermal energy uses the energy stored in the earth layers for energy production, or heating and cooling, especially for offices, warehouses, and buildings (Acciaro et al., 2014a; Le et al., 2020). In European ports, only the near-surface geothermal energy is used (EC, 2014). However, due to very scarce research, the efficiency and applicability of geothermal energy in ports remains unclear (Sifakis and Tsoutsos, 2021).

3.4.1.5. Fuel cells

As mentioned earlier, hydrogen fuel cells are clean since they do not produce direct CO2 emissions and air pollutants; the life cycle emissions, however, depend on the production ‘colour’ of hydrogen, with green hydrogen (produced by renewable energy sources) having the lowest impact (Staffell et al., 2019; Balcombe et al., 2018; Speirs et al., 2018; Brouwer, 2010; Larminie et al., 2003).

In ports, fuel cells can play a flexible role by either being applied for stationary power generation (base load) or backup power (peak load or emergency). When being used as continuous power generation option, everyday operations like OPS, cranes, port equipment, buildings etc. can take advantage of their stable power providence. When being used as a back-up or emergency installation, critical loads can be provided continuously, based on green electricity sources, replacing polluting technologies such as diesel generators, meanwhile also serving as a reliable and resilient solution in comparison to the national power grid or intermittent renewable sources only (Kinnon et al., 2021).

Today, operational and technical constraints at ports are still a main barrier for port's power provision based on fuel cells, as well as the current expensive price in comparison to fossil fuel alternatives - however, with predicted falling prices of green hydrogen, fuel cell application will become a more interesting topic for ports (Kinnon et al., 2021; Schmidt et al., 2017; Raucci et al., 2015).

3.4.2. Energy management systems

With energy efficiency being a key lever to become greener, the energy consumption of ports has become the focus of attention in recent years (Di Vaio et al., 2018). Meanwhile, in 2004, energy consumption was not listed among the 10 environmental priorities of the European port sector, the topic ranked third in 2013 (Woo et al., 2018). Therefore, implementing energy management system (EMS) has become a top priority. The aim of EMS in ports is to control, optimize and match energy demand, energy supply, energy flow and energy storage by connecting real-time operation monitoring via smart devices (Iris and Lam, 2019; Ngai et al., 2011). The main reasons for variations in energy consumption are variations in ship calling patterns and handling volumes, seasonality in energy requirements of reefers containers and fluctuations in staying times in ports for import, export, transshipment and reefers containers (Wilmsmeier and Spengler, 2016). By implementing EMS, both emissions and energy costs can be significantly decreased (Fossile et al., 2020; Lam et al., 2017; Styhre et al., 2017; Acciaro et al., 2014a). Hence, lacking information about energy consumption can distort a port's real carbon footprint. In order to establish and comply with such systems, ports can refer to ISO 50001 energy management system standards (Iris and Lam, 2019).

The main drivers for ports to install EMS are to tackle increased energy prices without compromising quality, the depletion of primary resources by reducing waste and gaining in competitiveness in global markets (Alzahrani et al., 2020; Acciaro et al., 2014a; Petrecca, 2012; Barros, 2003. The main barriers consist in technological, economic and regulatory aspects (Iris and Lam, 2019).

3.4.2.1. Energy management plans

Establishing an energy management plan (EMP) is fundamental to meet energy consumption reduction and thus improve the efficiency of a port's operating system (Parise et al., 2016a; Hippinen and Federley, 2014; Pavlic et al., 2014). To establish an energy profile, ports must acquire a detailed, long-term and reliable database, which will evaluate and analyse the energy

consumption and performance in order to make realistic projections, as well as enable appropriate correction measures and technologies (Cammin et al., 2020; Boile et al., 2016; Lam and Notteboom, 2014; Pavlic et al., 2014).

3.4.2.2. Energy storage systems

Energy storage systems (ESS) are fundamental to integrate and balance the fluctuations of renewable energies by helping the power grid to collect and transit excess energy, as well as meet the local power demand to ensure a port's unhampered functionality (Sifakis and Tsoutsos, 2021; Sifakis and Tsoutsos, 2020; Ahamad et al., 2019; Verma et al., 2018; Papaioannou et al., 2017; Lan et al., 2015). Without ESS, the reliance on 100% renewable electricity sources (RES) for ports would be impossible (Sifakis and Tsoutsos, 2021). The main used technologies of ESS are batteries, supercapacitors, flywheels and more recently hydrogen fuel-cell systems (Sifakis and Tsoutsos, 2021; Ahamad et al., 2019; PIANC, 2019; Yigit et al., 2016).

3.4.2.3. Smart microgrid

Smart grids, which rely on renewable energy sources, consist in a centralized automated system or platform to manage power flows between the grid and electricity consumers, including information technologies like sensors, smart meters, real-time monitoring systems and control tools (Iris and Lam, 2019; Lam et al., 2017; Siemens, 2017; Spbp, 2017; Bayindir et al., 2016; Ihle et al., 2016; Parise et al., 2016b; Yigit et al., 2016; Mondragon et al., 2015; Sharma and Saini, 2015). A typical integrated technology using information and communication is the so-called "virtual power plant", which switches off and on the connected generators, depending on the availability and need of power (Kenzhina et al., 2019; Nwauka et al., 2018; Kaur et al., 2016; Dulau et al., 2014; Dulu et al., 2014; Saboori et al., 2011). The aim of smart grids is to enhance reliability, stability, efficiency, flexibility, and performance of an electric system, meanwhile giving participants and decision makers the opportunity to determine an ideal operational environment (Leva et al., 2017; Tuballa and Abundo, 2016). Micro grids are often integrated in a smart grid and are also indispensable to support and manage the energy needs of future ports and represent a stand-alone energy network comprising different electricity sources and controllable loads that can operate synchronously with the traditional centralized grid ("grid") or disconnect and function autonomously ("island" or "islanding mode") (Roy et al., 2020; Parise, 2016; Katiraei et al., 2015; Sudhoff, 2015).

Smart (micro) grids are very likely to replace traditional power grids in ports of the next generation (Sifakis and Tsoutsos, 2021; Siemens, 2017). Meanwhile rendering the possibility of increasing the use of renewable energy sources, reduce energy consumption and overall port emissions, smart grids increase ports energy security by assuring business continuity during emergencies or grid disruptions (Alzahrani et al. 2021; Kinnon et al., 2021; Alamoush et al., 2020; Molavi et al., 2020; Razeghi, 2018 ; Samuelsen, 2018; Ansari et al., 2016; Li, 2016; Rahbar et al., 2015; Kanchev, 2014; Mazidi et al., 2014; Karabiber, 2013; Basak, 2012; Mohammadi et al., 2012).

Also, they offer the possibility to connect to the electricity markets by offering grid services and hence benefit from lower electricity prices meanwhile increase revenues from energy sale in expensive peak hours, optimized resource management coupled with cost reduction of potential transmission expansion, provision of voltage support and regulation at the interconnection point, demand response enhancement and vehicle to grid applications (Harnischmacher et al., 2023; Petri et al., 2020; Alasali et al., 2019; Razeghi, 2018; Majzoobi and Khodaei, 2017; Gao, 2016; Lv and Ai, 2016; Guo, 2015; Li, 2014; Zhang et al., 2014; Duong and Long, 2013; Justo, 2013; Zhang et al., 2013; Madureira and Peças Lopes, 2012; Ustun et al., 2011; Hall, 2010; Driesen and Katiraei, 2008; Yuen and Oudalov, 2007; Piagi and Lasseter, 2006).

On the downside, the high investment costs, safety (e.g. cyber-attacks) and legal implications are barriers to overcome for smart grids in ports (PIANC, 2019; Schulte et al., 2017).

Securing critical smart grid infrastructure in ports is fundamental to avoid disruptions (Niglia, 2017). Therefore, Liang et al. (2014) recommend ports to firstly undergo a load analysis of equipment (energy fluctuation based on RES generation), then to prepare a smart grid scenario analysis (peak shaving and demand response planning), before focusing on energy balancing (energy storage planning) and finally conduct a benefit analysis (tariffs and costs).

3.4.2.5. Smart load management

Smart load management (SLM) is another technique part of EMS, especially necessary considering the increasing electrification of ports (Gennitsaris and Kanellos, 2019; Tao et al., 2014). On the one hand, SLM focusses on load shifting by moving certain operations with high electricity demand to times with lower electricity demand, which minimizes costs since peak loads are the most expensive electricity prices (Alamoush et al., 2020). A common example would be to charge electric equipment over night, where grid demand and electricity prices are low (Schmidt et al., 2015; Ihle et al., 2014). On the other hand, peak shaving is another SLM technique applied to reduce the energy demand by the use of intelligent sensors, for example for reefers, yard lights, heating or office fridges (Alamoush et al., 2020).

3.5. Identified research gaps

Based on the 44 articles read for collecting the above literature findings, several criteria compilations can be done. Hence, as indicated in the table below, the amount of published articles increased every year, with 0 publications in 2015, 10 publications in 2022 and already 6 publications as of March 2023. This does not just validate the chosen time frame but also demonstrates the increased need of research in the field of green ports, even if the publication years of the primary sources are not included.

2015	2016	2017	2018	2019	2020	2021	2022	2023
0	1	2	4	6	7	8	10	6

Table 11: Literature publications by year. Source: own illustration.

When focusing on the exact content of the publications, it sticks out that most findings remain theoretical and explain the different decarbonization options, mainly stating their decarbonization potential, functioning, advantages, and disadvantages. However, after systematically

screening and reviewing the literature, the number of empirical research studies actually focusing on the successful implementation of these enumerated measures remains scarce. In this sense, Argyriou et al. (2022), authors of the 44 fully analysed publications, state that "although researchers and policymakers have focused on quantifying sustainability, a limited number of studies have been conducted on the quality that focuses on the organizational challenges for implementing appropriate measures". In concordance with this statement, Wang et al. (2023), another author group of 44 fully analysed publications, agree for the need to "find the best practices to help ports achieve zero emission as soon as possible and make significant contributions to global emission reduction". Based on those findings, the upcoming goal of this master thesis is to contribute to filling the current lack of guidance for ports and to progress the research theory slightly towards the practice to overcome uncertainties.

To set a specific focus for successful implementation, a look at the geographical distribution of the 44 analysed publications is necessary. In the table below, it appears that 15 studies did centre on ports in Asia, 7 studies on ports in Europe, 2 studies on ports in Africa and 1 study respectively on North and South America. 11 studies focused on several worldwide ports at a time and 7 further studies relied on very general results. Having read them in detail, the majority of the ports from the undergone theoretical research are either located in developed or emerging countries, or on important trade routes. The geographic location of the primary sources from the 44 publications are not included, but the below table does give an indication on regional research preferences.

Asia	World	Europe	General	Africa	North America	South America
15	11	7	7	2	1	1

Table 12: Literature publications by geographic location. Source: own illustration.

Wang et al. (2023) have further made the same discovery by analysing the countries where emission reduction measures have already been implemented. It results that these countries seem to have the basic local economic conditions to proceed to the implementation for emission reduction measures. Since Europe is shown to be rather advanced in both theory focus and implementation according to Wang et al. (2023), and also due to the authors location on the European continent, the following field research shall be conducted within the borders of the European Union only, in order to assure sufficient experience with the implementation of emission reduction measures.

Lastly, and with a look on the methodologies used by the 44 studies, it appears clearly that the main focus in this research field relies on quantitative research only, applied by more than half of the researchers. Less research uses qualitative and quantitative approaches (6), literature reviews only (6) or qualitative research only (5). The mix of literature reviews with qualitative research is even more rare (3). Again, the research methodologies of the primary sources could not be added.

Quantitative	Qualitative and quantitative	Literature reviews	Qualitative	Literature review and qualitative
24	6	6	5	3

Table 13: Literature publications by methodology. Source: own illustration.

With all these research methods revealed, the author decided to do even more by combining three methodologies to answer the research question. Therefore, besides the conducted systematic literature review, a quantitative and qualitative approach have been chosen to comply with all advantages of these research methods for getting the most solid results.

Since emission reduction measures are carried out in stages and cannot be adopted all at once (Wang et al., 2023), the aim of this trifold research is to provide an overview of prioritization of measures, to identify the different stakeholders and their responsibilities to implement the measures, as well as to present a list of identified best practices to contribute to successful implementation guidance in the transition towards green ports.

4. Methodology 2 – Quantitative and qualitative research

After having acquired the necessary theoretical details of the most impactful emission reduction measures, this second research methodology follows the call from the literature to focus on the implementation of emission reduction measures for port decarbonization.

The following section will describe in further details the general research designs used for empirical research. Then, the concrete instrument design with all applied approaches and procedures for data collection will be explained in detail, both for the conducted survey and the interviews.

4.1. Research design

Adequate research designs are usually divided into qualitative and quantitative research.

The methodological task of quantitative research is to establish a representation of what the members of a target group do or think regarding a specific topic. This is achieved by creating a copy of perceptions in data form based on mental facts, answering the question “how many?”. Hence, through quantitative research, particular phenomena and their level of incidence can be counted, and connections between certain phenomena can be made. However, the size of a data base needs to be sufficiently large, and the conditions controlled (Barnham, 2015). The three main conditions for quantitative research are validity, reliability, and objectivity (Hussy et al., 2013).

For qualitative research, the data collection is done through either interviews, observations or analysis of documents while focusing on the “interpretation of phenomena in their natural settings to make sense in terms of the meanings people bring to these settings” (Perumal, 2014). The goal of qualitative research is to understand the respondent’s thoughts, impressions, attitudes, and perception, by asking the questions “why” and “how” (Perumal 2014, Barnham 2015). However, the questions about the “why” can only be enquired after establishing of the initial landscape of participants opinion (Barnham, 2015).

For the scope of this study, a mixed method was chosen, following a deductive process. First, the main quantitative research method in shape of a questionnaire relies on the theoretical foundations of the literature review, meaning the previously analysed emission reduction measures for port decarbonization and their respective characteristics under the specified 'Green Port' scope. Second, once most quantitative data has been collected, further qualitative information has been gathered via interviews by asking for explanation and recommendations based on the primary identified tendencies of the questionnaire results.

The goal of both the questionnaire and the interviews is to explore their match with the beforehand analysed literature and to fill the identified gaps by weighting and complementing the findings, always under the angle of successful implementation. To do so, a large number of port and port association employees in the European Union have been involved into the research project to get more practical and in-depth understanding from experts of the field. It is again to be mentioned that for simplicity reasons, the terms "port" comprises all entities regulating, managing, and developing port activities, operation, infrastructure, and facilities, because the allocation of ownership and business tasks vary from port to port.

4.2. Instrument designs

In this subchapter, both the procedure of the survey and the procedure of the interviews will be explained.

4.2.1. The survey

First, a focus will be set on the survey.

4.2.1.1. Population sample

The specific population target set for the survey comprises the employees of ports and port associations of the European Union. To get a proper list of the existing ports, the website worldportsource.com has been used as supporting database. Worldportsource.com aims to be the first internet website with publicly accessible information of ports and harbours throughout the world, providing among others localizations, satellite images and contact information (World Port Source, 2023). Further, the website categorizes the size of ports into 5 dimensions: very small, small, medium, large and very large. For the purpose of this survey, only the medium, large and very large ports of the European Union have been extracted since it appears that those ports are the main ones with decarbonization need as well as with most time, human capital and financial resources for a transition towards becoming green ports. As a result, a list of 172 European ports has been established. In addition, the port associations of the European Union have also been scanned. As a first source, the website of the European Sea Ports Organisation, espo.be, has been utilised to identify the national port associations. Since the ESPO is "the principal interface between European seaports and the European institutions and its policy makers" (ESPO, 2023), numerous member associations have been listed on the website. As a second source, the internet has further been scanned via the search platform Google, for each of the 27 countries of the EU.

4.1.1.2. Questionnaire design

The elaborated questions of the questionnaire have been integrated into the program q-set.de (Q-Set, 2023). Q-set is an online survey tool free of charge without limitation of questions, of runtime and in the number of survey or participants, but including certain design options and more importantly, with the possibility of SPSS export. Furthermore, Q-set offers the integration of a large variety of design features regarding possible answer types, necessary for the pre-elaborated questionnaire. Also, Q-set has been recommended by various marketing professors at the authors universities. With the author's additional own requirement for professionalism, an ad-free version of the final survey has been purchased, which makes the survey look cleaner meanwhile building up the online pages faster.

The questionnaire has been divided into 5 different parts. The first part can be considered as a general part, starting with an introduction addressing the participants, giving a brief introduction into the relevance of the topic, and explaining the reason for the survey (master thesis), and the important need for participation. Also, the frame of the upcoming questionnaire has been explained, including the number of questions (29 questions), the necessary time (about 15 minutes) and the content of the different pages. Furthermore, brief instructions about how to answer the questions have been given. Lastly, an offer for obtention of the results of the survey has been made, via direct email request to the author. The questions of the first part referred to the participants themselves, as well to general topic question before deep diving into each measure. The remaining parts have all been structured according to the categorization results of the systematic literature review. Hence, the part 2 of the questionnaire focussed on port management, part 3 on port operation, part 4 on ship-to-port and port-to-land interfaces, and part 5 on renewable energies, with each category including between 5 and 7 subtopic-specific questions. In total, the questionnaire comprised 29 questions. The raw questionnaire is attached in annex 4.

For the convenience of the respondents, a curser has been added to the questionnaire, indicating their advancement in answering the questions. They have also gotten the possibility of going back to a previous page and the option of pausing the questionnaire for a later continuation.

For the questionnaire, a set of question types has been used. 24 of the questions are closed questions and 5 are opened. More precisely, regarding the closed questions, 7 questions are closed-ended questions with binary response format of yes or no for facilitated statistical analysis. 5 questions are ranking questions, where participants must rank a given number of options regarding their priority. Furthermore, 4 closed questions are represented as matrix questions, presented as a grid between options and their categorization. In addition, 8 closed-ended questions with single choice response format were asked, contributing to prioritization of competing options of a same subtopic. Finally, 1 question can be considered a closed-ended question with a single choice format for categorized collection of demographic data.

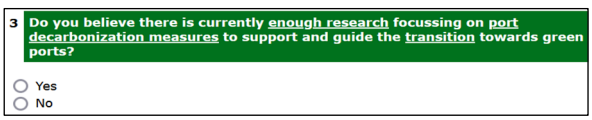

Figure 4: Example of closed-ended question with binary response format. Source: own illustration, Q-Set.

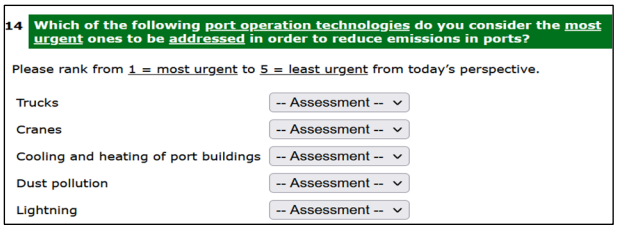

Figure 5: Example of ranking question. Source: own illustration, Q-Set.

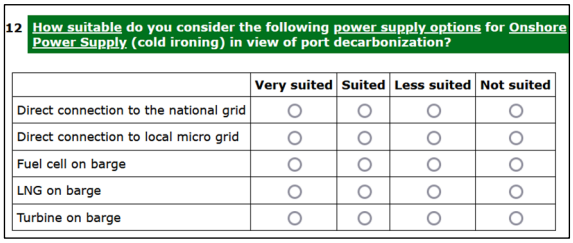

Figure 6: Example of matrix question. Source: own illustration, Q-Set.

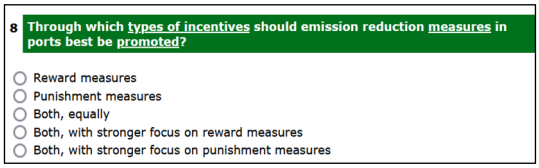

Figure 7: Example of closed-ended question with single choice response format. Source: own illustration, Q-Set.

As for the 5 opened questions, 1 question can be defined as an open-ended question, allowing the respondents to choose the amount of information they want to reveal in regard to their touchpoint with the port ecosystem. The 4 remaining opened questions give free answer possibility for success factors, best practices or additional information about port decarbonization. In this way, additional qualitative data is added for later interpretation and verbatims.

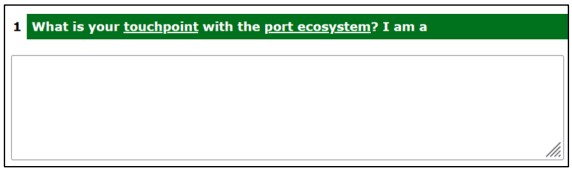

Figure 8: Example of open-ended question. Source: own illustration, Q-Set.

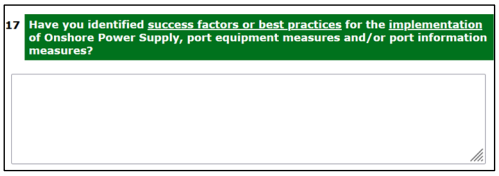

Figure 9: Example of open-ended question with free answer possibility. Source: own illustration, Q-Set.

The number of different question types does make the analysis more complex. However, it has been proven that by using various types of questions, the motivation of the respondents is more likely to be maintained.

The type of scale used for most questions is an ordinal scale, with the data being presented in a hierarchical manner, but without measurable distance between them. For the matrix or single choice response formats, the opinion options are presented verbally. The chosen ordinal scale is inspired by the very commonly used Likert scale. The neutral mid-point, however, has been

removed, which leaves 4 possible answer choices for the concerned questions. Since the questions are not related to personal opinions about the respondent's behaviour, but about their knowledge and estimation of the development of an external phenomenon, leaving out the neutral mid-point is plausible. The aim was to encourage the participants and increase their commitment towards one tendency, rather the positive or the negative one. This approach is in fact appropriate for particular subject matters. For a small number of questions, nominal scales have been used.

Concerning the duration of a questionnaire, (Question bank, 2007) mentioned that the time accorded should not surpass 15 minutes. Therefore, the questionnaire has been designed around this value and is supposed to take maximum 15 minutes of time.

4.1.1.3. Testing of the questionnaire

Before spreading the questionnaire to the identified target group, it had to be tested. The testing has been done in two phases. In a first place, one of the author's colleagues with a master's degree in marketing, as well as a fellow co-student of the author with a bachelor's degree in marketing have independently gone through the structure of the questionnaire and submitted their suggestions for adjustment and improvement. Both have had classes and experience in conducting surveys, which is why their valuable recommendations have been adopted. Secondly, the adapted questionnaire has been sent to two other colleagues of the author, both professionally focusing on the maritime sector, and with decent knowledge in regard to ports. Some minor feedback has been expressed, which had then as well been inserted into the questionnaire, for ending up with a third, reviewed questionnaire version.

Through the testing, both validity and reliability have been proofed. According to (Perumal, 2014), validity "refers to quality and can be applied to any aspect of a research and is supposed to measure and to perform as it is designed to perform. Reliability is the extent to which the survey produces the same results on repeated trials".

4.1.1.4. Data collection

Data collection is the core phase in the process of a survey because it will determine the quality of information resulting from the questionnaire. In fact, a maximum of responses is required by the corresponding target group to avoid inconsistency and errors (Question bank, 2007). Therefore, this step is to be caried out conscientiously. With the aim of reaching out to the employees of ports and port associations across the European Union, the most adapted way to carry out the survey was via an online questionnaire. Giving the opportunity of easy access to the respondents, online questionnaires are one of the most popular options for carrying out surveys today, especially compared to printed versions or via telephone. Furthermore, online surveys offer the possibility to track the responses. The literature also found that online survey participants tend to answer the questions asked more honestly (Nolinske, n.d.).

The data collection phase started in April 2023 by scanning the mentioned internet pages worldportsource.com, espo.be and Google to identify the scope of existing ports and port associations in the European Union. A list of both target groups has been elaborated in a separate excel sheet. Meanwhile the questionnaire was in elaboration, the author visited the trade fair "Hannover Messe" in Germany in the context of her simultaneous internship for a hydrogen-to-power company, providing, inter alia, a cold ironing solution for ports. Hannover Messe is the world's largest trade fair for industrial technologies, including the maritime sector (Hannover Messe, 2023). Exchanges with stakeholders of the maritime sector were held during the 2-day visit of the fair, resulting in various verbal agreements for later forwarding of the questionnaire to the experts' port network.

At the beginning of May 2023, the final version of the questionnaire was ready for being sent to the prospects. Therefore, the websites of the identified ports and port associations were explored, one by one. It immediately appeared that only a small number of ports revealed the identity and contact details of their employees. Since sending the questionnaire only to a generic email address has been categorized as insufficient and imprecise, it was absolutely necessary to go further. In this spirit, the author elaborated a creative approach by using LinkedIn profiles and the generic email addresses. Firstly, a LinkedIn Premium account has been set up to get more access to the profiles. Secondly, the "People" section of the official LinkedIn pages of all selected ports and port associations has been called up to identify the employee's names and functions. And thirdly, the names of the employees have been matched with the end part of the generic email address found on the websites. The main possible combinations tried out were the following ones:

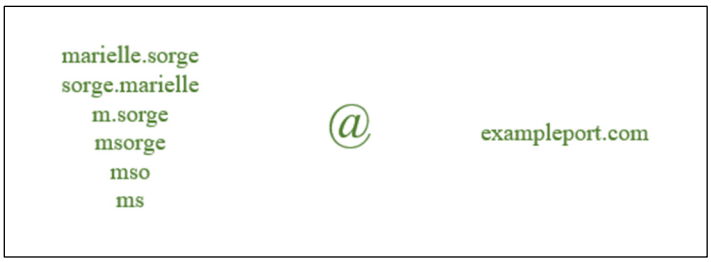

Figure 10: Example of e-mail combinations conducted. Source: own illustration.

Through this creatively applied approach, the number of concrete contacts of the European port environment has been capitalized to 714. This thorough, detailed, and meticulous work took place during 3 weeks' time and necessitated great endurance. But the result confirmed the worthiness. All the 714 contacts have been kindly invited to participate in the questionnaire, with a short explanation of the master thesis project as well as the demand to forward this email to their port network. Also, it has been offered to send the results of the survey, if desired. In order for the potential participants to feel more addressed through the author's message, the content has been translated into different European languages. Only prospects of countries where English is used as a common language have been addressed in English. The contact list is attached in annex 2 and the contact sheet is to be found in annex 3.

Some obstacles could, however, not be overcome by the creative contact approach. In fact, the number of contacts per country differed, which is mainly due to the number of ports and related

employees of the 27 different countries. Also, not all employees use LinkedIn, and some interesting contacts have hidden their name on this social network. Furthermore, not for all ports the creative combination used was successful, which is why the request could only be sent to the generic email address – if it even existed. In fact, several ports did not even have a website and thus any contact information at all. As for the profile of the employees, it was difficult for the author to capture which one would be the most adequate one with the necessary knowledge to answer the questionnaire. This is because neither are ports obliged to have environmental managers, nor does every port have one, by far. Further, it was expected that also other employees could have sufficient knowledge of emission reduction measures for port decarbonization, and that only the ones with familiarity of the topic would take the time to answer.

Finally, the author undertook a last effort for data collection by visiting the trade faire "E-World energy and water" in Essen, Germany, an information platform for the European energy industry (E-World, 2023). Even if this trade fair is less focused on the maritime sector, further exchanges with maritime experts seeking for the energy transition in ports have been held as a last spreading initiative of the questionnaire.

The questionnaire was opened from 1st of May 2023 until 31st of May 2023, thus for more than 4 weeks' time, which has been considered as a sufficient timeframe.

4.2.2. The interviews

In addition to the questionnaire, qualitative data was gathered through expert interviews to complement the results of the survey. Conducting interviews is in fact considered a good method to gain a thorough and in depth understanding of a given topic.

While filtering the contact list for the questionnaire, eight individuals have been chosen for interview request, mainly based on their matching position in the context of the green port topic. Another three contacts were requested via direct connection from the author's internship colleagues. These two approaches resulted in four positive answers. The final interviewees are the "Green Port Masterplanner" from the Port of Antwerp-Bruges, referred to as interviewee 1, the "Environmental Strategist" from the Ports of Stockholm, referred to as interviewee 2, the "Innovation and EU projects responsible" from the Port of Seville, referred to as interviewee 3, and the "Director of Energy Transition and Sustainability" from Fundación Valenciaport, referred to as interviewee 4.

The interviews were held between the 25th of May 2023 and the 7th of June 2023, thus towards the end of the timeframe of the questionnaire, which opened the opportunity to align the interview questions with the questionnaire results for centred answers. The 14 interview questions were sent to the interviewees beforehand for preparation, as well as a declaration of consent for data processing. The filled and signed declarations of all 4 interviewees are to be found in annex 6.
The interviews were held via Microsoft Teams for a duration of 30 minutes each. After a short personal introduction, the structure of the master thesis has been explained to the interviewees.

It has especially been underlined that the focus of the interviews lied on giving reasoning to certain questionnaire results and on finding best practices for the implementation of each measure. The questions were asked in a structured manner, based on the question rank sent beforehand, in order to guide the interview within the complex topic of green port transition and to extract as precise answers as possible. Only when the interviewees did not understand a certain aspect correctly or did not give an answer going into the precise direction of the question, the initial questions have been rephrased – otherwise, the author mainly stayed out to avoid manipulation of responses. The transcripts of the records are available in annex 5.

In the pursuit of further interview partners, the author used the visit of the trade fair "Salón Internacional de Logística" in Barcelona (SIL Barcelona, 2023) from 8th to 9th of June 2023 within her professional internship as an opportunity to connect with further port employees. In fact, various ports were represented with an onsite stand, and an entire conference stage was dedicated to the topic of ports. The author listened to the two following panels: 15th MedPorts & Shipping Summit "Session 2: Towards a Sustainable Shipping and Port Industry in the Mediterrean" and UfM Conference "Greening Maritime Transport in the Mediterranean Green Ports: Emission Reduction Measures, Energy Transition and Eco-Certification". After the panels, the author talked to or got the contact details of most of the panellists, which were the President of MEDPorts Association, the Secretary General of the European Sea Ports Organisation (ESPO), the Head of Transport and Urban Development of the Union for the Mediterrean, the Strategy, International and European Affairs responsible of the Grand Port Maritime de Marseille, the Head of Environmental Sustainability of the Port of Barcelona and a Lawyer/Economist at Hellenic Port Association. Unfortunately, either no matching time window has been found with the potential further interview partners, or they did not answer the follow-up email. Since the general time for data collecting available for this master thesis was restricted, the author decided to move on and stick to the answers of the four interviewees mentioned above. Still, the participation at the two panels at SIL Barcelona did help the author to get an even broader understanding of the topic of green ports and the prioritization and actions to take for implementing emission reduction measures.

5. Results and overview of findings

In this chapter, the findings derived from the survey and the interviews will be presented and analysed. The results will be listed in the same order as the questions in the questionnaire.

In total, the questionnaire has been called up 365 times without being answered at all, and 43 respondents have started the questionnaire but not fully completed it. Finally, 59 questionnaires have been fully completed. Since the reflection of the green port knowledge of the participants was needed in its entirety, the answers of the 43 not fully completed questionnaires have not been integrated into the final results. 59 respondents out of 714 contacted individuals represents a response rate of 8,26%.

Considering the very specific target group of port and port association employees of the European Union and the short timeframe given, 59 fully acquired questionnaire answers is a very

considerable amount. However, this number of participants remains too small for actually filtering out correlations and for categorizing the results to a specific subgroup. In fact, this questionnaire is not a typical consumer marketing survey trying to figure out correlations between demographical data and personal subjective preferences. Instead, the aim is to filter out the general tendencies of objective preferences for emission reduction measures implementation, based on rather rational and practical expert knowledge on the topic.

5.1. General questions

In the first section of the questionnaire, the respondents were demanded to indicate some personal data, with the aim of assuring profile validity.

When asked for their touchpoint with the port ecosystem, numerous specific positions within the port sector have been mentioned, from whose most fit into the positions available in ports and port associations. In this logic, two participants had to be out selected due to their external role in ports, being an "expert in a company in the port sector" and a "business developer proposing cold ironing solutions". For facilitation, the remaining different positions have been categorized into the corresponding departments, as represented in the diagram below.

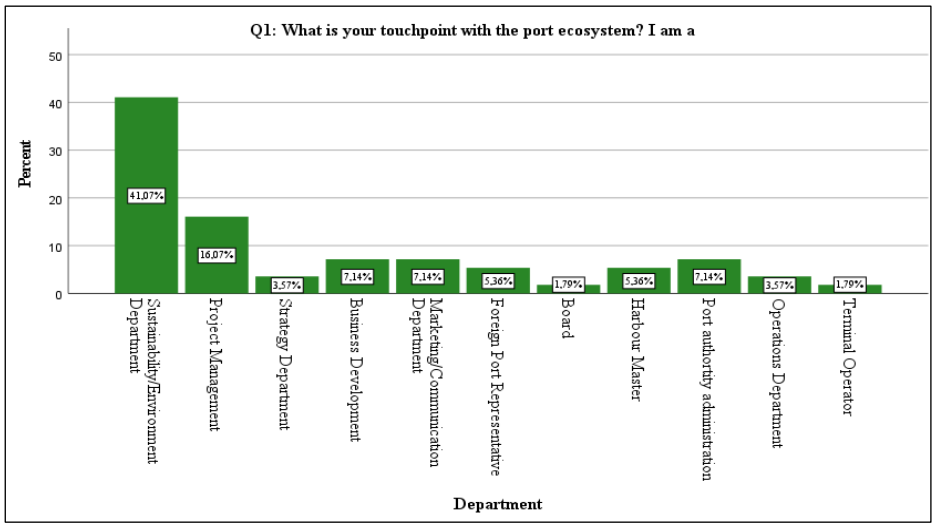

Figure 11: Q1: Touchpoint with the port ecosystem. Source: own illustration, SPSS.

With about 41%, the participation rate of members of port's Sustainability and Environment Department was topmost. This is well suited for the quality of the responses since it is assumed that those candidates have the broadest knowledge on the green port topic due to their professional specialisation in the field. The second department group of respondents are the Project Managers, who probably work on the implementation of some of the identified measures for port greenification. The Business Developers, the Marketing and Communication Department, the Port Authority Administration, the Foreign Port Representatives and the Harbour Masters speak for 5% to about 7% of the respondents. The participation rate of Strategy Departments, Operations Departments, Boards and Terminal Operators is below 4% each.

The participation of 11 different departments within the port and port association sector consents with the before-mentioned hypothesis during questionnaire spreading that not only employees working specifically on environmental issues have knowledge on the green port topic, probably because it touches the entire range of port applications. This conclusion is also drawn on the basis of the great number of people having opened the questionnaire without answering, combined with the numerous e-mail returns received regarding missing expertise in the topic. Also, the very small number of missing answers throughout the questionnaire is another argument. Hence, it is assumed that only participants with sufficient knowledge on green practices in ports took the 15 minutes of time to answer the questionnaire.

A second verification criteria chosen was the nationality, which was necessary for checking whether the participants are from the European Union or not. In this logic, one Japanese participant had to be out selected. With a look at the remaining participants, almost one third is of German nationality, more than triple the amount of the second most represented nationalities. These are French, Austrian and Portuguese, with almost 9% each. The Belgian, Polish, Finish, Bulgarian, Romanian, Greek and Swedish nationalities represented between about 3% and 7% of all participants. Finally, the Dutch, the Hungarian, the Danish, the Latvian, the Spanish, and the Italian participants were only represented by under 2%, meaning one participant each.

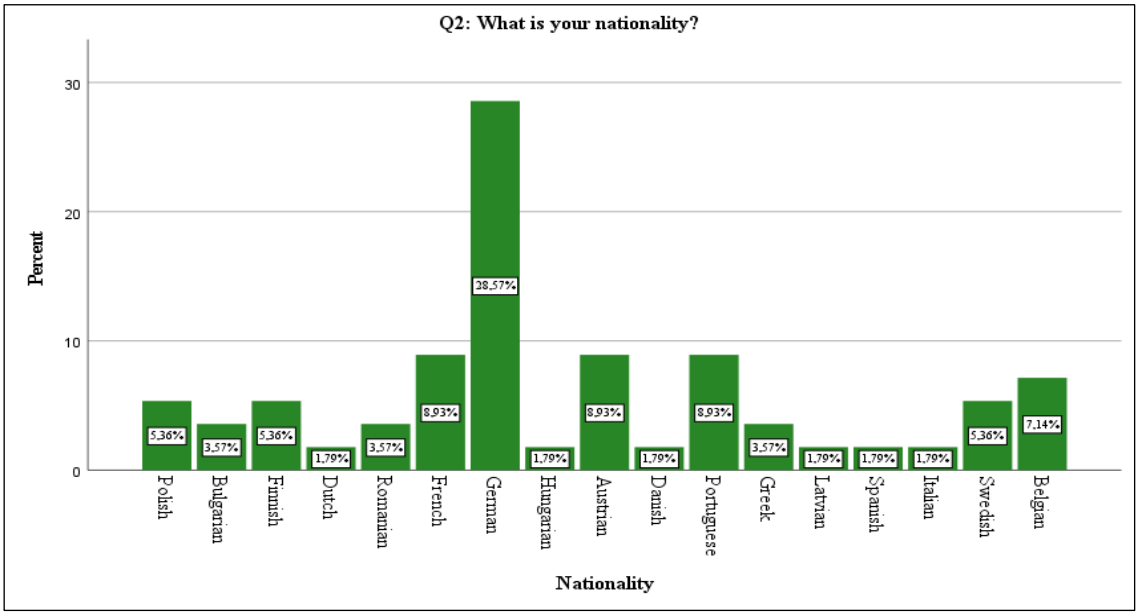

Figure 12: Q2: Nationality. Source: own illustration, SPSS.

Even though the ports and port associations of all 27 countries of the European Union have been contacted, only 17 nationalities are represented among the respondents. This, however, is still a very high number considering the time available for undertaking the questionnaire, the randomness of contact with lacking connection, and the fact that the number of ports in each country in the EU is not evenly distributed. For instance, while Germany counts 23 medium to very large ports (resulting in most respondents), Slovenia and Estonia only have one port each (resulting in no respondents). Also, a certain sympathy and belonging effect is observed, comparing the writing of the author's master thesis for a German and a French university with the nationality-based response rate, being highest and second highest for German and French.

The respondents have not been asked for their years of experience in the port or port association sector because the topic of green ports is still a rather new one. Therefore, a participant with a long experience in the conventional port sector could not have been rated as having more or less experience than a participant with little experience in the green port sector.

Before deep diving into the topic, the respondents were asked in question 3 whether they believe there is currently enough research focusing on port decarbonization measures to support and guide the transition towards green ports. This question was considered a warm-up question. With just under two thirds of respondents indicating that there is currently not enough research carried out for the transition towards green ports, the essential purpose and urgent need of this master thesis research project has been validated.

In question 4, the respondents were demanded to rank by urgency from 1 to 9 the identified emission reduction measures identified in the literature. Whereas in question 5, the respondents were asked to categorize the development of the same measures into their current lifecycle category. The placing of question 4 and 5 at the beginning of the questionnaire was chosen strategically before deep diving into each measure by itself, in order to not manipulate the opinion of the respondents. Since a ranking gets more difficult the more options are available, the two measures “electric energy for ship propulsion” and “hinterland integration” have not been listed due to their more external connection to port activities. However, their importance has been surveyed at a later stage.

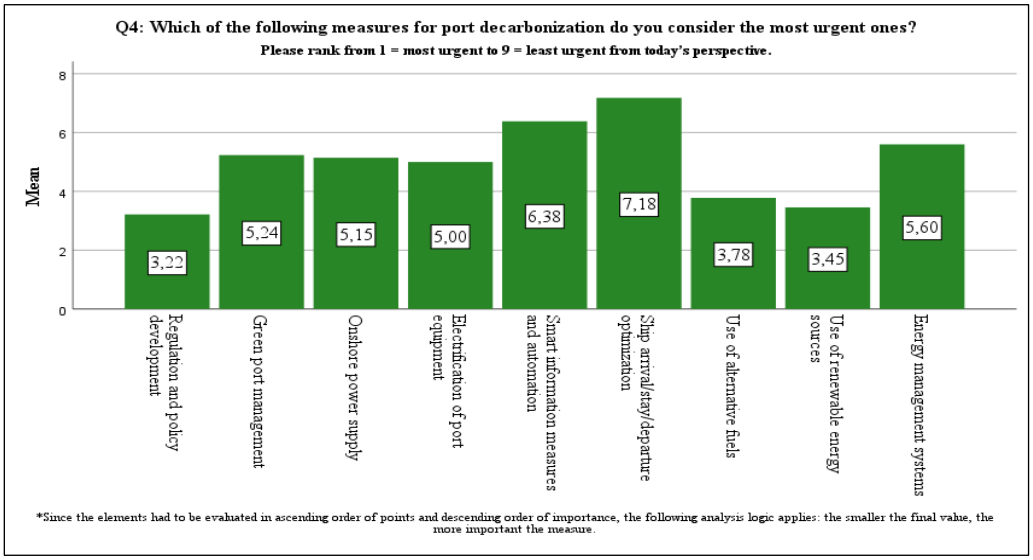

Figure 13: Q4: Most urgent measures for port decarbonization. Source: own illustration, SPSS.

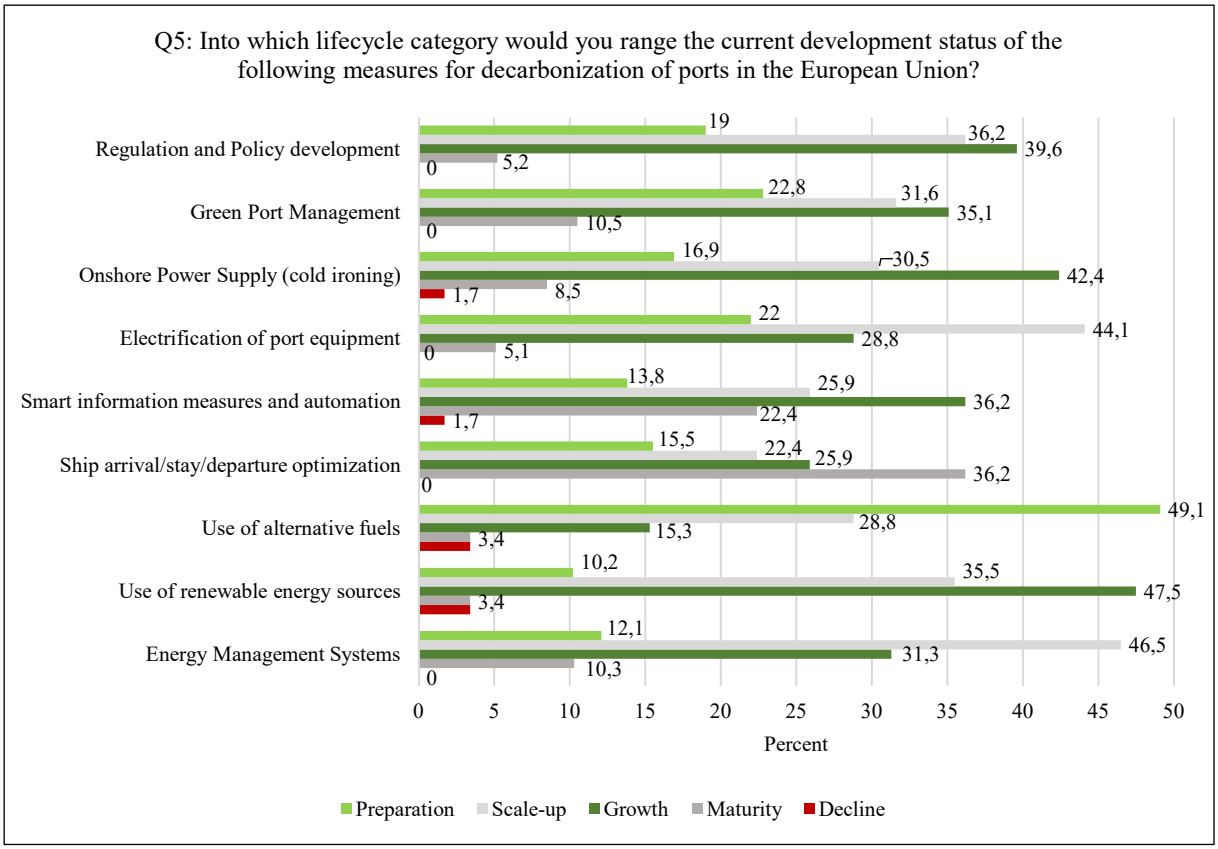

Figure 14: Q5: Lifecycle category of decarbonization measures in ports in the EU. Source: own illustration, Excel.

From all other 9 measures listed, regulation and policy development (mean of 3,22) is considered the most urgent matter, followed by the use of renewable energy sources (3,45) and the use of alternative fuels (3,78). When comparing these results with the ones from question 5, regulation and policy development is considered to 55,2% to be in the preparation or scale up category and to 39,6% in the growth category. The comparison of these two questions underlines the necessary of speed up needed for regulation and policy development. The use of renewable energy sources is perceived to be to 45,7% in the preparation or scale up category and to 47,5% in the growth category. With almost half of the respondents believing this measure to be growing as of today, it is an indicator that the upcoming energy supply bottlenecks have been started to be addressed, based on decarbonized energy sources. As for alternative fuels, they are said to be to 49,1% in the preparation category, to 28,8% in the scale up category and to 15,3% in the growth category. In comparison to the high accorded urgency from question 4, it is underlined that the development of alternative fuels also needs a fast speed up to meet the decarbonization goals on time and in quantity.

These three measures have by far a smaller mean than the second group of urgent measures, which are electrification of port equipment (5), onshore power supply (5,15), green port management (5,24) and energy management systems (5,6). According to the results of question 5, it appears that electrification of port equipment is currently switching from the scale-up phase (44,1%) to the growth phase (28,8%), which is an excellent indicator. According to the respondents, the current lifecycle category of onshore power supply is slightly more advanced to the electrification of port equipment, with 30,5% categorizing the development into the scale-up phase and 42,2% into the growth phase, a satisfying result also regarding upcoming mandatory

regulations for onshore power supply in European ports. Further, the results for green port management are almost identical between scale-up (31,6%) and growth (35,1%), with a considerable percentage of 22% even in the preparation category. The varying results might be linked to different perceptions of the actions taken but ports seem to have understood the urgency of green port management for driving the change. As for energy management systems, they are said to be mainly in the scale-up phase (46,5%), to 31,3% in the growth phase and to 12,1% in the preparation. This result is quite ideal and matches with the renewable energy supply perception, two measures which go hand in hand, together with energy consumption. From all these measures, it is noticeable that the ones directly related to energy are on the forefront. Simultaneously, it seems like the implementation of all these measures does need guidance and support from the responsible governance bodies. In that regard, it is rather surprising to see that the green port management is only on the urgency rank 6, despite their governance role on the operational side.

Finally, smart information measures and automation are on rank 8 (6,38) and ship arrival/stay/departure optimization (7,18) on rank 9 as least urgent measures. A reasoning of these two measures being on the last urgency ranks might be their advanced application, as standing out in question 5. It appears that over 60% declare smart information measures and automation to be in one of the three most advanced lifecycle categories, which are growth, maturity and decline. As for ship arrival/stay/departure optimization, more than 62% have qualified this measure in the same advanced lifecycle categories, with over 36% in the “maturity” category.

5.2. Port Management

In question 7, the respondents were demanded to categorize a list of stakeholders regarding their responsibility for port decarbonization. The two options “very responsible” and “responsible” have been compiled to “rather positively responsible” and the two options “less responsible” and “not responsible” were combined to “rather negatively responsible”, to facilitate the reading. It results that Port Authorities/Administrators are almost entirely responsible for port decarbonization (98,31%), very closely followed by the European Union (96,61%) and National Governments (94,92%). The shipping companies were also attributed a high responsibility share of 86,44%. Furthermore, local industry is considered responsible by more than three quarters of the respondents, and the institutions by two thirds of respondents. It needs to be underlined that from these six main responsible stakeholder groups, three groups (Port Authorities, shipping companies, local industry) are foremost on the operational level, whereas the three other stakeholder groups (EU, National Governments, institutions) are foremost on a regulatory level. Hence, the close relation between a clear theoretical regulatory framework and the practical implementation of decarbonization measures have been confirmed to go hand in hand. Local organization (33,9%) and citizens (27,12%) are considered less responsible for port decarbonization, but do have an obligation to raise their voice, too, even if less fundamental.

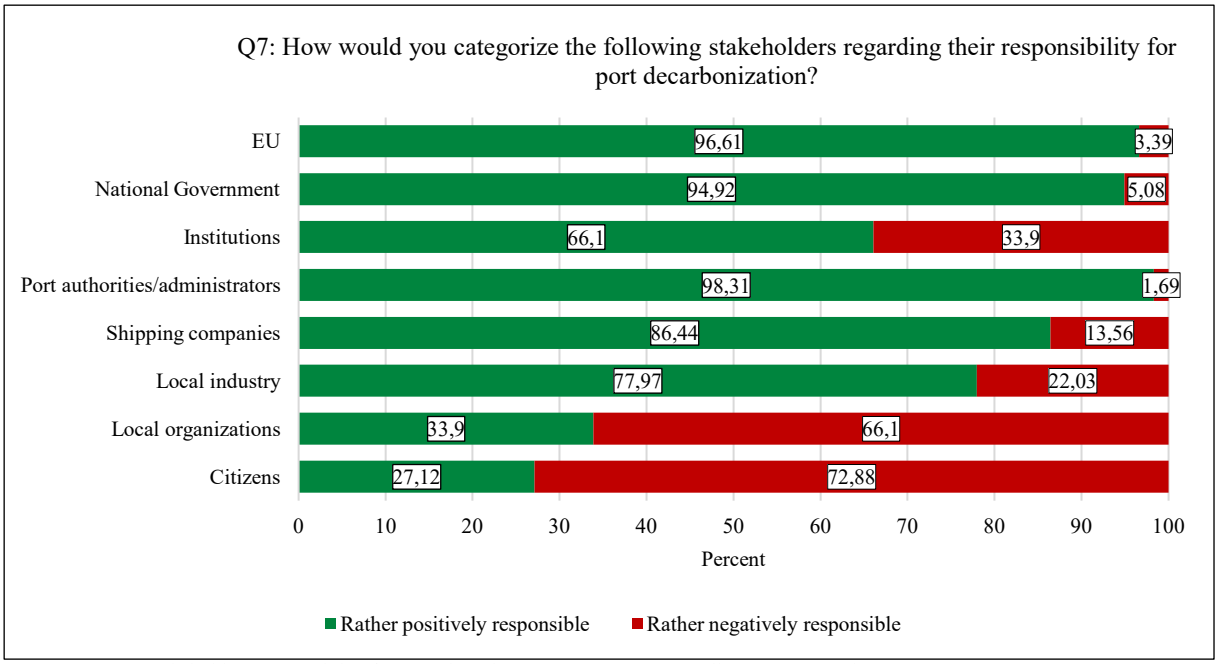

Figure 15: Q7: Stakeholder responsibility for port decarbonization. Source: own illustration, Excel.

Interviewee 4 agrees that *"transforming a regular port to a green port involves not just the Port Authority, but mainly actually concession companies, truck operators, the city"*. Interviewee 3 confirmed that in the stakeholder context, *"everything is related and needs to be put together. That's more complicated"*. In direct relation, interviewee 1 *"wouldn't say there's a lot of trust in between all parties in the sector. The shipping industry is what I call a self-organized eco-system, so it's got many, many parties that play a small role in a very large chain of events or a very large supply chain without having really one single responsible for the entire chain. So, the actor field in the port is very complex, very diverse"*, a statement protruding the reasons for the cooperation complexity.

When focusing on recommendable practices for the integration of port related stakeholders into the transition towards green ports, the words cooperation and collaboration between stakeholders have further been mentioned by 7 respondents, be it regarding European ports, customers, shipping companies, private sector, or cities. According to one respondent, the numerous advantages would for instance be *"setting up logistic chains, share expertise, share costs, use synergies, strengthen competitiveness"*. Several examples of concrete practices mentioned are European research and funding programs (4 times), the general sharing of information, building of port community networks, the collaborative planning platform of start-up "PortXchange" in the Port of Rotterdam, strategic agreements or Memorandums of Understanding (2 times), and engagement of consultants, if viable. According to interviewee 2, collaboration between stakeholders already exists in her port, but to date focused on rather economic issues: "*When it comes to the shipping customers, the direct dialogue is mostly done through our market department and those responsible for different shipping segments within our organisation. So they have the dialogue with the customers, but I think that we need to perhaps change that for the future. We need to have a more active dialogue around environmental issues"*. In addition, interviewee 1 believes in the necessity of *"having Port Authorities being more of managing stakeholders, I think we need to move more towards a participation approach where we really co-create, co-operate"* for a common strategy of a desired green port, as well as by setting up all kinds of

corporations on the operational level: *"that's not part of the culture yet, but we are working on that"*. In the opinion of interviewee 4, the role of ports is *"to create spaces. How you create the space will be different from port to port, based on dialogue and agreement. So, you have to find places of dialogue to convince and to collaborate"*. An example he mentions from the Port of Valencia is the initiative ECO Port, involving all participants in regular meeting and also through a dedicated website, however the latter has been qualified as not critical for the dialogue by interviewee 4. Furthermore, interviewee 2 claims that for ports, it is fundamental to know: *"What kind of techniques are our customers investing in? What kind of alternative fuels are they going to use in the future?"*. The answers to these questions are not yet available, but she believes there is a *"need to be more systematic and more structured in our dialogue with the shipping customers"*. All these additional comments left by the respondents and mentioned by the interviewees highlight the complexity of the managerial task to engage the different port stakeholders.

In question 6, the respondents were asked which kind of framework they consider the most effective one for implementation of port decarbonization measures. With a look at the below graph, it is clearly visible that more than half of the respondents (51,79%) prefer both compulsory regulations and voluntary initiatives, however with a stronger focus on compulsory regulations. Compulsory regulations alone are only consented by 7,14%, whereas voluntary initiatives alone only by 1,79%. On an almost identical level are both options equally (21,43%) and both with stronger focus on voluntary initiatives (17,86%). In summary, this graph shows that according to the assessment of the respondents, compulsory regulations and voluntary initiatives need to be applied simultaneously for achieving port decarbonization, with compulsory regulations and policy taking the lead. In this regard, it can be assumed that voluntary measures alone would not be adequate for sufficient speed in the transition. In fact, one respondent added that the most important aspect is *"regulation, regulation, regulation"*, with another respondent appealing for *"coherence vis-à-vis existing European and national legislation, and with the recently defined policy initiatives and objectives set out in the European Green Deal, the RepowerEU plan and the Net-Zero Industry Act"*.

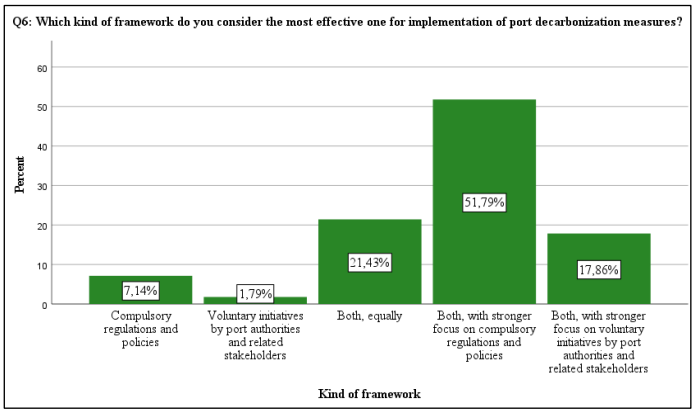

Figure 16: Q6: Implementation framework. Source: own illustration, SPSS.

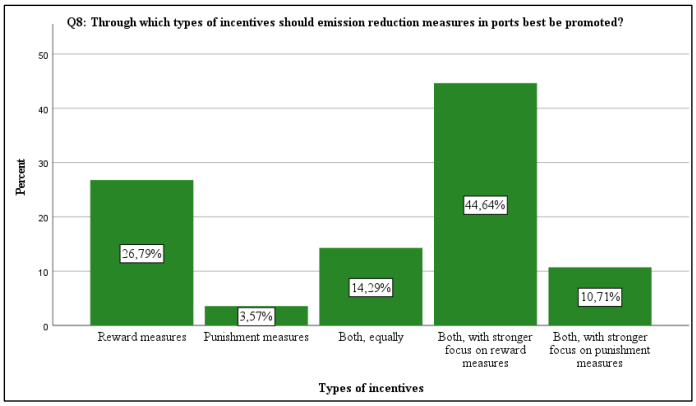

Figure 17: Q8: Incentive types. Source: own illustration, SPSS.

These superordinated compulsory regulations had further to be ranked between reward and punishment measures in question 8, as indicated in the above graph. When combining the "Reward measures" only option (26,79%) and the "Both, with stronger focus on reward measures" option (44,46%), they result in 71,25% of the respondents being in favour of positively applied incentives. When carrying out the same procedure for "Punishment measures" (3,57%) and "Both, with stronger focus on punishment measures" (10,71%), the negatively applied incentives are only favoured by about 14% of all respondents. This number is at the same level for applying both incentive types equally. In addition, 7 respondents and interviewee 4 left a comment to underline that within the reward measures, funding, subsidies, and eco-incentives are the most needed incentives for pro-environmental actions, which brings us back to the before analysed responsibility of regulatory stakeholders.

Furthermore, another question of the survey demanded whether ports should employ specialized and dedicated managers or agents for the process of port greenification, to which 87,5% responded "yes", and only 12,5% responded "no". In the comments, one respondent added that *"the management of every port needs to make the first steps. "Not having the time and resources" is a reason for insufficient environmental action but being aware of this gives the opportunity to change it"*. Another participant adds that *"ports are organized in different ways but they need the necessary resources (human resources, regulation, finances) to develop the necessary changes"*. Furthermore, the need for clear green port strategies has been commented 3 times, including fixed priorities and key objectives, which might be dependent of regulation and funding options. Hence, the willingness of the port management to engage in the green transition appears to be a key lever. A further respondent proposes environmental assessment schemes and certification to motivate the port management to take action. Besides the management, the staff was described to be needed to be engaged, too.

When asked for successful implementation of certain management structures or policies, interviewee 3 mentioned the philosophy of working with nature, actively applied in her port. Similarly, interviewee 4 speaks of a strategy being *"related to something called environmental task. Environmental task means purification"*. Interviewee 1 noted the investment in so-called lighthouse projects for demonstration of systemic change or innovation, a procedure *"happening in most European ports"*. A long-term environment and climate action plan are notions stated by interviewee 2, where *"for each environmental goal, we have identified a few strategies to work on, to be able to fulfil these environmental targets. Then, each year, every department within*

the Port of Stockholm implements their budget, including their respective action plan activities for the next year. In that way, the activities and budget can be united".

In addition, the respondents were asked in question 10 whether ports should use a green marketing strategy to promote their decarbonization efforts. Almost 95% of the respondents answered with "yes" and about 5% answered with "no", which clearly spotlights the importance of green marketing campaigns for ports. Furthermore, one respondent added that *"reports on emissions and measures are very important for transparency"*. With focus on the implementation, interviewee 1 reported about such a marketing campaign, with the argument that *"what we tried to do is to make that visible, to inspire the community to make that also part of the mainstream, like to create a sense of urgency also with all of the others. Having them become aware of their peers will make people more tempted to move themselves as well or act, that's a psychological thing"*. On the contrary, interviewee 4 added a comparative weighting, saying that *"the promotion of green practices via marketing campaigns are nice to have and will become increasingly important, but they are not critical. Operational and logistical issues are today more important in this balance"*.

5.3. Port operation

In the third part, the questions focused on port operation, with question 11 evaluating the significance of barriers for the implementation of onshore power supply. For simplification, the two options "very significant" and "significant" have been compiled to "rather positively significant" and the two options "less significant" and "not significant" were combined to "rather negatively significant". This query filtered out that all the five barrier categories, being costs, technical specifications, standards and regulation, integration into port operation and stakeholder collaboration, have a significance degree of over 80% when it comes to their practical implementation.

Still, slight differences are observed. From all barriers, the cost-aspect is with nearly 95% of agreement the main barrier according to the respondents. In this sense, interviewee 3 remarks: *"we are looking for grants to be able to finance the OPEX because it's so expensive and not only for our infrastructure, but also the modifications in the ships that are needed"*. At the same time, interviewee 2 speaks about an incentive contribution of 1,000,000 Swedish crowns made to a vessel that has been retrofitted to OPS. Further, interviewee 2 noted, that *"either we had the investment for the installation of OPS in the port but no customers or vice versa"*. For encouragement of the customers, an environmental discounted port fee has been set up for a long time. The second most significant barrier are standards and regulation with almost 90% of approval, followed by stakeholder collaboration and technical specifications, both with almost 85% of positive significance degree. Regarding the regulation, one respondent counts on an upcoming regulation obliging shipping lanes to use OPS when they are in ports. In direct relation, interviewee 2 is convinced that *"the fit for 55 package and the FuelEU Maritime legislations will now push OPS further, with the obligation to install OPS in all TEN-T ports until 2030"* and that *"the customers are much more aware now of higher environmental standards"*. The regulatory aspect again overlaps with the stakeholder collaboration, as pointed out by interviewee 1: *"It's actually a bit of a chicken and egg problem, a paradoxical situation in which*

the sector calls for clarity on roles and responsibilities. But I would think that once the policy-makers in Europe take an initiative and make clear what the roles and responsibilities are, they will face a lot of resistance from the sector – […] that's not how the democratic process in Europe works". According to interviewee 4, *"the aspect which is not clear yet is the business of how the operators will operate in the future"*, a probable reason for the insecurities. As for the technical specifications, one respondent wrote that there is a need for incoming vessels supporting the OPS technology. In that regard, *"a constant dialogue with technological providers is necessary and to involve innovation actions"*, says interviewee 4. Further, the integration of OPS into the port operation is to 81,36% significant. One respondent shared a best practice in this regard, which refers to the ports of Stockholm, Helsinki, and Tallinn in the Baltic Sea, having decided to set same standards for cold ironing for the ships operating in all three ports. A further respondent added that *"OPS in liner traffic is by far the easiest to start with. That, in turn, builds in-house know how to help in tackling the more difficult OPS cases, for example the container and cruise segments"*. Also, the elaboration of studies related to port equipment, infrastructure, performance and safety for OPS implementation are said to be key, as well as participation in EU projects like the EALING project.

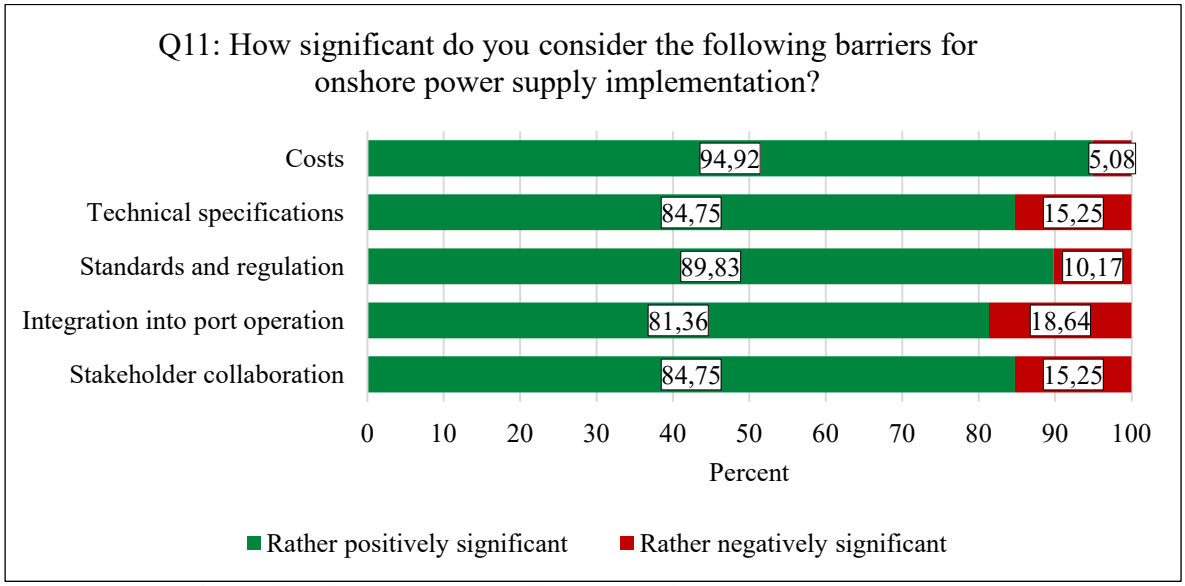

Figure 18: Q11: Significance of OPS barriers. Source: own illustration, Excel.

In question 12 below, the respondents were asked to rank the suitability of various power supply options for OPS into "very suited", "suited", "less suited" and "not suited". The same simplicity representation as in question 11 applies. Clearly, almost all respondents categorize the connection to the national grid as the most positively suited power supply option for OPS with 96,55%, closely followed by the direct connection to a local microgrid in the port with about 85% of suitability. However, the additional comments underlining systematic risk for local port grid stability (2 times) and the need for strengthening the grid around the port do show that ports are in fact aware of the possible grid overload. From the other options, it is especially the fuel cells on barge which seem to be an alternative power supply option, having been rated by 50% of respondents as a positively suitable power supply option for OPS. LNG on barge, however, is rather seen as a negatively suited option by over 75% of respondents and turbines on barge even by over 85%. These numbers give an approximate ranking of the three grid-independent and peak levelling options for power supply for OPS in ports.

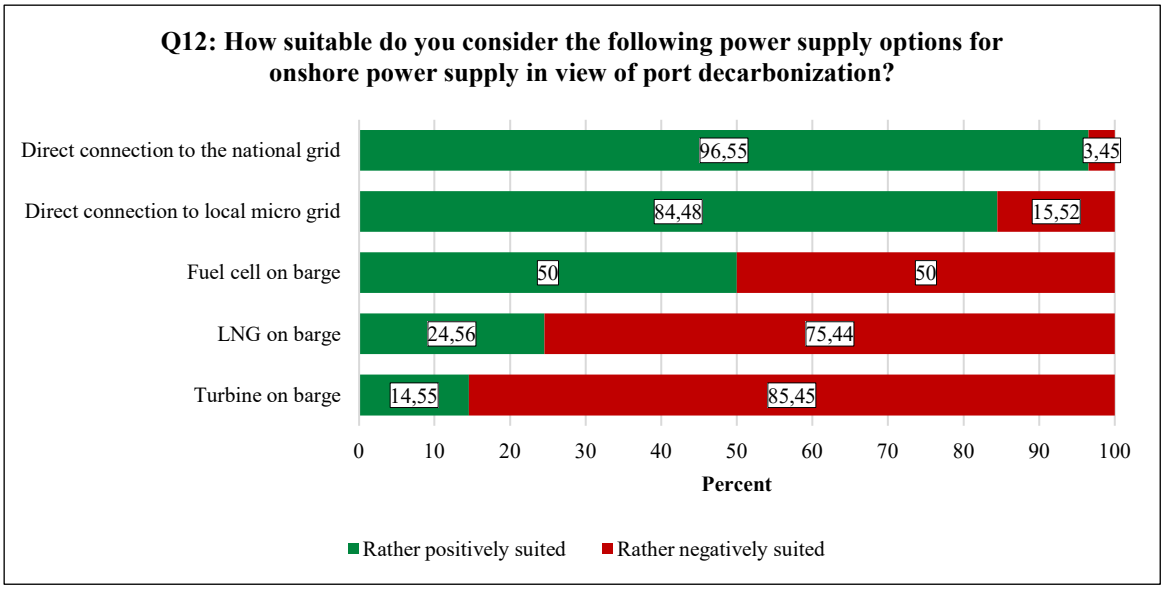

Figure 19: Q12: Power supply options for OPS. Source: own illustration, Excel.

But still, a respondent expressed his insecurity: *"Our port tends to go for electric supply of ships and vehicles. The amount of energy is huge (over 2 GWh/day). The energy needs to be there. Who can assure that?"*. Interviewee 3 seems to agree: *"There are also other struggles like the energy capacity"*. According to interviewee 4, *"electric grid expansion is something needed in every port before going into providing OPS, and it is more difficult when the Port Authority is not the grid owner. These ports need to start conversations, convincing the transmission or distribution system operators to build the upgrade"*. To get a clear vision of the needed capacity for integrating the volumes into the infrastructure planning, a respondent of the questionnaire proposes the setup of procedures for letters of intent or expressions of interest. As integrated best practice, another participant mentioned the existence of a port service company that can undertake the sale of electricity and thus give financial guarantees to develop OPS. A third participant mentioned the combination of OPS and auto mooring systems to reduce the emissions and time from ships at berth, which directly results in decreased power need for OPS. *"In terms of business model, the ports need to talk to everyone possibly involved. But it also depends on the regulation, in which sense the Port Authority can also play a role in which to guide the regulators"*, submits further interviewee 4.

Question 13 below focusses on the operational equipment used in ports and asked on which of five given options ports should primarily put the focus on. Hence, over 35% of respondents favour an equal focus on both working efficiency improvement and the transformation/replacement/retrofit of equipment, which is ideal when considering the emission reduction potential of both measures previously analysed from the authors. 23,21% of respondents speak up for equipment transformation/replacement/retrofit only, and another 21,43% for both measures at once but with a preference for equipment transformation/replacement/retrofit. Together, the preference for fleet transformation under all its aspects accounts for almost 45%, which is an important viewpoint considering the long life span of today's fossil-based equipment used in ports. On the contrary, only 1,79% of respondents prefer to put the focus on working efficiency improvement alone, and about 18% selected both, with stronger focus on working efficiency improvement.

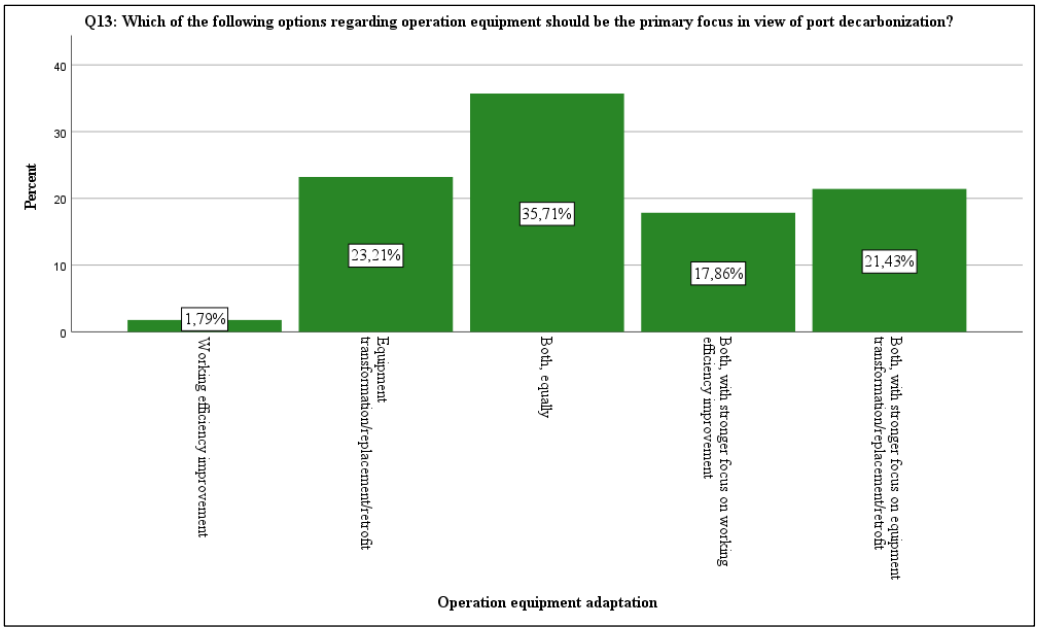

Figure 20: Q13: Operation equipment: efficiency vs. transformation/replacement/retrofit. Source: own illustration, SPSS.

Certain comments were left by the respondents, with one saying that *"swapping batteries is the most relevant way to reduce costs and to improve the life cycle of the batteries"*. Another respondent argued that there is no need to build a solution to cover all possible exceptions, but that focusing on energy efficiency can be an adequate option - which is an understandable argument in favour of energy efficiency, especially during the transition where concrete retrofit and fuel options are still not clear. A third respondent speaks up: *"Do not consider it as a classic business case - consider the environmental return as the most important one, and the economical ROI in the longer run"*, a motivational statement for speeding up the take of actions. And again, the issue of sufficient energy capacity has been raised by a respondent considering electric supply for port equipment.

Question 14 below goes one step further, asking for a ranking of proposed operation technologies being the most urgent ones to be addressed in the given context. Interestingly, the accorded importance has been attributed in the randomly proposed order of equipment type. Hence, trucks appear to be the most urgent ones to be addressed (mean of 1,57), followed by cranes (2,38), followed by cooling and heating of port buildings (3,32), followed by dust pollution (3,63) and finally, lightning (4,11). At this stage, it can be assumed that the reason why trucks are on first position is related to their higher share in terms of number of trucks operating in a port compared to the number of all other proposed solutions. Another interesting finding is that lightning has been categorized as being the least urgent equipment to focus on in regard to decarbonization, meanwhile one respondent reminds that *"traditional energy reducing measures in ports (buildings, lighting, etc.) are still underutilized options"*. Another respondent added an operation equipment, which is an emission-free workboat in the Port of Bergen, running on a battery pack and carrying out harbour operation like maintenance or towing.

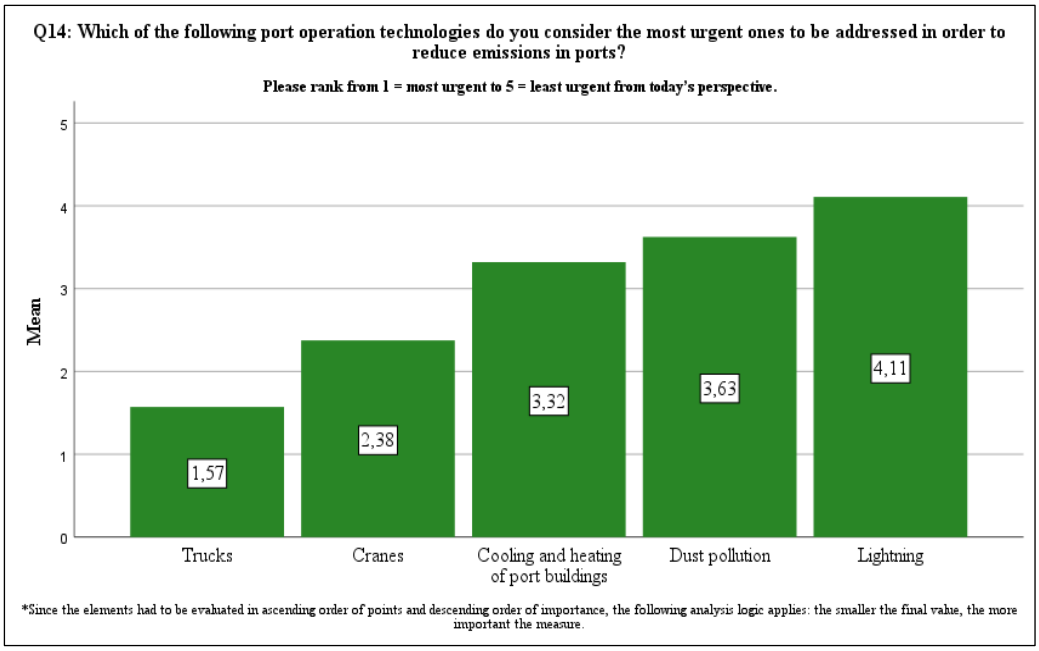

Figure 21: Q14: Implementation urgency of port equipment. Source: own illustration, SPSS.

Further, the interview partners were asked for recommendations on how ports could make the best choice between new, replaced or retrofitted operation equipment. Interviewee 3 admits: *"If vehicles or machines could be easily retrofitted, we would beat on that, but the technology is not yet completely tested. Sometimes, it's not economically worthy because the machine is very old, or the size isn't viable. […] I think that once the technology is fully tested and the current equipment is fully depreciated (amortized), that will be the moment where we should replace the old machines for the new ones"*. The background idea of this statement does go into the right direction; however, it also reveals a certain risk of shifting the environmental action in time, which underlines once more the urgent need for acceleration of retrofitting expertise for port equipment. In the port of interviewee 2, the following logic applies: *"Heavy vehicles, for example, can go from diesel fuel to hydrogen, and we are partly converting terminal tractor to dual fuel technique hopefully. Otherwise, I know for when it comes to cranes and so on, we sell it on the market to another port or other business that is interested. […] When it comes to retrofitting, I think it's most important to put in effort and money to retrofit the existing vessels because we cannot wait just for the new vessels to be environmentally friendly since they have such a long lifetime"*. The risk of deferral of environmentally friendly port operation has hereby been approved by an expert. However, the mentioned sale of the older port equipment when opting for replaced or new equipment reveals the threat of carbon leakage associated with this precise issue. Finding a solution will be crucial because by transferring a fossil-based equipment to another port or industry, the overall emission reduction is not achieved. This might, again, be a pro-retrofit argument. Another issue is raised by interviewee 4, who already includes solution approaches: *"The Port Authority is not the owner of any equipment. There is not much the Port Authority can do rather than, for example, support innovation actions. I think, it will highly depend on the specific local conditions. For an RTG crane in which the energy part is not very important, but the global investment cost of the RTG is very high, retrofitting may make a lot of sense. In terminals however, trucks which have a smaller life span and where the weight of the total cost of the energetic use is much higher than the equipment investment, it might make more sense to opt for a newly purchased truck. This, however, will also depend on the*

technology". Finally, according to interviewee 1, *"the way you could approach the issue is by using the merit order, which helps making decisions"*.

In question 16, the respondents were asked whether ports which do not implement automation processes into their daily operation will stay environmentally and economically competitive in the middle and long term. Almost 90% of all respondents answered with a "no", which is a very clear statement. But what at first glance appears to be good news for the environment, has a differing reason. In fact, when the interviewees were asked whether in ports eyes, smart and automation measures were rather applied for economic or for ecologic reasons, all four admitted that it was more for economic reasons. Interviewee 4, for instance, states: *"I think initially, the focus lies on economic reasons because you can increase productivity. But it is true that with automation, the electrification is much easier, and you can explore other concepts and other technologies that it will be much more difficult with non-automated terminals. I would say that right now, the economy is first, but there is also an increasing interest for ecological energy transition reasons for this type of measure"*. With this in mind, the respondents and interviewees have hereby pointed out to what extent automation measures respond already today to the needed combination of economic and ecologic advantages. This is probably also a reason why automation measures are among the most advanced implemented green measures today, as resulting from question 5.

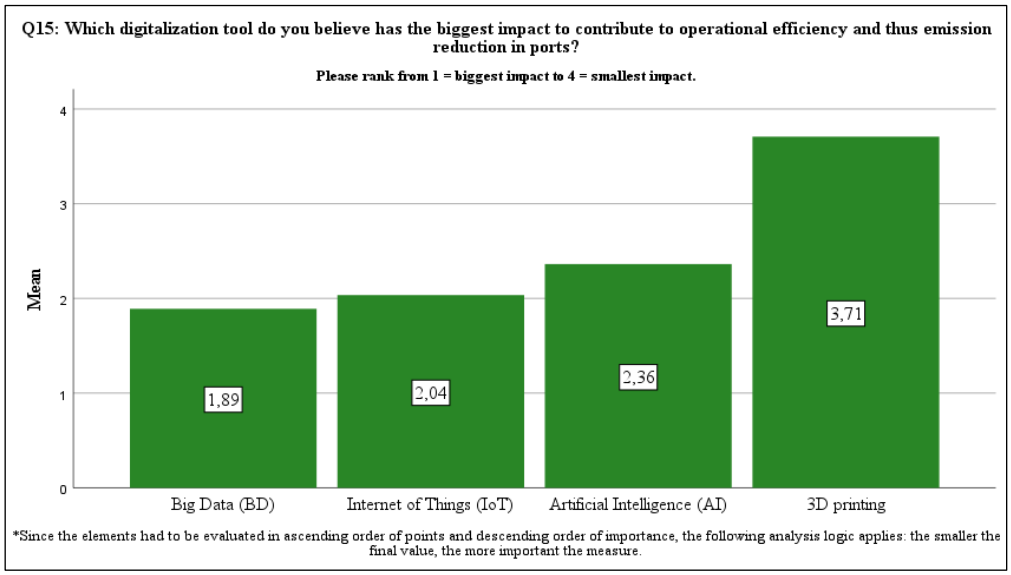

Figure 22: Q15: Impact of digitalization tools. Source: own illustration, SPSS.

In regard to the digitalization tools having the biggest impact for the contribution to operational efficiency and thus emission reduction in ports, the created graph of question 15 below shows that Big Data, Internet of Things and Artificial Intelligence will have the biggest impact in descending order, with a mean of 1,89, 2,04 and 2,36, respectively. 3D printing, however, has been ranked by almost all participants as the tool with the smallest impact of all four option, with a mean of 3,71. However, one participant added the 5G as a further digitalization tool. The same participant also mentioned that disruptive technologies can *"highly contribute to optimize capacity and traffic/congestion, with resulting extra benefits for the environment"*. Also, three further participants remarked the need for digital platforms for tracking real-time emission data in the port, captured by sensor networks, and enabling to tackle the main emission sources first. The underlined statements by both the interviewees and the respondents regarding automation

and digitalization tools fall perfectly under the in the literature filtered out "smart port" concept, based on modern knowledge platforms. The actual need of the four technologies of question 15 for port decarbonisation of the port and their distance in terms of preferences are not directly evident from the result of the questionnaire, but the clear answer from question 16 regarding automation already confirms that digital technologies will play a role in ports, for economic and soon, ecological reasons.

5.4. Ship-to-port and port-to-land interfaces

In question 18, an evaluation of whether ports should impose an immediate reduction of vessel speed and time at berth as short-term applicable measures to reduce emissions took place. Concerning the reduction of vessel speed, the results show that about 43% are in favour and about 57% in disfavour, whereas about 36% answered with a "yes" and about 64% with a "no" regarding the reduction of berthing time. The opinions are quite identical for both measures and the respondents have a rather negative attitude. Also, it is to be taken into account that the question centres on the short-term, which opens the possibility of the result being different in the mid and long term.

The qualitative content gives further clarity on the perspectives from ports. Hence, interviewee 4 admits that *"there is a trend to reduce speed because the impact of the speed is quite high on energy consumption"*. However, several constraints are brought to light. According to interviewee 1, *"it's not the ports that reduce the speed, right? It's the vessels. Since it's open water, the ports are not responsible for the speed that the ship is taking. […] That should be part of the strategy of the shipping line"*. This opinion is shared by interviewee 2 and 3. Furthermore, interviewee 3 reveals that *"the entrance into our port is very constrained by the tidal conditions. It usually takes like 5 hours to go from the sea mouth to the port"*. This barrier is also well known to interviewee 1, whose port is 80 km inland which gives only a certain time window due to fast changing river tides, as well as to interviewee 3, where the way through the archipelago is quite long, too. Another interesting aspect has been added by interviewee 3, who has *"heard that a speed beneath 10 knots is not recommended for safety reasons"*. Further, interviewee 3 concludes: *"In general, we will have to do a trade-off between being earlier in ports for whatever reasons and ecologic reasons like fuel saving"*. Finally, both interviewees 1 and 3 argue that the reduction of vessel speed should be easier to implement in seaports.

Regarding the reduction of berthing time, interviewee 2 underlines the extent to which the port is in the hands of the customers, and that ferries for instance only stay about an hour in the port, which makes the time reduction difficult. Interviewee 4 agrees that *"the shorter the ships are at berth, the better. But it also depends on other aspects such as the number of cranes available, the number of containers that you have to move, etc. In a global sense, you have to be as productive as possible in order to stay as less time as possible at port"*. The aspect of productivity needed has also been added by one respondent. As for interviewee 1, he agrees on the needs but criticizes that *"it's however part of an entire operational chain, so I don't really see how reducing the berthing time in itself could be a measure. The only way would be if you could increase efficiency of the container terminal, for instance. But then, reducing berthing time is*

rather some kind of a consequence of another measure, being improving efficiency of the terminal". He adds that in his port, digital tools are used to optimize the vessel traffic to increase efficiency. The comment left from a respondent also focusses on technological tools, in this specific case auto mooring systems are proposed for optimizing ship speed and time spent waiting. Another respondent recommends automated traffic management systems. All these comments clearly reinforce the role of digital automation measures for supporting port decarbonization. For the berthing time reduction, interviewee 3 brings the tidal constraints mentioned for vessel speed up again, adding that *"if there was any margin to reduce the speed and berthing time by taking into account these constraints, we would study it"*, meanwhile also admitting: *"I don't think it would have a very significant impact in our port"*. Last, interviewee 2 mentions a new aspect by integrating vessels using their own batteries, *"which might need to stay longer at berthing time to charge their batteries"*.

Afterwards, in question 19, an evaluation of the respondents regarding the responsibility of ports for the development of alternative fuel use was carried out. The answer appears to be rather clear, with about 65% of respondents believing ports are responsible for the use of alternative fuels. Almost 18% even believe that ports are very responsible in the development of alternative fuels. On the counter side, only 12,5% believe ports are less responsible and 5,36% believe ports are not responsible at all. These rather negative answers are quite remarkable considering ports important role today for the use of fossil fuels. Surely, ports do not directly contribute to the development of these fossil fuels, but they do collaborate for providing the necessary infrastructure and operation. Therefore, it is questionable why some respondents believe ports should not get involved for renewable fuels, too. With this in mind, it is a very assuring statement that the majority of the port and port association employees have responded with a proactive opinion, which should encourage the will for alternative fuel development.

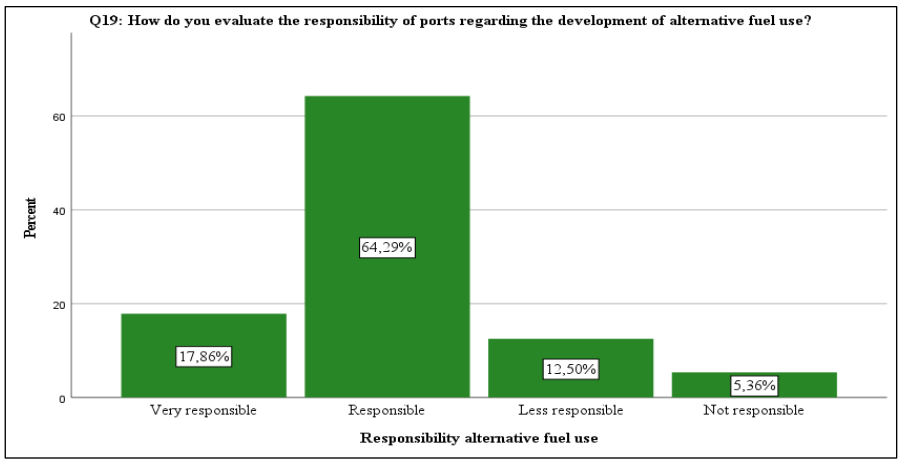

Figure 23: Q19: Port responsibility for alternative fuels. Source: own illustration, SPSS.

With the same scope, interviewee 4 explains: *"If we focus on the Port Authority, I think they should be facilitators. Because in the end, the Port Authority will not be the one providing the fuel. There will be others. There will be third companies that apply for the use of some space on the port land to be able to store and supply the alternative fuel"*. In addition, *"we have no people available to develop the use of alternative fuels and it's not our role as I said, but we really think that we should promote it, be in contact with the concerned industry, by mounting common projects and facilitating the installations in the port"*, adds interviewee 3. According

to interviewee 1, the positioning that ports should take regarding alternative fuel use is *"first and foremost providing a framework, because a port is responsible for safeguarding safety in the port"*, falling under the European Port Services Regulation. He adds that *"the port could also provide land where intermediate storage of these compounds can happen. […] There is plenty of storage capacity today for conventional, fossil fuels in the port, and since these fuels in a way chemically and physically very comparable, there is no need to have specific infrastructure for that"*. Concerning the risk, interviewee 4 moreover accentuates the need for *"Port Authorities' personnel […] to be properly trained and informed about the risks of these alternative fuels in the port environment"*. In this matter, interviewee 2 speaks up about ports becoming an energy hub: *"We look at the port as a hub to be able to provide fuels and energy both for the shipping sector but also for road transport, for example from the port and inlands. This topic of ports becoming energy hubs is very interesting and a growing issue in the future"*. With the aim of becoming future energy hubs, the reflected opinion of the respondents concerning the role of ports for the development of alternative fuel use is very much ideal, and numerous have in fact internalized the related responsibility. Two comments left by respondents propose closer collaboration between ports, energy companies and local industry for assuring availability, operating the infrastructure, and financing the projects.

Within the topic of alternative fuels, the participants have further been asked to rank from 1 to 5 the major identified alternative fuels. When looking at the resulting graph underneath, it appears obvious that all options have a mean rank between 2,33 and 3,53, which can be translated in a certain average suitability degree for each single fuel when speaking of port decarbonization. Hence, it can be estimated that each fuel might play its own role in future ports. Still, hydrogen (mean of 2,33) seems to date to be seen as the most promising alternative fuel for the port and shipping sector, closely followed my methanol (2,69). What is surprising, however, is that both ammonia (3,31) and LNG (3,53) have received the lowest ranking despite being already in use today. This underlines again the prevailing ambiguity and confusion in the transition timeline between today and the future, considering all advantages and disadvantages.

In fact, according to interviewee 4, *"there is currently a huge uncertainty and difficulty to decide which of the alternative fuels that are currently on the table will prosper"*. Meanwhile, interviewee 1 believes *"ports should include options for all these fuels. LNG, hydrogen, ammonia, methanol. I'm not too big of a fan of biofuels"*. *"In order to decide which fuels will be used, we need again the dialogue with the customers and the surrounding society. But I see that we would have actors who can perhaps have a fuelling station close to the port for heavy vehicles and decide with them what kind of fuels we will be able to offer. Will it be electricity? Biodiesel, LNG?"* is a proposition made by interviewee 2.

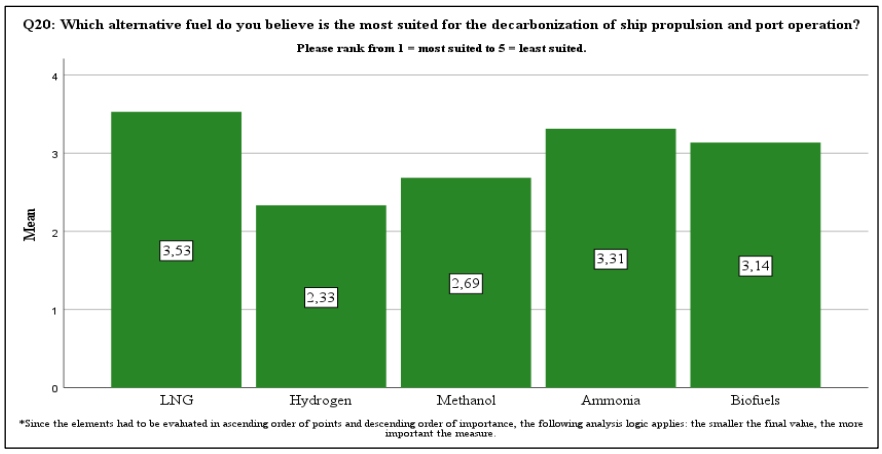

Figure 24: Q20: Suitability of alternative fuels. Source: own illustration, SPSS.

In the comments, a respondent is calling for immediate solutions to replace currently used diesel, with another underlining the need of exploring all possible energy production options, just as the Port of Marseille is conducting it by using household waste of the region for local bioLNG production. In this matter, another participant sees a necessity in the feasibility of new fuels which need to be analysed and tested, both in terms of operation and cost-effectiveness. Furthermore, procedures for letters of intent or expressions of interest are said to be needed to be set up for assuring sufficient fuel capacity, and to have a robust supply process by the operators, as spelled out by another respondent. In summary, the choice of alternative fuels will depend very much on local conditions as well as the need for the shipping customers of the port. It is therefore questionable whether the competition between ports will get to another level in the coming future, when vessels opt for a certain new fuel and will need to reevaluate which port does in fact supply this fuel in assured quantity, at the needed point in time.

Another focus set in the questionnaire lies on the role of ports for the development of renewable electricity technologies for assisted ship propulsion, asked in question 21 below. On one hand, 16% of respondents attributed a very important role to ports and 46,5% an important role, resulting in 62,5% of rather positive importance. On the other hand, about 34% attributed a less important role and 3,5% an important role, thus 37,5% of rather negative importance. This finding is surprising considering the before mentioned facilitator role attributed to ports when it comes to alternative fuels, since no special storage facilities or infrastructure need to be installed on the port site for the renewable electricity technologies due to their fixed integration on the ships.

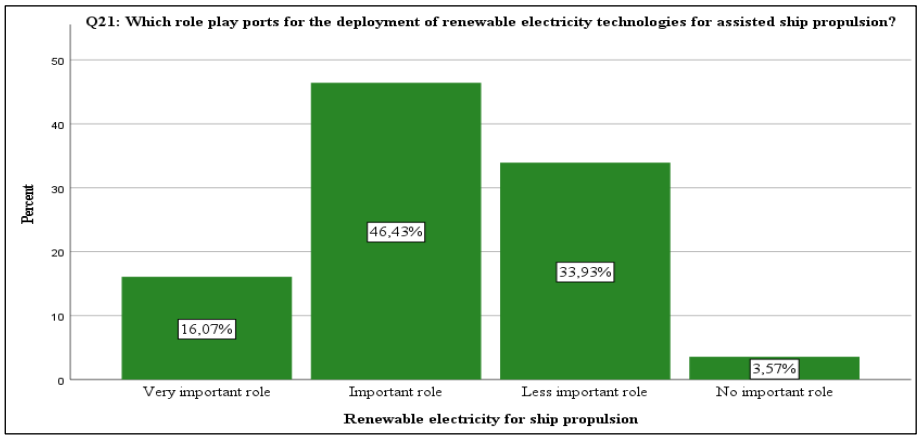

Figure 25: Q21: Role of ports for RES assisted ship propulsion. Source: own illustration, SPSS.

In order to understand the reason of the high importance attributed to ports from the port and port association employees themselves, the interviewees have been asked for some reasoning. Surprisingly, all 4 interviewees have an opposing opinion to the 62,5% of respondents having attributed a rather positive importance to ports in that regard. Hence, according to interviewee 2, ports are not responsible for it, but they are a support. As for interviewee 3, she believes that *"we as ports need to foster the development of these technologies and even need to produce green electricity in the port as well. But on ships, it's up to the shipping companies to invest in their own technologies for the propulsion of their ships. We can help with that and we will for sure do it and facilitate the change, make our contribution. […] Because it is something that we want to happen"*. A possible reason for the survey result of question 21 is given by interviewee 1, who explains that *"ports gain money by quoting ships visiting the port. What we do is give reductions on the port dues for green ships. This could be a reason. But apart from that, I don't really see how a Port Authority has the responsibility this on, it's up to the ships"*. Finally, interviewee 4 points out the following new aspects: *"It's the same as for the alternative fuels. Ports have to be facilitators, but they are not the regulators, they're not the International Maritime Organisation. So, ports can support ship owners to transform their fleet to carbon neutral use as far as they can, for example through environmental taxes benefits. Authorities have to be technology neutral, meaning open of any alternative that ship owners have in mind"*.

To buckle up with the opinion of the participants, the swapping of batteries has again been mentioned, which is another probable reason for implication need of ports, to guarantee the provision of sufficient electricity supply. Also, the Environmental Ship Index (ESI) has been referenced by a respondent, as well as "Green Ports Awards" for green ships and shipping companies. Lastly, offering eco-incentives for environmentally friendly actions of customers is another mentioned need of ports to support renewable electricity for assisted ship propulsion, according to a comment.

With focus on the port-to-land interface, the respondents were asked in question 22 how crucial they see the integration of the hinterland for contribution to port decarbonization. At first glance, it appears very obvious that almost all port and port association employees having participated in the questionnaire do consider the integration of the hinterland for contribution to port decarbonization as rather positively crucial, with 56% having opted for "very crucial" and 42% for "crucial". In fact, only 1,82% have opted for "less crucial" and no single participant believes the hinterland is not crucial. Herewith, the co-responsibility of ports in reducing negative externalities linked to their indirect operation, in this specific case for the hinterland, has been undoubtedly confirmed.

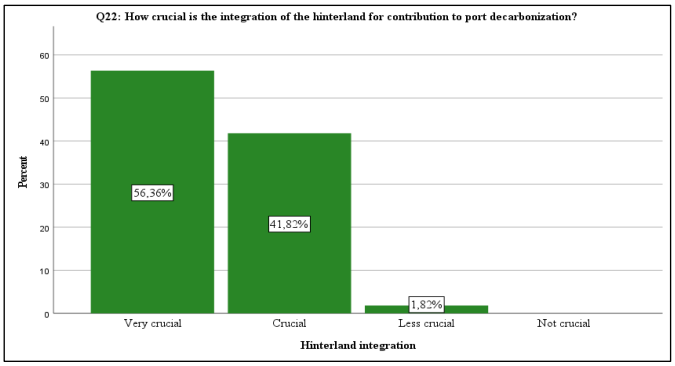

Figure 26: Q22: Integration of the hinterland. Source: own illustration, SPSS.

In regard to the role of ports for hinterland decarbonization, interviewee 1 answers: *"As a Port Authority, we don't really operate the hinterland part. But I do think it's partly within the port's responsibility since we are providing employment for many people that also live around the areas of the port. Also, in the port there's quite some emissions of nitrogen oxide, a particular matter, and also Sox. These also put pressure on the communities surrounding the port, so we definitely should take some responsibility there as well"*. Interviewee 3 agrees, adding that *"it's not only about the internal but about the whole city. […] It is in fact very necessary that trucks are involved, that trains are involved, that ships are involved, that the port terminals are involved with their cranes and their vehicles"*. Some options to road transport mentioned by interviewee 2 as well as two respondents of the questionnaire are river and railway transport, but road transport seems to be remaining the main transport option from ports to the good's final destination. *"For using the train, you need railways outside the port. And road transport is probably the most difficult sector to decarbonize in the port activities […]. There needs to be a willingness of ports to deliver low carbon fuels in the close port environment. Since the alternatives are not yet in a very mature state, participation in innovation projects is useful to validate some of the alternatives that are on the table right now. To date, there are pure electric trucks, hydrogen trucks, etc. but they are not yet in a very commercial state"*, mentions interviewee 4. To assure a successful implementation, *"we need to connect and have partners that are more experts in that kind of issues, able to provide the fuelling station, for example"*, adds interviewee 2. Additional best practices proposed by two respondents of the questionnaire are mobility modelling and studies of alternatives, as well as automated traffic management for trucks.

5.5. Renewable energies

In order for ports to cover their overall electricity need considering decarbonization, the participants were asked for their opinion on the power supply path to ideally be chosen. For the two options "reliance on the national electricity grid" and "self-supply electricity system", respectively 9,26% of respondents do believe they are the best option. Further, 20,37% of respondents voted the same for each of the two criteria "both, equally" and "both, with stronger focus on self-supply electricity system". Hence, the single criteria with most respondents is the answer "both, with stronger focus on reliance on the national electricity grid", with 40,74% of respondents opting for this preference. Just as in the very specific case of onshore power supply, special trust is put in the decarbonization of the national electricity grid, which is not in the hands of

the port, usually. Regarding the immense amount of additional capacity needed in the upcoming years and decades, this reasoning does make sense. However, it is positively surprising to see that about one third of respondents prefer a self-supply electricity system, which permits an assured reliance on renewable sources only. Nonetheless, it is also remarkable to read in the results that the reliance on the national electricity grid is still a generally favoured option by about half of the respondents, which results is a high trust level of external decarbonization of the national electricity grid.

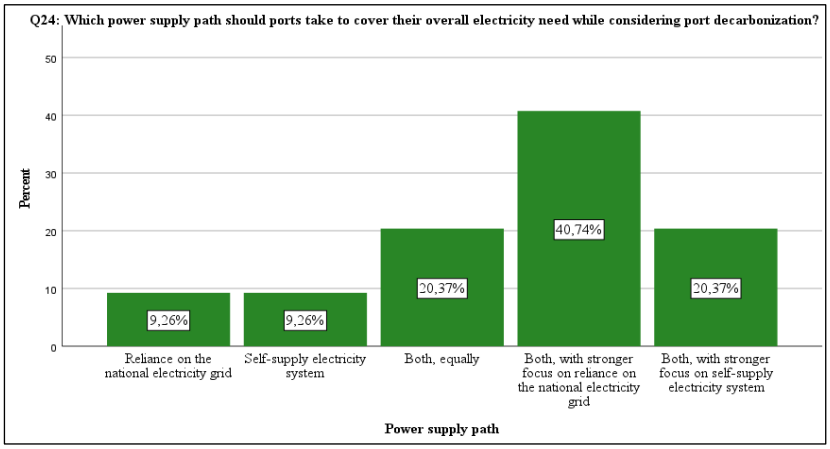

Figure 27: Q24: Power supply paths. Source: own illustration, SPSS.

In the comments of the questionnaire, a respondent explained that *"the use of locally produced renewable energy is very dependent on the actual port layout. In some cases, own production can be very feasible, but for example in our case, the reliance on the massive development of the national renewable energy production is a better option"*. Furthermore, resilience is another aspect mentioned by a respondent in this context. Interviewee 1 *"would say we need more focus also on different ways of thinking and different ways of organizing"* when it comes to addressing the future electricity bottlenecks of ports. From the point of view of interviewee 2, *"we will need quite a lot of power reinforcement to our ports. We need to go up to 200 megawatts in 2030 and we now have, I think 70 or 80 megawatts. […] In the process, we are mainly talking to the grid owner. […] Since they need five or six years to be able to come up to that power, it takes a lot of time, and it costs us very much. That's the problem, really"*. A similar statement has been made by interviewee 3, who thinks *"the only way is by finding the funds and by overcoming the technical constraints. Meetings for the exchange are important as well. We have recently signed an agreement with the energy supply company that is working in Spain because it is in their hand […], they just give us the connection to the grid"*. Indeed, the collaboration with the energy sector, implying both energy companies and local transmission and distribution systems operators, has been commented by 2 respondents as well. Another participant mentioned the role of expressions of interest for an overview of capacity need. Furthermore, the role of ports becoming energy hubs has been brought to light in the comments again. This same respondent refers to the review of the 2013 TEN-T guidelines, through which the Transport Council tries to motivate ports to join the comprehensive network if they *"contribute to diversification of energy supplies and acceleration of renewable energy as main activity of the port"*. Clearly, the involvement of the energy sector is fundamental in developing the use of renewable electricity sources.

In question 25, which is content-wise related to question 24, the participants were invited to rank four proposed renewable energy sources. The results show an equivocal preference for both solar energy (mean of 1,75) and wind energy (1,77), which is not very surprising due to today's widespread adoption of both technologies and their complementarity. On the third rank is marine energy with a mean of 3,12, certainly due to the ever-existing wave circulation and tidal movement in (sea)ports, which offers "freely produced" energy. As for geothermal energy (3,37), the fourth and last rank seems to be well suited, especially because of today's low applicability in ports.

In addition to these traditional and rather base load energy technologies, a supplementary question focused on fuel cells. The respondents were asked whether they believe that fuel cells will play a mayor role in balancing intermittencies for (partly) energy self-reliant ports. The answer had a positive outcome in the spirit of this innovative technology with more than two thirds voting in favour of fuel cells for application in ports in the near future. Since ports have been revealed to become energy hubs including the alternative fuel of hydrogen, sufficient back-up supply can be expected to be available on site. The term "in the near future" is primordial in the context of this question since this technology us currently still under development.

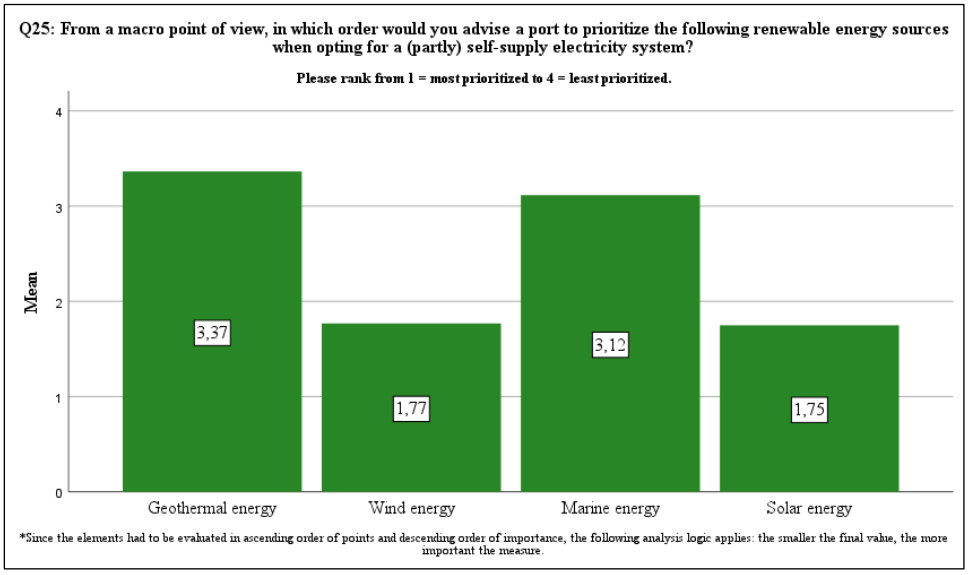

Figure 28: Q25: Prioritization of renewable energy sources. Source: own illustration, SPSS.

When asked about how to overcome the future bottlenecks of green energy supply in ports, interviewee 4 responded *"by upgrading and increasing the green production of electricity, with wind or solar energy. Exploring new options is important, for example offshore potential, but that will depend on the geographical area of each port. Energy storage will be needed, which is a great challenge but also required for integrating the electrification and reduce the peaks of the supply. Also, intelligent grid management is very crucial. These three are main topics to be dealt with in the coming years"*. That the different technological options depend on the exact geographic and meteorologic conditions in a port has further been mentioned by a respondent in the comments. In that same context, another participant speaks about a feasibility analysis and a study on the conditions of construction for renewable energy sources, also including a proposal for implementation, follow-up actions and recommendations. Furthermore, interviewee 3 admits that *"we do have problems when the energy companies come and say they*

want to have a lot of space for PV, for green energy production. That's something that we cannot feed them with because we have to reserve our spaces for industry or for logistic". To solve this issue, 2 participants propose the installation of PV panels on rooftops of port buildings to solve the space availability issue, even though it requires cooperation with the building owners. Another participant even brings up the idea of installing solar panels on the sea water surface inside the port area. As for wind energy, one participant suggests seaports to be great locations for the installation of offshore wind parcs in line with the literature, with the specificity that the planning of those parcs must include the routing of ships approaching the port. Finally, one more comment rises the need for repowering of both wind turbines and PV panels after a certain time of operation, usually between 20 and 30 years, because *"in that way, more output electricity can be produced within the same available space"*. Since all these additional comments from both the respondents and the interviewees solely focus on solar and wind energy, it once more approves the favourability of ports to use these options as renewable power supply technology, as already highlighted in question 25.

Finally, an estimation of the participants was required in order to know whether or not ports need to install energy management systems to control and optimize their (future) energy demand and supply. As expected, the majority (89,09%) of respondents answered with a "yes", against 10,91% saying "no". This clear statement advocates the emphasis of energy management systems. In this sense, it is still surprising to see that more than 10% of the respondents do not consider energy management systems crucial for energy optimization in ports, despite the before well protruding importance of ports becoming energy hubs for both supply and demand.

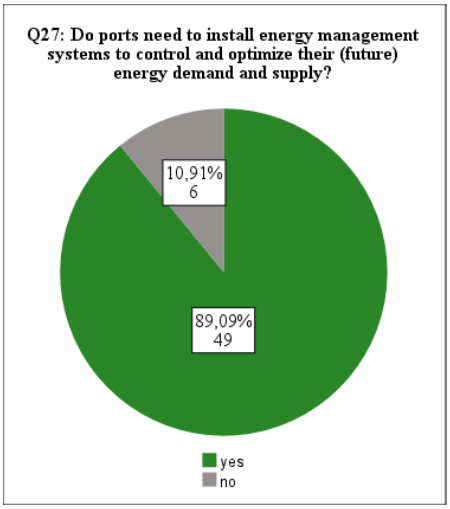

Figure 29: Q27: Installation of energy management systems. Source: own illustration, SPSS.

Some reasons for the need of energy management systems are that *"we have a lot of wind turbines and solar PV in the port, so a lot of intermittent energy supply. Then, there's very limited amount of demand side management in the port. In that regard, energy management systems could really help to align these two"*, explains interviewee 1. Interviewee 2 agrees: *"What kind of energy we are using? Which emissions are resulting of this energy use? That's the major environmental aspects of our business and that's why it's crucial for us"*. Interviewee 3 sees energy management systems as important assets for both ecologic and economic reasons

"because nowadays, we don't have any numbers. We just receive the invoices and that's all. But we have to check whether the demand of the invoice matches the availability of the electricity in the port or if there is something that is not working correctly". In the same logic, interviewee 4 argues that *"it will not just be a need for being competitive but also for being positive because we are moving from a pretty straightforward energy management, in which the producer produces and there are a lot of consumers. But the energy value chain will be a more complex one in which you will produce yourself electricity at the terminal, you will buy from your neighbour, and you will have surplus all at once. We have to be prepared and foresee the energy demand required"*. The statements of all four interview partners as well as the result of question 27 indicate that the need for transparent energy consumption to reducing both emission and energy costs and to assuring capacity has been recognized by ports, and with energy management systems being the solution to this specific issues. When it comes to the responsibilities, interviewee 1 has expressed a restraint, because he sees energy management systems as *"regulating the mentioned intermittencies is really up to the distribution system operator or even the transmission system operator, they have the corresponding responsibility. I think ports can play a role in building the community or something, but that's not our expertise"*. Interviewee 3, on the contrary, speaks of a pilot project for energy management system which the port has just terminated and which seems to be working well. It appears that also for energy management system only within the port, the responsibilities are not yet clarified. It is however clear that ports do play a role since they are the ones having primary access to the numbers. But just as interviewee 1, two participants added comments to encourage ports to create energy communities based on renewable sources inside the port, complemented with an intelligent energy management system. Therefore, a validate database firstly needs to be set up, with all other measures depending on it, as argued by another respondent.

While contacting the 714 employees of ports and port associations of the European Union, very enthusiastic feedbacks have been obtained. The most convincing answers have been anonymised and enclosed to the annex 7 for adding a personal touch while revealing some background activity from the data acquisition phase for this master thesis. Besides the positive feedbacks, already 15 employees from ports and port associations of the European Union have requested to obtaining the results of the above presented survey in the frame of this master thesis. This reveals again the importance of the conducted research, eagerly awaited by the industry professionals.

6. Discussion

After having presented and analysed the results of the survey and conducted interviews, a reconsideration of the research question is undertaken: ***The transition towards 'Green Ports': Which implementation approaches can be employed for an effective adoption of the most impactful emission reduction measures in view of port decarbonization?***

To get the most compact answer to this question, all information sources used for this master thesis will be compiled and considered. In fact, by integrating not just the empirical data from the survey and the interviews, but also the additional findings of the systematic literature review

addressing the given issue, a complementary result can be provided through comparison and match making. Still, the concrete provenance of each valuable finding of the recommendations below is indicated in annex 8. Only by combining the three data collection types, a most complete image can be drawn.

6.1. Recommendations

The aim of this subchapter is to categorize and compile the different findings for solid conclusion and recommendations. It is however to be mentioned that no concrete timeline with key dates can be established based on the findings because it would differ too much from each single port regarding size, number of calls, and available resources, for instance. Also, one of the overall most present barriers for the implementation of green practices in ports is usually the financial aspect involved in the transition. Since the financial resources of each port vary largely, the following recommendations basically exclude the financial evaluation, which is always very specific to each project, port, and nation.

6.1.1. Prioritization for implementation of emission reduction measures in ports

Now, both the quantitative and qualitative information are weighted equally and divided into three differentiated levels, with "+" being considered as relevance 1, "0" being considered as relevance 2 and "-" being considered as relevance 3. This categorization is inspired of recommendation reports from renowned organizations like the OECD, Xerfi or KPMG. To be able to rank the quantitative data from the questionnaire into these categories, two different scales have been applied. When means have been calculated, the span width between the lowest and the highest mean has been divided by 3, with the lowest third counting as relevance 1, the middle third counting as relevance 2 and the highest third considered as relevance 3. When tendencies between options had to be indicated, the percentage of 100% has been equally divided by 3, with vice versa relevance regarding the height of percentage. As for the qualitative data, the findings of the questionnaire comments, the conducted interviews and the systematic literature review have been ranked into "+", "0" and "-" regarding the depth of their meaning. The following three subchapters are based on arguments summarized in compilation tables in annex 8. The initial sources of the literature are either directly mentioned in the following text or indicated in the same appendix 8 to assure the originality of information. The readers are recommended to have those tables at hand while reading the associated text.

Firstly, the key measures identified through the systematic literature review are prioritized. The resulting table below shows the final categories.

Compilation of quantitative and qualitative findings						
Topic	Quantitative rank	Quantitative category	Qualitative rank	Qualitative category	Final rank	Final category
Environmental policy and regulatory framework	1	+	2	+	1,5	+
Renewable electricity sources	2	+	3	+	2,5	+
Green port management	6	0	1	+	3,5	+
Alternative fuels	3	+	4	+	3,5	+
Onshore power supply	5	0	6	0	5,5	0
Energy efficiency for port equipment and fleet transformation	4	0	7	0	5,5	0
Energy management systems	7	0	5	+	6	0
Hinterland integration	/	+	8	0	/	0
Renewable electricity for ship propulsion	/	+	9	0	/	0
Smart resources and automation	8	-	10	-	9	-
Energy efficiency for ships in ports	9	-	11	-	10	-

Figure 30: Priorities: compilation table. Source: own illustration.

Hence, the four measures "environmental policy and regulatory framework", "renewable electricity sources", "green port management" and "alternative fuels" are recommended for involved port stakeholders to be considered in decreasing order of importance as priority 1 when speaking of port decarbonization. As priority 2 follow, as well in decreasing order, the five measures "onshore power supply", "energy efficiency of port equipment and fleet transformation", "energy management systems", "hinterland integration" and "renewable electricity for ship propulsion". Finally, the two measures "smart resources and automation" and "energy efficiency for ships in ports" are recommended to be considered as priority 3. With the measures having been categorized and ranked between each other, the responsible port related stakeholders are given a certain feeling based on solid argumentation on which measures they should firstly and mostly focus their temporal, financial and human resources on when considering decarbonization of medium, large, or very large ports. As emission reduction measures are usually carried out in stages and often interdependent or linked to each other, it is further recommended to start working on the implementation of several measures simultaneously.

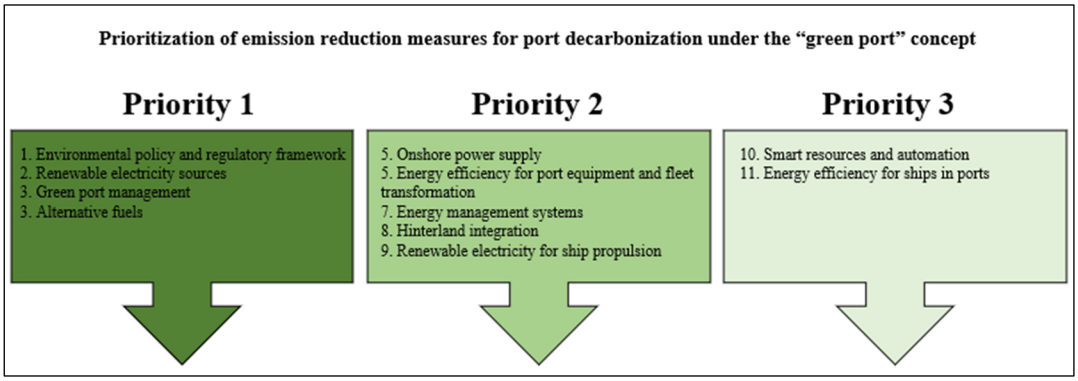

Figure 31: Priorities by measure. Source: own illustration.

Within these measures, the corresponding subcategories have also been ranked and weighted to bring the prioritization to a next level.

Priority 1: Environmental policy and regulatory framework

The port and port association employees have explained themselves to be guided by the given policy, which confirms the need with deriving recommendations for regulatory bodies to take significant action for leading the change. Global governance initiatives are considered a top priority within this measure, which has both been underlined by the empirical study results and the literature. In fact, the review revealed that port policy has been proven to influence green

port implementation strongly and directly (Munim et al., 2022), and numerous initiatives, publications, and roadmaps from organizations and on a governmental level have been listed, for example from the IMO (2018a; 2018b), the OECD (2011) and the WPCI (2010).

Regarding the policy framework, the empirical research results suggest that compulsory and voluntary measures should mainly be implemented at the same time, with a stronger focus on compulsory regulations and policies in the first place, to speed up the transition by strengthening the rules. Regarding the incentive type, both reward and punishment measures should be used, with a recommended stronger focus on reward measures to positively influence the change. The analysed literature did only mention the possible types of applicable incentives, without prioritizing them, a gap which has been covered by this thesis. However, the listed punishment measures are recommended by Xu et al. (2021) to be controlled within a reasonable scope to avoid further negative influences, a thought in line with the respondent's opinion.

Priority 1: Renewable electricity sources

The need for sufficient and clean energy capacity in ports have highly been accentuated by the questionnaire respondents and interviewees. Also, the literature has highlighted that the percentage of energy from renewable resource is considered a typical KPI for green and sustainable port evaluation. (Buiza et al., 2015; STP, 2015; Acciaro et al., 2014). When opting for the renewable electricity path, ports are recommended to primary focus simultaneously on a self-supply electricity system and the national electricity grid, while ideally having a stronger focus on the latter, with sufficient trust in its own decarbonization. Opting either for both with a stronger focus on a self-supply electricity system or for both options equally are also choices recommended to be considered, which will however result in stronger direct responsibilities for setting up the decarbonized energy sources. This, in return, might potentially include the risk of delays for the electrification of usages due to a lack of installed capacity. The focus on either of the two supply options only is not recommended for port decarbonization. The empirical results are an extension to the literature, which did not very much include the possibility of connecting to the national electricity grid, probably because of today's still carbonized national energy mixes. In fact, Peng et al. (2021) urged for consideration of the indirect life-cycle emissions, too. Still, not connecting to or expanding the national electricity grid would result in immense missing capacities for port operation today, with expected following disruptions in global supply chains and thus, economic loss.

As for the concrete renewable electricity sources to be used, both solar and wind energy are very much recommended for baseload. These empirical findings are in line with the literature, which proved photovoltaics of having the highest applicability rate in ports (PLB, 2016), while seaports are said to be an ideal location for wind energy due to their exposure to high-speed winds (Li et al., 2018; Weiss et al., 2018; Kotrikla et al., 2017; Yarova et al., 2017; Spiropoulou et al., 2015; Solari et al., 2012). For non-intermittent peak load, fuel cells are the best options ports should focus on today and especially in the near future, both according to the empirical study and the literature (Kinnon et al., 2021). Marine energy is a medium recommended energy source, among others because of today's scarce research in the field, and geothermal energy should only be used in suitable locations, which is in line with the low and unclear identified

applicability in ports (Sifakis and Tsoutsos, 2021). The suitability of tidal and geothermal energy is however potentially evolving, and it is worth having an eye on the development.

Priority 1: Green port management

With Munim et al. (2022) having proven that besides port policy and regulation, it is also the port management which drives the development of green ports the most, as well as the interviewees having pointed out the specific relevance of green port management, this measure has obtained a general higher urgency need by combining qualitative and quantitative data. Whether it is stakeholder participation, the integration of environmental managers or setting up green port strategies - within this subcategory, all measures are equally important and should be considered simultaneously by Port Authorities for guiding the green transition. These sub measures go hand in hand and are very powerful for managing and successfully implementing operational measures. The empirical results are in line with Kahane et al. (2013) who revealed the number of stakeholders in a port, with Pavlic et al. (2014) and Ng et al. (2013) who have pointed out the fundamentality of dedicated managers for structured processes, with (Campisi et al., 2022; Heij and Knapp, 2012; Mellin and Rydhed, 2011; Petrosillo et al., 2009) who underlined that integrating the human factor into the transition to green ports is fundamental, and with Lam and Li (2019) who accentuated the need of green port strategies to be aligned to the overall port strategy. However, the number of authors for green port management actions remains scarce, another reason why the self-collected empirical data adds valuable insights while revealing research gaps.

Priority 1: Alternative fuels

Alternative fuels are fundamental for substituting today's used poor-quality and highly polluting fuels (Zhan et al., 2019; Zetterdahl et al., 2016). From all alternative fuels identified, hydrogen is an overall promising alternative according to the survey result, mainly due its characteristic of emitting near-zero GHG and air pollutants at combustion (Daniel et al., 2022; Hoang et al., 2022; Chang et al., 2019; Bicer and Dincer, 2018; Castellani et al., 2018; Chang et al., 2016; Pereira et al., 2014; Wang et al., 2013; Arteconi et al., 2010). Hydrogen is also considered an alternative fuel capable of replacing today's fossil fuel of ships and port application (Wang et al., 2023). Port stakeholders are therefore encouraged to foster the development of this specific alternative fuel further. All other renewable fuels, namely methanol, biofuels, ammonia, and LNG do however also take a significant role on the path towards port and shipping decarbonization, which is why their specific use is recommended to be developed further, too. Despite methanol's high GHG reduction potential (Gilbert et al., 2018; Brynolf et al., 2014), biofuels climate-friendliness in comparison to fossil fuels (Gaurav et al., 2017), ammonias existing infrastructure in place (Daniel et al., 2022; Lan et al., 2012; Klerke et al., 2008) and LNG's current superordinated role (Daniel et al., 2022; DNV, 2019; IMO, 2016), their exact role in the decarbonization of ports and shipping remains unclear today, especially in comparison to hydrogen. Nevertheless, no possibility of renewable fuel should be neglected from today's research and development, which is in line with the overall literature sources which do in

fact list numerous advantages and disadvantages for each fuel, with sometimes mutually compensating criteria, depending on each single application. For this specific reason, the empirical research was neither capable of giving a revolutionary answer.

Priority 2: Onshore power supply

From all power supply options for onshore power supply, port stakeholders are primarily recommended to focus on the direct connection to the national electricity grid and on the direct connection to a local micro grid, if available. Just as for the overall power supply path for ports, the indirect lifecycle emissions need to be considered, too, as previously highlighted by Peng et al. (2021). When grid connection is not possible due to missing grid reinforcement, fuel cells on barge are an ideal stationary and independent asset to cover the electricity need for OPS. Both LNG on barge and turbines on barge are not very much recommended. These three stationary options have been proposed by Coppola and Quaranta (2014) and Battistelli et al. (2012), without further discussion. Once again, the prioritization revealed through the empirical data has brought the guidance for ports one step ahead.

Priority 2: Energy efficiency for port equipment and fleet transformation

When the responsible stakeholders in ports think of decarbonizing their port equipment and fleet, it is highly proposed for them to target both working efficiency improvement and transformation/replacement/retrofit equally. However, in a general manner, the transformation/replacement/retrofit option is very well suited for prioritization. Through the self-collected data, the long lifespan of machines has been revealed as one reason. Through the literature, the higher identified energy usage saving (Vlahopoulos und Bouhouras, 2022; Luque et al., 2016; Vujicic et al., 2013; Yang and Chang, 2013; Jinru, 2011) as well as the soaring diesel prices, increasing terminal operation costs and stricter air pollution regulations are other identified reasons that force ports to rather focus on replacing their operation equipment (Yang, 2017). However, since this measure does need some time until completion, energy efficiency measures are very well suited for the simultaneous transition using conventional port equipment. Despite the literature having underlined that energy efficiency is considered as one of the green port indicators the EU priorities, leading to a steep increase of energy efficiency programs in European ports (ESPO, 2018; Chen and Pak, 2017), solely focussing on working efficiency improvement is not sufficient and therefore not recommended according to the empirical findings.

When zooming on the exact equipment type, trucks and cranes are the equipment to firstly decarbonize. Meanwhile the survey respondents assume trucks to be the most important and cranes to be the second most important, the literature revealed that quay cranes have the second highest emission source in ports after ships, yard cranes are on third position and trucks on the fourth. (Yun et al., 2018). Hence, it would make sense to firstly put a focus on cranes since the overall goal is decarbonization. A reason for the differing perception between literature and empirical research might be the number of trucks operating in a port compared to the number of cranes, which is susceptible to have biased the perception. Also, lightning has been categorized on rank 5 even though it consumes about 3-5% of total energy in the port (Acciaro et al.,

2014a), and the switch to LED lights having proven great savings of electricity costs in various European ports (Van Duin et al., 2017; Hippinen and Federley, 2014). On the contrary, both cooling and heating of buildings and dust pollution have only been mentioned by one author each (Wang et al., 2023; Alamoush et al., 2020), meanwhile being on the survey rank 3 and 4, respectively. This could either mean that these measures should be less prioritized because other equipment shows higher decarbonization need, or the literature should focus more on how to reduce the emissions from both, because they are much more relevant in port and port associations eyes. Furthermore, another respondent has added an operation equipment not covered by the literature, which is an emission-free workboat running on a battery pack and carrying out harbour operation like maintenance or towing. Due to the very varying findings and perceptions between literature and empirical data, it is recommended to assess the type of port equipment to be primarily decarbonized in each port individually, based on criteria like the number of equipment type available or the total time of use.

Priority 2: Energy management systems

The overall priority needs of energy management systems for getting transparent information on energy consumption to reduce emissions and energy costs and to assure capacity consumption has been revealed by the empirical data as well as the literature (Di Vaio et al., 2018) and further resulting research analysis. Apart from one survey respondent having underlined the primary setup of a validate database from which all other energy management measures derive, no further prioritization has been made by the survey respondents and interviewees, which is why this finding is almost entirely covered by the literature. Hence, energy management plans (Parise et al., 2016a; Hippinen and Federley, 2014; Pavlic et al., 2014), energy storage systems (Sifakis and Tsoutsos, 2021; Sifakis and Tsoutsos, 2020; Ahamad et al., 2019; Verma et al., 2018; Papaioannou et al., 2017; Lan et al., 2015) and smart microgrids (Sifakis and Tsoutsos, 2021; Siemens, 2017) are the most important steps to be considered when implementing energy management systems, ideally in this same order to be coherent. Smart load management is also important but is suggested to be addressed in a second step in the setup of energy management systems, when the three measures above are installed (Gennitsaris and Kanellos, 2019; Tao et al., 2014).

Priority 2: Hinterland integration

Integrating the hinterland into port decarbonization strategies is an overall very crucial measure, a complementary result between the empirical research and the literature (Alamoush et al., 2020; Du et al., 2019; Gonzalez-Aregall et al., 2018; Kavakeb et al., 2015; Lirn et al., 2013; Bergqvist and Egels-Zanden, 2012). Through survey and interviewee comments, as well as the sources IMO (2018b), IAPH (2007), Mamatok and Jin (2016) and You et al. (2010), modal shift from trucks to rail and river transport has been categorized as the most appropriate and impactful path for decarbonizing the hinterland. As for road transport, necessary accompaniments with the responsible stakeholders for road transport is also highly proposed due to the superordinate role of road traffic for transportation of goods, especially by one survey respondent, two interview partners and 13 literature sources. However, the chapter of the literature review dealing with the hinterland has resulted to only be a small one, with a comparably small

number of citable authors. Considering the need of the hinterland integration, researchers are urged to fill the discovered theoretical gap to contribute more concretely to the successful implementation of green measures for port hinterlands.

Priority 2: Renewable electricity for ship propulsion

From all enumerated renewable technologies for assisted ship propulsion, solar propulsion (Hoang et al., 2022), wind propulsion (Mofor et al., 2015; Carlton et al., 2013) and fuel cell propulsion (Hoang et al., 2022; Kinnon et al., 2021; Pagliaro, 2020; Bicer and Dincer, 2018; Sharaf and Orhan, 2014) are all very ideal and recommendable alternatives. Nuclear propulsion, on the contrary, is not esteemed to be a useful energy source for traditional ships (Khlopkin and Zotov, 1997). This categorization has solely been drawn with the help of the literature, as the self-acquired data did not indicate any technology-specific prioritization, except the overall importance for renewable electricity for ship propulsion to contribute to port decarbonization.

Priority 3: Smart resources and automation

Smart resources and automation processes are a generally interesting topic for ports to stay competitive, as underlined by the survey results. Reasonings for this measure to still be comparatively low ranked might be the fact that the exact emission reduction potential is unclear, as no single number has been revealed through the systematic literature review. Also, the literature emphasises smart resources and automation to be more considered by the "smart port" concept than within green ports (Buiza et al., 2015; Siror et al., 2011), a statement agreed by the interviewees who have admitted that the primary focus lies on economic reasons, with only some deriving ecologic benefits. Further, this measure already has a high applicability rate in comparison to other measures, as underlined by the survey results and (Jiang et al., 2013), which decreases their urgency need. For the use of smart resources for port decarbonization, Big Data, Internet of Things and Artificial Intelligence are very useful applications for technological shift, as well as 5G which has been contributed by solely one survey participant. 3D printing is however less important, due to its specific characteristics. The self-obtained ranking gives an additional degree of importance of all described technologies in the literature, but their concrete application share will depend on the specific project. Overall, automation is mainly enabled through the increase of electrification of port equipment (Sifakis and Tsoutsos, 2021).

Priority 3: Energy efficiency for ships in ports

Some reasons why energy efficiency for ships in ports is on the last rank are their overall smallest emission reduction impact on the entire port calculated (Bergqvist and Monios, 2019; Yun et al., 2018; Chang and Jhang, 2016; Johnson and Styhre, 2015; Moon and Woo, 2014; Zis et al., 2014), the very numerous operational implementation barriers enumerated in the literature, as well as the comparatively advanced applicability rate in comparison to other measures, as underlined by the survey. Within the measure of energy efficiency for ships in ports, it is proposed to primary transpose the reduction of vessel speed in waterway channels before reducing the time spent at berth to reduce emissions according to the survey result. In fact, berthing time

reduction is rather a consequence of other efficiency measures in port operation, as revealed by the interviewees.

6.1.2. Stakeholder responsibilities for implementation of emission reduction measures in ports

In this second subsection, a zoom on different stakeholder groups and their respective responsibility level in the transition towards green ports will be conducted. Again, it is recommended to stick to annex 8 for more detailed background sources, including the authors of the literature sources.

Based on the result of question 7 from the questionnaire, which focussed on this specific issue, a big picture can be drawn below. For the categorization, the percentage 100% has again been equally divided into three parts, with '+' standing for the most responsible stakeholders, '0' for medium responsible stakeholders and '-' for the least responsible stakeholders.

Quantitative results

Scale Q7
+ = 66,6-100
0 = 33,3-66,6
- = 0-33,3

Q7: Stakeholder responsibility	Rank	Score	Score category
Port Authorities	1	98,31%	+
EU	2	96,61%	+
National Governments	3	94,92%	+
Shipping companies	4	86,44%	+
Local industry	5	77,97%	+
Institutions	6	66,10%	0
Local organizations	7	33,90%	-
Citizen	8	27,12%	-

Figure 32: Stakeholder responsibility: quantitative results. Source: own illustration.

According to the quantitative findings, five stakeholder groups have been evaluated as having the most responsibility for port decarbonization, which are, in descendent order of relevance, the Port Authorities, the European Union, the national governments, shipping companies and the local industry of all kinds. Despite the ranking, the responsibility levels of the groups are very closely related. Therefore, these five stakeholder groups are hereby encouraged to closely collaborate and proactively cooperate for implementation of all possible decarbonization measures. Relying on actions of or shifting responsibilities to other stakeholder groups is not suggested because it is assumed to only slow down the transition. In the medium responsible stakeholder group are listed the institutions, which are therefore appealed to closely follow the dialogue and actions taken, as well as to support the top five responsible stakeholder groups in their procedures. Since both local organizations and citizens are considered the least responsible stakeholder groups, their role does remain in the background, however they are highly encouraged to speak up their opinion and pressure the directly involved stakeholders for faster operational decarbonization efforts in ports. This resulting categorization shows that port and port association employees are aware of the rising attraction of integrating citizen to participate in climate actions in the European Union, as highlighted by (Spandagos et al., 2012). In sum, it has been approved that Port Authorities are by far not the only highly responsible stakeholder group for port decarbonization. In that regard, it is astonishing to see that only Kahane et al. (2013) have mentioned this aspect of stakeholder co-responsibility.

Ideally, the prioritizations 1, 2 and 3 recommended in part 6.1. should be used as a guideline, however the exact involvement need of each stakeholder differs between the measures. To present a clearer picture, the results from the qualitative information, hence the questionnaire comments, the interviews, and the literature, have been consulted in regard to the distribution of responsibilities for each measure, too. The identified stakeholders will be listed below, and the number of total mentions per source indicated in a small table, which underlines the importance of combining all three information sources for a more precise result. The exact sources having revealed each identified stakeholder is to be found in annex 8, including the exact primary source of the literature finding for originality of information. This does not just give a broader scope of supposedly engaged stakeholders, but it does also evidence the complementarity of findings based on the three types of sources used for the research approach. Since often, numerous authors came to the same finding, they have each been added to the count individually, which makes their number often higher than the number of findings themselves. The new, often singular findings based on the empirical research are however not to be neglected. It is to be added that the number of mentions per stakeholder is not necessarily representative for the final level of responsibility. The listed stakeholders are in fact recommended to divide the responsibility shares via constructive dialogue for each kind of project.

Priority 1: Environmental policy and regulatory framework

International organizations, policymakers (EU and governments) as well as Port Authorities are advised to take the major responsibilities for this specific measure.

Questionnaire comments	Interview comments	Literature
5	5	21

Priority 1: Renewable electricity sources

Port Authorities, energy companies, transmission and distribution system operators, policymakers, independent energy producers and port customers are the stakeholders which will have to address the issue of renewable energy sources together, both on the supply and demand side.

Questionnaire comments	Interview comments	Literature
10	11	0

Priority 1: Green port management

Mainly Port Authorities and third parties like consultants are in charge of implementing a green port management to set up strategies and actively coordinate the transposition of measures.

Questionnaire comments	Interview comments	Literature
5	3	3

Priority 1: Alternative fuels

Port Authorities are recommended to be facilitators for the development of alternative fuel use. The more active stakeholders identified are shipping companies, local industry, energy companies, shipping fuel provision companies, trucking fuel provision companies, policymakers, and organizations, mainly due to their greater experience in the topic or due to their provision need.

Questionnaire comments	Interview comments	Literature
11	15	1

Priority 2: Onshore power supply

Numerous stakeholders have been identified for the implementation of onshore power supply. These stakeholders are Port Authorities, shipping companies, policymakers, technological providers, transmission and distribution systems operators, service companies selling the generated electricity, agencies, and the labour in the port. All of them are recommended to closely work together to set up OPS projects while sharing the involved responsibilities since each one brings in their own added value.

Questionnaire comments	Interview comments	Literature
3	18	0

Priority 2: Energy efficiency for port equipment and fleet transformation

When focussing on the port equipment, the Port Authority and port equipment providers should strongly co-act for transforming or replacing the port equipment with more carbon neutral options.

Questionnaire comments	Interview comments	Literature
0	6	3

Priority 2: Energy management systems

For the installation of energy management systems, the Port Authority is prescribed to take a supporting role. From the results, it is rather up to energy companies, consumers and transmission and distribution system operators to take the lead for setting up or contributing to the setup of the underlying steps of energy management systems.

Questionnaire comments	Interview comments	Literature
0	10	3

Priority 2: Hinterland integration

For the integration of the hinterland, Port Authorities should partly take responsibilities for offering more climate friendly transportation modes for goods arriving at the port. But it is more up to railway companies, inland shipping companies, trucking companies, cities, and trucking

fuel provision companies to decarbonize land transportation in general, and therefore also in regard to port links, based on their respective expertise.

Questionnaire comments	Interview comments	Literature
4	14	20

Priority 2: Renewable electricity for ship propulsion

For the creation of greener ships by using renewable electricity for ship propulsion, Port Authorities are advised to support the ship owners in converting their vessels. However, it is up to the shipping companies themselves, the policymakers, and organizations to take the lead for this measure.

Questionnaire comments	Interview comments	Literature
2	9	0

Priority 3: Smart resources and automation

In the category of smart resources and automation, Port Authorities and port equipment providers are recommended for involvement. Even if none of the sources did have a deeper focus on this specific measure, and considering the fact that numerous specific resources are needed for transposing this measure and integrating it into daily port operation, it only seems plausible to add technology providers to the list and encouraging them to get involved, too.

Questionnaire comments	Interview comments	Literature
0	0	2

Priority 3: Energy efficiency for ships in ports

Considering energy efficiency for ships in Ports, the Port Authority does again have a certain responsibility, shared with the shipping companies. These main stakeholders are hereby encouraged to scanning all possible optimization options for both vessel speed reduction and the reduction of time spent at berth.

Questionnaire comments	Interview comments	Literature
0	6	6

6.1.3. Best practices for implementation of emission reduction measures in ports

With the aim of guiding ports in their transition to becoming green, a very large number of best practices has been identified through the three-dimensional research approach. Again, these findings will be presented below, categorized into the three priorities and with an indication of total number by type of initial sources. The identified responsible port stakeholders of part 6.2. are recommended to take the best practices drawn from both researchers and port actors of the field to either copy or get inspired by the proposed best practices. It is however to be mentioned

that the here presented options are certainly only a part of the actual, non-exhaustive list of existing positive proceedings. Next, the main best practices per measure will be explained, but it is considered worthy for the readers to stick to the entire content of the compiled tables in annex 8. Again, the results combine the survey results, the interviews, and the literature, with the latter being indicated in the text and the mentioned annex 8 to assure the originality of the findings. Since often, numerous authors came to the same finding, they have each been added to the count individually, which makes their number often higher than the number of findings themselves. The new, often singular findings based on the empirical research are however not to be neglected.

Priority 1: Environmental policy and regulatory framework

For global governance, clear and coherent regulation and distribution of responsibilities is needed to be set up at fast pace and in a democratic process, ideally through the direct dialogue with the Port Authorities and other relevant port stakeholder groups. At the beginning of the current transition, pilot research and funding projects are recommended to be set up to test and adjust certain implementation procedures for a following faster development throughout the European ports. Environmental assessment schemes and certifications can be further options to motivate the actors of the sector. When focusing on other incentive types, rewarding measures should predominantly be applied to encourage instead of discouraging the stakeholders to invest into greener operations. Therefore, mainly funding, subsidies and eco-incentives (tax fee reduction, port fee discount) are best suited according to the survey comments, interviews, and literature (Xu et al., 2021; Wang et al., 2020; Tseng und Pilcher 2019; Radu and Grandidier, 2012; EU, 2003). In case of the use of punishment measures, they are recommended to be controlled in a reasonable scope to avoid negative influences (Xu et al., 2021).

Questionnaire comments	Interview comments	Literature
17	9	6

Priority 1: Renewable electricity sources

For the general topic of renewable electricity, Port Authorities are encouraged to collaborate with the corresponding production, transportation, and distribution companies of the energy sector, while energy companies are encouraged to increase their business operation in and around port locations. To assess the energy capacity needed, procedures for expressions of interest should be set up to get a clearer vision of all end user's needs. If renewable energy sources have been installed for a long time (20 to 30 years), consider repowering for increased output electricity within the same available space. If new renewable sources need to be installed, assess the suitability of all different technological options, including the exact geographic location and meteorologic conditions. Different ways of thinking and organizing are fundamental to avoid electricity supply bottlenecks. For solar energy, the installation on the roofs of all kinds of port buildings, of ships and container docks is highly recommended by respondents and literature (Sifakis and Tsoutsos, 2021; Song and Poh, 2017; Boile et al., 2016; Vincent, 2014; E-Harbours Electric, 2012), and on the nearby water surface, according to a survey comment. When purchasing photovoltaic panels, monocrystalline solar cells are very suited in terms of efficiency,

whereas solar water heating is suggested to be used for high-temperature industrial processes (Hess et al., 2011; Labouret and Villoz, 2010; Hagopian et al., 2007). Wind energy can be built onshore but especially offshore (Cavvazi and Dutton, 2016) – the exact location is further to be assessed in detail including for instance wind speed, geological structure of the site, transmission networks and the required material and resources (Blazauskas et al., 2015). Before implementing tidal energy due to the constant exposition of (sea)ports to waves and tides, concrete feasibility studies are urgently to be conducted before implementation (Cascajo et al., 2019; Li et al., 2018). Unfortunately, no best practices have been identified for the use of geothermal energy and fuel cells, which is certainly linked to their comparatively immature commercialization. If none of the above technologies can be installed at a port site, renewable power-purchase agreements can be signed (Li et al., 2019; PIANC, 2019; Christoforaki and Tsoutsos, 2017; Blazauskas et al., 2015).

Questionnaire comments	Interview comments	Literature
11	4	16

Priority 1: Green port management

In general, green port management should be highly motivated to start creating an operational philosophy around the environment. Since port management drives the development of green ports the most, ports need to start setting environmental parameters (Hua et al., 2020), while considering the efforts for becoming a green port as a distinguishing attractiveness factor (Munim et al., 2022). Investments in demonstration projects are fundamental, while also integrating the private sector, for example by switching from a private governance model towards a landlord model. Speaking of stakeholder participation, an increase of trust between parties is fundamental for increasing the urgency of cooperation and coordination for co-creation based on shared information, shared expertise, shared costs, used synergies and strengthened competitiveness. The aspect of cooperation and coordination has also been mentioned by the literature (Cheon, 2017; Le et al., 2014). The dialogues are encouraged to be more systematic and structured around environmental issues, which could be fostered by signing strategic agreements or Memorandums of Understanding, or by setting up corporations on the operational level. Building community networks through regular meetings, collaborative platforms or websites can help in the process of structuring the dialogue around environmental issues. Consultants are ideal for external but qualified support. Internally, Port Authorities are animated to engage green port managers or agents solely focussed on the transition in its whole in the port, as accentuated by the survey result and the literature (van der Heijden et al., 2012; Dunphy et al., 2007). This does not just include pro environmental actions, but also increases the engagement of port staff into the processes. One way to do so is through the implementation of environmental multi-disciplinary teams (Pavlic et al., 2014).

Further, the responsible bodies for environmental measures need to be integrated into the port structure (organizational chart) (Lam and Li, 2019). To avoid different visions between ports and governments, national umbrella organizations can be implemented to fulfil the need for coordination and uniformity (Homsombat et al., 2013). All these actions need of course to be set up within a green port strategy with short to long term visions, aligned with the overall port

strategy (Lam and Li, 2019). The green port strategy urgently needs to have fixed priorities, key objectives, and a solid action plan, with the necessary budget for each environmental goal implemented in each department for the upcoming year. Also, the specifications of environmental goals are to be presented in the mission statement, the vision, and the organizational chart. All green efforts undertaken are recommended to be made public and transparent through emission reports, news releases, publications, or the port's website. In this way, credibility in the customers and regulators eyes can be assured, and other stakeholders or ports can be motivated to get engaged to increase their efforts, too Lam and Li (2019). Furthermore, ports should let go of today's mainly used private governance model by switching to a landlord model for pushing private operators to implement green practices (Munim et al., 2020).

Questionnaire comments	Interview comments	Literature
20	16	14

Priority 1: Alternative fuels

For bringing forward the development of alternative fuel use, very close collaboration is urged to take place between the supply side, including Port Authorities, energy companies and local industry, as well as on the demand side, including again the Port Authority, shipping, and trucking companies. Feasibility studies for each single renewable fuel are recommended to be conducted because it is not yet sure which of the fuels will mainly be used in the near future and for which exact equipment type. Setting up procedures for letters of intent or expressions of interest is highly probable to help getting a clearer vision. Also, it is fundamental that the Port Authority's personnel is properly informed and trained about the risks and operation of all these alternative fuels. The fuel LNG is prescribed to be ideal for the propulsion of large ships and for inland operation (Xu and Yang, 2020; Ni et al., 2020; Sifakis and Tsoutsos, 2021), whereas biofuels are rather suited for small and medium-sized ships and certain port operation equipment, too (Ni et al., 2020). Methanol, hydrogen, and ammonia can be blended with each other and with diesel (Rehmatulla et al., 2017; Valera-Medina et al., 2017; Westlye et al., 2013; Boretti, 2012; Reiter and Kong, 2011; Reiter and Kong, 2008).

Questionnaire comments	Interview comments	Literature
5	3	10

Priority 2: Onshore power supply

For the setup of onshore power supply, the concerned stakeholders are primarily urged to follow the regulatory development for OPS obligation to align their strategies and efforts. Ideally, same standards are to be set between cooperating ports to facilitate the implementation. It is recommended to start using OPS for liner traffic to build in house knowledge, because the cruise and container ships are more difficult cases. Studies are needed to be undertaken to get aware of the belonging port equipment, the infrastructure, performance, and safety of this specific operation, meanwhile ideally participating in EU projects. Again, the collaboration with the energy sector and the shipping lines is necessary for assuring sufficient energy capacity by strengthening the power grid around the port. Also, technological providers, for example for peak levelling technologies like fuel cells, are encouraged to being involved, as well as port service companies in

charge of selling the electricity while giving financial guarantees. To make OPS projects viable and overcome the main barriers which are the associated costs, seeking grants for both CAPEX and OPEX is unavoidable. Therefore, Port Authorities are hereby encouraged to guide the policymakers for a visible and feasible regulatory framework for OPS.

Questionnaire comments	Interview comments	Literature
10	9	0

Priority 2: Energy efficiency for port equipment and fleet transformation

When opting for working efficiency improvement, reasonability is the main driver for optimal trade-off between time and fuel saving (Yun et al., 2018). When no other options are available or when it simply takes a longer time to convert the equipment in question, energy efficiency is a very adequate option. Within this, speeding up the handling efficiency of cranes and trucks is highly recommended Yun et al. (2018), as well as switching from alternative current drive to direct current technologies or using the hoist-down movement for cranes (Zhao et al., 2014; Tran, 2012).

With a deeper focus on the purchase, replacement or retrofit of port equipment, it is primarily fundamental to consider the environmental return as the most important one, and the economical ROI in the longer run. In general electrification is considered the most promising way to decarbonize the use of port equipment of all types, followed by hybridization of fuels (CARB/EPA, 2015). For electrification, sufficient capacity of electricity needs to be available. For fuels, fuel cells are a rapidly emerging technology to be scrutinised, with way faster charging times than batteries (Kinnon et al., 2021; Curtin and Gangi, 2014). For cranes, the ranking E-RTG < ARMG < RMG < RTG is considered the most environmentally friendly one (Hoang et al., 2022), but the transposition into practice needs to be assessed first. For other equipment such as forklifts, rail movers, yard trucks, stacking cranes and automated guided vehicles, swappable and portable “battery electric” systems are recommended, too (Hoang et al., 2022; Dhupia et al., 2011). In general, it is recommended to opt for newly purchased port equipment when the equipment has a small life span but high energetic use and lower global investment costs. Opting for retrofitting is better when an equipment has rather low energy consumption but high global investment costs. If the choice between these options is too difficult, the merit order can be used for making the right decision. Participating in innovation projects is also suited for supporting the decision for the overall equipment. Guarantee the necessary energy capacity and urgently include energy storage options like batteries, flywheels, or supercapacitors (Antonelli et al., 2017; Niu et al., 2017; Tan and Yap, 2017; Greencranes, 2012; Flynn et al., 2008; Kim and Sul, 2006). Be aware of carbon leakage when selling the older port equipment on the market instead of preferring the retrofit option. With regard to other equipment improvement measures, the use of LED lamps is highly recommended (Sifakis and Tsoutsos, 2021). In order to minimize cooling demand and heat loss in port buildings, green roofs, walls painted in white, cleaned lamps, the use of cold storage insulation and the use curtains are traditional measures to be implemented more systematically (Alamoush et al., 2020). As for the reduction of dust in ports, the installation of sprinkler systems, dust-proof nets and thatch covers are very well suited (Wang et al., 2023).

Questionnaire comments	Interview comments	Literature
6	8	18

Priority 2: Energy management systems

For the implementation of energy management systems, compliance with ISO 50001 energy management system standards is crucial (Iris and Lam, 2019). The integration of smart devices for real time operation planning is fundamental, which helps create an energy community (Iris and Lam, 2019; Ngai et al., 2011). Based on the data, energy management plans are central to be established for acquiring an energy profile, contained on a reliable database for analysis of energy need and consumption (Cammin et al., 2020; Boile et al., 2016; Lam and Notteboom, 2014; Pavlic et al., 2014). Further, for energy storage systems, batteries, flywheels, supercapacitors, and fuel cells are to be considered (Sifakis and Tsoutsos, 2021; Ahamad et al., 2019; PIANC, 2019; Yigit et al., 2016). When considering the installation of a smart grid, secure and critical smart grid infrastructure shall be installed together with the information technologies like sensors, smart meters, real-time monitoring systems and control tools to avoid disruptions (Iris and Lam, 2019; Lam et al., 2017; Siemens, 2017; Spbp, 2017; Bayindir et al., 2016; Ihle et al., 2016; Parise et al., 2016b; Yigit et al., 2016; Mondragon et al., 2015; Sharma and Saini, 2015). Making of the smart grid a smart micro grid is an even more reliable option for opening the opportunity to synchronously operate with the traditional centralized grid ("grid") or disconnect and function autonomously ("islanding") (Roy et al., 2020; Parise, 2016; Katiraei et al., 2015; Sudhoff, 2015). Therefore, load analysis of equipment, smart grid scenario analysis, energy balancing and benefit analysis are necessary (Liang et al., 2014). As for smart load management, both load shifting and peak shaving are loading strategies easy to implement to control the instant energy capacity and related electricity prices (Alamoush et al., 2020).

Questionnaire comments	Interview comments	Literature
3	0	28

Priority 2: Hinterland integration

For integrating the hinterland, it is fundamental for Port Authorities to connect with partners that are more expert in this specific sector. Especially the road sector needs to be addressed extremely urgently. Several best practices for better managing the trucks outside the port have been identified. One way would be by banning or excluding trucks on a voluntary basis from the terminal (Clott and Hartman, 2013; Norsworthy and Craft, 2013). Also, installing truck appointment systems, automated gate processing systems, extending off peak terminal and gate hours and coupling trucks empty return with loaded pickups are other ways to reduce emissions from trucks (Schulte et al., 2017; Chen et al., 2013; Guan and Liu, 2009; Giuliano and O'Brien, 2007). Furthermore, truck replacement, retirement, repowering or retrofit are suited options, too (Alamoush et al., 2020). In any case, Port Authorities are urged to proof willingness to deliver low carbon fuels in the close port environment. Despite all, the very best option for transporting the goods into the hinterland is by improving modal shift and modal split using railway, barges, or short-sea shipping, as identified by the survey, the interviews and the literature (IMO, 2018b; IAPH, 2007). These options are in fact the most elemental for hinterland

decarbonization. In any case, mobility modelling and studies of alternatives need to be conducted first. As for the transportation of people, Port Authorities and companies working in the port are hereby invited to encourage their employees for using bicycles or public transportation (I2S2, 2013).

Questionnaire comments	Interview comments	Literature
4	6	11

Priority 2: Renewable electricity for ship propulsion

For the use of renewable electricity for ship propulsion, Port Authorities are invited to support the transition to green ships by facilitating the change and making contributions, for example by offering eco-incentives for environmentally friendly actions of the customers. Also, Port Authorities should be technology neutral. For solar propulsion, photovoltaic panels are advised to be installed on ships upper decks (Hoang et al., 2022). For wind propulsion, all kind of sails are recommended to be used, from Flettner rotors to kites or spinnakers over soft sails and wing sails until wind turbines (Mofor et al., 2015; Carlton et al., 2013). In general, the most suitable conditions for wind propulsion are for speeds under 16 knots and for smaller sized vessels between 3000 and 10000 tons (Smith et al., 2016; Smith et al., 2013). As for fuel cells, they can use them both for the propulsion of rather smaller ships or for port equipment, but applicators should also be aware that applications of fuel cells for ship propulsion are still scarce today (Hoang et al., 2022; Kinnon et al., 2021; Pagliaro, 2020; Bicer and Dincer, 2018; Sharaf and Orhan, 2014). As for nuclear power, which is not recommended to be used, suits rather for warships, submarines, aircraft carriers or icebreakers (Khlopkin and Zotov, 1997).

Questionnaire comments	Interview comments	Literature
1	5	11

Priority 3: Smart resources and automation

In regard to information measures, digital platforms and sensors are recommended to be installed for tracking real-time emission data. Especially common industry 4.0 technologies like Big Data, Artificial Intelligence, Internet of Things, 5G and 3D printing are highly suitable for implementation. As for the process, the responsible stakeholders are suggested to proceed with data collection to identify the source, then to set up monitoring systems for optimization based on external effects in ports, before reporting the results (Kang and Kim, 2017; Tichavska and Tovar, 2015a; Tichavska and Tovar, 2015b; Lam and Notteboom, 2014; Darbra et al., 2009; Peris-Mora et al., 2005). As for automation, new automation concepts shall be explored including different kinds of new technologies, which will furthermore facilitate the electrification process. As of today, ports should get inspired by current functioning automation uses like gate automation, scheduling yard trucks and container tracking PEMA (2016). Automated traffic management systems for ships are very much recommended, too, as well as automatic shutdown and start-up systems, automated mooring systems, double loading cycles of quay cranes, twin-lift or tandem-lift operations in gantry cranes, variable speed generator for RTGs, eco-

driving, route optimisation, acceleration techniques for port vehicles, intelligent and autonomous vehicles (IAVs), waterborne autonomous guided vessels and drones and robots for warehouses (Sifakis and Tsoutsos, 2021; Tan et al., 2018; Zheng et al., 2017; Accenture and SIPG, 2016; Lee et al., 2015; Yang, 2015; Hippinen and Federley, 2014; Gelareh et al., 2013; IAPH, 2007).

Questionnaire comments	Interview comments	Literature
7	2	16

Priority 3: Energy efficiency for ships in ports

When implementing vessel speed reductions, it is highly recommended to use the 10 knots line as indicator since it is the most energy efficient speed, which has been highlighted by an interviewee and the literature (Yun et al., 2018; Cariou, 2011). In general, trade-offs between time and fuel saving are essential, ideally connected with virtual arriving times (Du et al., 2015). With focus on reducing berthing time, it is primarily needed to increase the entire efficiency and productivity of the terminal to improve operation time around the ships, which is again best supported by digital tools. Also, since the current 'first-come-first-serve' model makes ships speed up to assure a place at berth, ports are urged to switch to an arrival booking scheme to guarantee a berth place at arrival and thus opening the possibility to reducing the speed and berthing time (Kontovas and Psaraftis, 2011). For most of these aspects, information communication systems, electronic data interchange, single windows, port community systems, vessel traffic management, streamlined ship clearance and standardized documents are very well suited for support (Styhre and Winnes, 2019; Poulsen et al., 2018; IMO, 2015; ESPO, 2012). Also, automated traffic management systems like automatic mooring systems are highly recommended for optimization of ship speed and time spent waiting. If viable, the number of cranes is also recommended to be increased.

Questionnaire comments	Interview comments	Literature
3	6	8

6.2. Limitations

After broadly screening and evaluating emission reduction measures for port decarbonization under the green port concept, this last subchapter will reveal the limitations of this work as identified by the self-conducted questionnaire and interviews.

6.2.1. Limitations related to the research topic

At the very beginning of this project, several definitions set by institutions and researchers of the term 'green port' have been exposed. At this stage already, different nuances of the term have been revealed. In order to narrow the scope of this master thesis down, only emission reduction measures have been included into the research project. However, by scanning the literature, asking the questionnaire respondents for additional comments, and exchanging with

the interviewees, the generally broader framework of the green port has been confirmed. Hence, a green port should in general be aware of the environmental consequences and effects that could have its activity by engaging for a minimum environmental impact, considering the environment, nature, biodiversity, and society as a whole. Still, the aspects of 'zero emission port', 'reduction of the carbon footprint' and 'no impact on the climate' have been underlined repeatedly, which indicates very well that reducing CO2 emissions is today's primary focus of ports.

Besides CO2 emissions, other negative external emissions like nitrogen oxides, sulphur oxides, particular matters, noise, and dust pollution urgently need to be considered within the topic of green ports, too. In this master thesis, these aspects have at least partly been covered by the systematic literature review but the focus in research needs to be addressed further.

Also, aspects covered by nature and biodiversity are needed to be explored more extensively. One of the subtopics identified would be the waste treatment to foster circular economy. For solid waste, available treatment methods and reception facilities for processes like recycling have to be used and assessed further, especially for the waste receipted from arriving ships. This assessment could also cover the use of more eco-friendly materials by the shipping companies. As for sewage or ballast wastewater, treatment plants need to be installed or made available from the local waste management companies, which might demand further development. Concrete methods for limiting oil spills from bunkering activities are another field which could be managed further. Keeping the focus on water surroundings, future researchers are also encouraged to focus on tidal behaviour, saline plugs, biological state of the statuary and overall water quality. Ports and researchers can also enlarge their scope of activity by including the surrounding marine ecosystem by improving nature to achieve mutual benefits, for example by regenerating nearby beaches or by managing the guidelines for landfills that could be used later as bird breeding sites, for instance. Also, solutions for coastal erosion and dredging activities for port expansion need to be found urgently, which demands additional specific investigations. As for the treatment of hazardous goods in ports, emergency plans for pollution and risks are recommended to be established for each single good.

Taking the social aspect into account will be a further research path in the context of green ports, especially by integrating the surrounding city, the citizens, and the workers of the port.

Furthermore, the conducted study revealed some differences between seaports and river ports in regard to the implementation of certain emission reduction measures, which might be necessary to be considered in upcoming research projects. Also, it is of fundamental importance to integrate the aspect of regionalization into the research of implementation of green measures, too. Some ports might for instance not be suitable for becoming energy hubs due to specific local conditions or simply by the size of the port. In fact, these here presented findings are only to be considered on a macroeconomic level.

6.2.2. Limitations related to the research method

For the systematic literature review, one database has been entirely scanned, which already resulted in a great amount of workload. Still, other relevant databases could be added to the review for extracting even more relevant sources of the green port topic. Although the chosen database Science Direct has been revealed to covering the greatest number of related studies

with corresponding journal quality, access and link to supply chain management, sometimes certain hidden studies can add very valuable insights. This practice is especially transposable with a less tightened timeframe.

For the questionnaire, only port and port association employees have been approached for giving their evaluation based on expert knowledge. They have been chosen because these are the stakeholders most closely related to the operation in ports and, as confirmed by the conducted research, have a certain degree of responsibility for initiating, supporting or transposing the implementation of each emission reduction measure. Still, it would have been interesting to conduct the same survey between the main different stakeholder groups identified, thus policy-makers (EU and national governments), shipping companies, local industry, institutions, local organizations, and citizens to filter out differences in perceptions and prioritizations. Again, due to the lack of time for conducting this research project and lack of concrete contacts of the enumerated stakeholder groups, a limit had to be set. Furthermore, the research has been conducted within the European Union only. Since employees of only 17 EU nationalities answered the questionnaire, it would have been great to get answers of at least one representative of each of the 27 EU countries, which has been tried to be achieved by having contacted 714 employees from all the 27 countries. Since no prospect can be obliged to participate, it was difficult to meet this requirement.

For the interviews, asking more detailed questions for gaining more detailed answers would certainly have revealed an even larger number of best practices. However, due to the tight schedule of the interviewees, who are all very engaged in the practical transition towards green ports, no longer time window for the interviews could have been provided. This specific aspect is also the reason why only one round of interviews has been conducted. In fact, with more time resources, it could have been considered to conduct the interviews according to the Delphi method, which implies at least two interview rounds with the same interviewees. In each round, the results of the previous rounds are presented to the interviewees in order to filter out whether or not their preferences are impacted.

Finally, the conclusions and recommendations of this research project can mainly be applied to ports within the European Union, or to ports of developed countries. In fact, since the transition towards green ports implies a great amount of needed public and private financing, as well as the corresponding know-how, not all recommendations presented are applicable in the same way to lower developed ports. It is therefore recommended for future research to make a distinction by specifically focusing on the needs and barriers of less developed ports. The results from the systematic literature review also revealed, for example, the very low amount of research conducted in Africa and South America. Still, these lower developed ports can consider the here presented measures and recommendations as final goals to get inspired for their specific transition path. As for the ports in developed countries, it is recommended for future research to dig deeper into concrete implementation for each measure on a singular and more granular level. In fact, the smaller the scope of a research project, the more concrete the results will be. For these measure-specific studies, which might be port- or project-based, it is urgently needed to include the timeframe, budget and financing opportunities. Overall, green practices in the port environment should continue to be promoted and researched for innovative ideas.

Conclusion

The rising volumes of goods shipped by sea continuously expand the operation in ports worldwide, which results in the increase of environmental degradation caused by these elemental global supply chain hubs. Despite the late recognition of the extensive contribution of the maritime industry to global warming, ports, international organisations, and policymakers have in the past decade steadily increased their focus on greener operations, a phenomenon often referred to as 'Green Ports'. Despite the varying definitions of the term 'Green Port', the primary focus is set on emission reduction measures for port decarbonization. Yet, the transition towards port greenification encounters numerous hurdles which hinder its development, especially in the shift from theoretical knowledge to practical implementation.

Thus, the present master thesis contributes to closing this identified research gap by extracting the existing emission reduction measures realisable in ports with their main characteristics, by analysing the point of view of port and port association employees regarding the identified measures, and by compiling the results of the empirical research and the literature findings for delivering practical guidelines with priorities, responsibilities, and best practices. Overall, the following research question has been studied:

The transition towards 'Green Ports': Which implementation approaches can be employed for an effective adoption of the most impactful emission reduction measures in view of port decarbonization?

To extract the most impactful emission reduction measures for port decarbonization, a systematic literature review within the database Science Direct has been provided, having combined the green port topic with keywords related to emission reduction in ports. The acquired solid theory of 44 high-quality scientific publications resulted in 446 primary sources which delivered the basis for the following generation of empirical data. For evaluation of the identified measures, quantitative data has been acquired through a survey, spread among 714 and responded by 56 valid port and port association employees in the European Union to capture their perception in relation to the filtered decarbonization measures. In addition, four qualitative expert interviews with port employees of the European Union focusing on green practices within their position have been conducted to get supplementary information and reasonings for some outcomes of the survey. In a last step, the great amount of valuable knowledge acquired from the survey, the interviews and the literature has been assembled and categorized for compact recommendations to answer the research question. Combining the findings of all three data types has resulted in consistent and complementary findings.

In the scientific literature, 11 main measures and their characteristics have been identified for the contribution of decarbonizing ports. They can be categorized into port governance measures, port operation measures, ship-to-port and port-to-land measures and renewable energy measures. By evaluating the findings of the literature, the survey, and the interviews, three prioritization categories of the 11 singles measures have been drawn, which underline three major tendencies. First, governance both on a regulatory and port operation level is the most critical lever to introduce emission reduction measures, represented by the measures of "environmental policy and regulatory framework" (priority 1) and "green port management" (priority 1). With leading governance, the need for structure, guidance, coherence, planning and vision

in the transformation process from conventional to green ports is more likely to be compliant with the urgent need. Second, energy related measures are the central driver for the substitution of current fossil based and thus polluting resources. The urgent commitment of ports to become clean energy hubs has largely been underlined by the research sources, be it for import, export, or local use. To assure the energy transition in ports, this research has pointed out that in a very first step, a sufficient amount of clean energy carriers needs to be available, represented by "renewable electricity sources" (priority 1) and "alternative fuels" (priority 1). Only when the energy supply side has been secured, the energy demand and control side can be successfully implemented for the identified uses, being "onshore power supply" (priority 2), "energy efficiency of port equipment and fleet transformation" (priority 2), "energy management systems" (priority 2), "hinterland integration" (priority 2) and "renewable electricity for ship propulsion" (priority 2). Third, today's most advanced and mature measures in terms of implementation are simultaneously the least urgent measures to be focused on in the transition towards green ports, which are "smart resources and automation" (priority 3) and "energy efficiency for ships in ports" (priority 3). In comparison, all other 9 measures are currently still in more early-stage lifecycle categories between the preparation, scale-up and growth.

In the port environment, a very large number of varying stakeholders is actively operating and doing business. When zooming on the respective responsibilities, the research has revealed that Port Authorities are by far not the only liable party for implementing emission reduction measures. For each specific field of action, a large number of specified actors is supposed to be responsible for their concrete business by using their individual expertise, but never in an isolated way. In this sense, the policymakers and institutions are the main responsible ones for supporting the measures by elaborating coherent regulations and setting frameworks. All types of energy companies need to become more active for production and distribution of all types of clean energies in and around port locations due to the identified energetic priorities. Shipping, trucking, and railway companies need to actively participate in assuring the availability of all necessary infrastructure, power, and technological components needed for their respective fleet. For all measures and thus all stakeholders, however, Port Authorities are the main interlocutor. Their high responsibility level remains focused on their self-executed applications, but for all other measures, they still do take the role of supporting body. Cities, local organizations, and residents are less responsible for port decarbonization but do have an important word to say in the process, too.

The identified best practices for the implementation of emission reduction measures are numerous, with varying degrees of detail. In the governance section, the switch from a conventional to a green port firstly needs to be considered as a convicted attractiveness factor. The three c-words cooperation, collaboration and co-creation are the heart of successful green port governance, based on trustful dialogues. Supported by clear and coherent regulation, funding and positive eco-incentives are key elements for practical trials for an even faster large-scale implementation. Visibility and transparency accompany good governance practices via communication channels. On the energy supply side, expressions of interest help collecting data about future electricity and fuel needs from the sector-overlapping users, which in return fosters the construction of corresponding production capacities. Through assessments of suitability, the local feasibility of each energy source or energy carrier can be inspected and weighted. So far, solar energy, wind energy, fuel cells and hydrogen are safe energy success sources, but still, all

energy production technologies and fuel types should be evaluated due to singular and characteristic-related suitability. Furthermore, adequate and sufficient energy storage needs to be available. On the energy use side, electrification and hybridization of ships, trucks and port equipment drive the operational decarbonization the most, besides the speeding up of terminal handling efficiency. The longer the lifespan of an equipment, the more the focus is needed to be on retrofit, and the smaller the lifespan, the more the focus needs to be on new purchased equipment to avoid delays in the green port transition. Through information technologies of the industry 4.0, energy consumption and real-life data can be captured, which does not just enable easier implementation of electrification measures but also provides the opportunity for ship and truck arrival and departure management for limiting congestion around the port and diminish related unnecessary fuel consumption. Differentiated transportation modes are further required by shifting the trucking shares towards the more environmentally friendly options of railway, barges, and short sea shipping. By starting to implement several prioritized measures simultaneously, solid in-house knowledge can be built and constantly developed further.

To conclude, the challenges for successful implementation of emission reduction measures for port decarbonization under the green port concept are a demanding mammoth task, not least because of the very large number of different but still interrelated measures and sub measures. Still, the obtained results contribute to guiding port stakeholders to switch from the theoretical knowledge to the practical application of relevant green port practices. In fact, 15 of the contacted employees of port and port associations have already requested the results of this master thesis for inspiration in their current job. Researchers are now encouraged to continue investigating the practical implementation of the identified measures on a granular micro scale, by integrating for instance exact timelines, local conditions, and financing strategies. Further, since the empirical research focused on the European Union, a distinction also needs to be made according to the specificities of both developed and less developed ports and countries.

Historically, port operation has been based on the most economically viable solutions, which have slowly been switched from manual manpower towards fossil-based resources and machine equipment. Today, it is inevitable for ports to get prepared for the next revolution by vastly investing in renewable-based resources and replacing and modifying the conventional machine equipment. In the near future, ports will very certainly be rewarded for their green efforts by benefitting from positive economic and ecologic returns on investment, contributing to the sustainable development of national and international trade, fostering a durable strategic position, and accelerating greener economic growth worldwide.

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APPENDIX

Annex 1: Article details of the systematic literature review

Search string: 'Green Port'

Search String	Criteria	Title	Author	Year	Database	Journal	Geographic Region	Methodology	Relation to emission reduction
"green port"	2015-2023; Open Access; TAK; Journal Quality 1	Evaluation and governance of green development practice of port: A sea port case of China	Chengying Hua, Jihong Chen, Zheng Wan, Lang Xu, Yun Bai, Tianxiao Zheng, Yijie Fei	2020	Science Direct	Journal of Cleaner Production	Asia	Qualitative & quantitative	Yes
"green port"	2015-2023; Open Access; TAK; Journal Quality 1	Transhipment port's competitiveness forecasting using analytic network process modelling	Ziaul Haque Munim, Okan Duru, Adolf K.Y. Ng	2022	Science Direct	Transport Policy	Asia	Qualitative and quantitative	Yes
"green port"	2015-2023; Open Access; TAK; Journal Quality 1	The coupling effect between economic development and the urban ecological environment in Shanghai Port	Jihong Chen, Weipan Zhang, Lan Song, Yafei Wang	2022	Science Direct	Science of the Total Environment	Asia	Quantitative	No
"green port"	2015-2023; Open Access; TAK; Journal Quality 1	A port attractiveness assessment framework: Chittagong Port's attractiveness from the users' perspective	Ziaul Haque Munim, Khandaker Rasel Hasan, Hans-Joachim Schramm, Hasan Mahbub Tusher	2022	Science Direct	Case Studies on Transport Policy	Asia	Quantitative	Yes
"green port"	2015-2023; Open Access; TAK; Journal Quality 1	Institutionalizing environmental reform with sense-making: West and Central Africa ports and the 'green port' phenomenon	Harry Barnes-Dabbana, Jan P.M. van Tatenhovea, Kris C.S.A. van Koppena, Katrien J.A.M. Termeerb	2017	Science Direct	Marine Policy	Africa	Qualitative	Yes
"green port"	2015-2023; Open Access; TAK; Journal Quality 1	Evaluating the key factors of green port policies in Taiwan through quantitative and qualitative approaches	Po-Hsing Tsenga, Nick Pilcher	2019	Science Direct	Transport Policy	Asia	Qualitative and quantitative	Yes
"green port"	2015-2023; Open Access; TAK; Journal Quality 1	A method for determining the allocation strategy of on-shore power supply from a green container terminal perspective	Yun Peng, Xiangda Li, Wenyuan Wang, Zhijun Wei, Xiao Bing, Xiangqun Song	2019	Science Direct	Ocean and Coastal Management	Asia	Quantitative	Yes
"green port"	2015-2023; Open Access; TAK; Journal Quality 1	A review of the port carbon emission sources and related emission reduction technical measures	Bei Wang, Qing Liu, Lei Wang , Yongjun Chen, Jisheng Wang	2023	Science Direct	Environmental Pollution	World	Literature Review and Qualitative	Yes
"green port"	2015-2023; Open Access; TAK; Journal Quality 1	A simulation-based research on carbon emission mitigation strategies for green container terminals	P.E.N.G. Yun, L.I. Xiang, W.A.N.G. Wenyuan, L.I.U. Ke, L.I. Chuan	2018	Science Direct	Ocean Engineering	Africa	Quantitative	Yes
"green port"	2015-2023; Open Access; TAK; Journal Quality 1	Alternative Maritime Power application as a green port strategy: Barriers in China	Jihong Chen, Tianxiao Zheng, Akhil Garg, Lang Xu, Sifan Li, Yijie Fei	2019	Science Direct	Journal of Cleaner Production	Asia	Quantitative	Yes
"green port"	2015-2023; Open Access; TAK; Journal Quality 1	Challenging a sustainable port. A case study of Souda port, Chania, Crete	Ioannis Argyriou, Tryfonas Daras, Theocharis Tsoutsos	2022	Science Direct	Case Studies on Transport Policy	Europe	Quantitative	Yes
"green port"	2015-2023; Open Access; TAK; Journal Quality 1	Cooperative optimization of shore power allocation and berth allocation: A balance between cost and environmental benefit	Yun Peng , Meng Dong , Xiangda Li , Huakun Liu , Wenyuan Wang	2021	Science Direct	Journal of Cleaner Production	Asia	Quantitative	Yes
"green port"	2015-2023; Open Access; TAK; Journal Quality 1	Deployment and retrofit strategy for rubber-tyred gantry cranes considering carbon emissions	Yi Ding, Yang Yang, Leonard Heilig, Eduardo Lalla-Ruiz, Stefan Voss	2021	Science Direct	Computers & Industrial Engineering	Asia	Quantitative	Yes
"green port"	2015-2023; Open Access; TAK; Journal Quality 1	Evaluating the economic and environmental efficiency of ports: Evidence from Italy	Rosalia Castellano, Marco Ferretti, Gaetano Musella, Marcello Risitano	2020	Science Direct	Journal of Cleaner Production	Europe	Quantitative	Yes
"green port"	2015-2023; Open Access; TAK; Journal Quality 1	Green port marketing for sustainable growth and development	Jasmine Siu Lee Lam, Kevin X. Li	2019	Science Direct	Transport Policy	World	Qualitative	Yes
"green port"	2015-2023; Open Access; TAK; Journal Quality 1	Two-sided sustainability: Simulating battery degradation in vehicle to grid applications within autonomous electric port transportation	Christine Harnischmacher , Lukas Markefke, Alfred Benedikt Brendel, Lutz Kolbe	2023	Science Direct	Journal of Cleaner Production	Europe	Quantitative	Yes
"green port"	2015-2023; Open Access; TAK; Journal Quality 1	Life cycle assessment of yard tractors using hydrogen fuel at the Port of Kaohsiung, Taiwan	Ching-Chih Chang, Po-Chien Huang, Jhih-Sheng Tu	2019	Science Direct	Energy	Asia	Quantitative	Yes
"green port"	2015-2023; Open Access; TAK; Journal Quality 1	Operating strategies of CO2 reduction for a container terminal based on carbon footprint perspective	Yi-Chih Yang	2017	Science Direct	Journal of Cleaner Production	Asia	Quantitative	Yes
"green port"	2015-2023; Open Access; TAK; Journal Quality 1	Towards a Green Port strategy: The decarbonisation of the Port of Vigo (NW Spain)	Carlos Botana, Emilio Fernández, Gumersindo Feijoo	2023	Science Direct	Science of the Total Environment	Europe	Quantitative	Yes
"green port"	2015-2023; Open Access; TAK; Journal Quality 1	The natural environment in port development: A 'green handbrake' or an equal partner?	S. Taljaard, J.H. Slinger, S. Arabi, S.P. Weerts, H. Vreugdenhil	2021	Science Direct	Ocean and Coastal Management	Africa	Qualitative	No
"green port"	2015-2023; Open Access; TAK; Journal Quality 1	Decarbonisation of seaports: A review and directions for future research	Ateyah Alzahrani, Ioan Petri, Yacine Rezgui, Ali Ghoroghi	2021	Science Direct	Energy Strategy Reviews	World	Qualitative	Yes
"green port"	2015-2023; Open Access; TAK; Journal Quality 1	Sediment management in coastal infrastructures: Techno-economic and environmental impact assessment of alternative technologies to dredging	A. Bianchini, F. Cento, A. Guzzini, M. Pellegrini, C. Saccani	2019	Science Direct	Journal of Environmental Management	World	Qualitative	No
"green port"	2015-2023; Open Access; TAK; Journal Quality 1	Planning low carbon oriented retrofit of diesel-driven cranes to electric-driven cranes in container yards	Shumin Lin, Lu Zhen, Wencheng Wang	2022	Science Direct	Computers & Industrial Engineering	Asia	Quantitative	Yes
"green port"	2015-2023; Open Access; TAK; Journal Quality 1	Optimal operation of hybrid energy system for intelligent ship: An ultrahigh-dimensional model and control method	Ruoli Tang, Qing An, Fan Xu, Xiaodi Zhang, Xin Li, Jingang Lai, Zhengcheng Dong	2020	Science Direct	Energy	Asia	Quantitative	Yes
"green port"	2015-2023; Open Access; TAK; Journal Quality 1	Research on ecological evaluation of Shanghai port logistics based on emergy ecological footprint models	Benkai Xie, Xiaoxiao Zhang , Junling Lu, Fan Liu , Yuqing Fan	2022	Science Direct	Ecological Indicators	Asia	Quantitative	No
"green port"	2015-2023; Open Access; TAK; Journal Quality 1	Optimal energy management and operations planning in seaports with smart grid while harnessing renewable energy under uncertainty	Ça ˘gatay Iris, Jasmine Siu Lee Lam	2021	Science Direct	Omega	World	Quantitative	Yes
"green port"	2015-2023; Open Access; TAK; Journal Quality 1	Multi-objective optimization of daily use of shore side electricity integrated with quayside operation	Jingjing Yu, Stefan Voß, Xiangqun Song	2022	Science Direct	Journal of Cleaner Production	Europe	Quantitative	Yes
"green port"	2015-2023; Open Access; TAK; Journal Quality 1	Joint berth allocation and quay crane assignment under different carbon taxation policies	Tingsong Wang, Xinchang Wang, Qiang Meng	2018	Science Direct	Transportation Research Part B	World	Quantitative	Yes
"green port"	2015-2023; Open Access; TAK; Journal Quality 1	Evolutionary game analysis on behavior strategies of multiple stakeholders in maritime shore power system	Lang Xu, Zhongjie Di, Jihong Chen, Jia Shi, Chen Yang	2021	Science Direct	Ocean and Coastal Management	Asia	Quantitative	Yes
"green port"	2015-2023; Open Access; TAK; Journal Quality 1	Green port oriented resilience improvement for traffic-power coupled networks	Lu Zhen, Shumin Lin, Chenhao Zhou	2022	Science Direct	Reliability Engineering and System Safety	Asia	Quantitative	Yes
"green port"	2015-2023; Open Access; TAK; Journal Quality 1	Identifying the appropriate governance model for green port management: Applying Analytic Network Process and Best-Worst methods to ports in the Indian Ocean Rim	Ziaul Haque Munim, Henrik Sornn-Friese, Mariia Dushenko	2020	Science Direct	Journal of Cleaner Production	Asia	Quantitative	Yes
"green port"	2015-2023; Open Access; TAK; Journal Quality 1	Key performance indicators for developing environmentally sustainable and energy efficient ports: Evidence from Italy	Assunta Di Vaio, Luisa Varriale, Federico Alvino	2018	Science Direct	Energy Policy	Europe	Qualitative	Yes
"green port"	2015-2023; Open Access; TAK; Journal Quality 1	A comparison of dispersion models for the LNG dispersion at port of Koper, Slovenia	Marko Gerbec, Peter Vidmar, Gianmaria Pio, Ernesto Salzano	2021	Science Direct	Safety Science			No
"green port"	2015-2023; Open Access; TAK; Journal Quality 1	Causation analysis and governance strategy for hazardous cargo accidents at ports: Case study of Tianjin Port's hazardous cargo explosion accident	Wenyu Hua, Jihong Chen, Quande Qin, Zheng Wan, Lan Song	2021	Science Direct	Marine Pollution Bulletin			No
"green port"	2015-2023; Open Access; TAK; Journal Quality 1	Ecological empowerment and Enterprise Zones: pain free transitions to sustainable production in cities or fool's gold?	Philip Monaghan, Peter North, Alan Southern	2016	Science Direct	Journal of Cleaner Production			No
"green port"	2015-2023; Open Access; TAK; Journal Quality 1	Improved Benders decomposition for stochastic yard template planning in container terminals	Hongtao Hu, Jiao Mo, Lu Zhen	2021	Science Direct	Transportation Research Part C			No
"green port"	2015-2023; Open Access; TAK; Journal Quality 1	Preconditions of new container terminal location in the Maritime Spatial Planning framework. A case study for the Central Port Concept in Gda´nsk	Ernest Czermansk, Aneta Oniszczuk-Jastrząbek, Jacek Zaucha, Barbara Pawłowska, Magdalena Matczak, Łukasz Szydłowski	2021	Science Direct	Marine Policy			No

Red = Outside the fixed scope

Orange = Duplicate

Search strings: “port” AND “emission reduction”, “low carbon”, “decarbonisation”, “energy efficiency”, “CO2”, “sustainability”

Search String	Criteria	Title	Authors	Year	Database	Journal	Geographic Region	Methodology	Relation to emission reduction
"port" AND "emission reduction"	2015-2023; Open Access; TAK; Journal Quality 1; Review article	A review of the port carbon emission sources and related emission reduction technical measures	Bei Wang, Qing Liu, Lei Wang , Yongjun Chen, Jisheng Wang	2023	Science Direct	Environmental Pollution	World	Literature Review and Qualitative	Yes
"port" AND "emission reduction"	2015-2023; Open Access; TAK; Journal Quality 1; Review article	A review on regulations, current status, effects and reduction strategies of emissions for marine diesel engines	Peiyong Ni, Xiangli Wang, Hu Li	2020	Science Direct	Fuel	World	Literature Review	Yes
"port" AND "emission reduction"	2015-2023; Open Access; TAK; Journal Quality 1; Review article	A sustainable electrical interface to mitigate emissions due to power supply in ports	T.Coppola, M.Fantauzzi, D.Lauria, C.Pisani, F.Quarant	2016	Science Direct	Renewable and Sustainable Energy Reviews	World	Quantitative	Yes
"port" AND "emission reduction"	2015-2023; Open Access; TAK; Journal Quality 1; Review article	Energy-related approach for reduction of CO2 emissions: A critical strategy on the port-to-ship pathway	Anh Tuan Hoang, Aoife M. Foley, Sandro Nizeti, Zuohua Huang, Hwai Chyuan Ong, Aykut I. Ölçer, Van Viet Pham, Xuan Phuong Nguyen	2022	Science Direct	Journal of Cleaner Production	General	Literature Review	Yes
"port" AND "emission reduction"	2015-2023; Open Access; TAK; Jou	Health impact assessments of shipping and port-sourced air pollution on a global scale: A scoping literature review	Natalie Mueller, Marie Westerby, Mark Nieuwenhuijsen	2023	Science Direct	Environmental Research	World	Quantitative	No
"port" AND "emission reduction"	2015-2023; Open Access; TAK; Journal Quality 1; Review article	Shore power as a first step toward shipping decarbonization and related policy impact on a dry bulk cargo carrier	Hugo Daniel, Joao Pedro F. Trovao, David Williams	2022	Science Direct	eTransportation	North America	Quantitative	Yes
"port" AND "low carbon"	2015-2023; Open Access; TAK; Journal Quality 1; Review article	A review of the port carbon emission sources and related emission reduction technical measures	Bei Wang, Qing Liu, Lei Wang, Yongjun Chen, Jisheng Wang	2023	Science Direct	Environmental Pollution	World	Literature Review and Qualitative	Yes
"port" AND "low carbon"	2015-2023; Open Access; TAK; Journal Quality 1; Review article	A review of energy efficiency in ports: Operational strategies, technologies and energy management systems	Çağatay Iris, Jasmine Siu Lee Lam	2019	Science Direct	Renewable and Sustainable Energy Reviews	World	Literature Review	Yes
"port" AND "decarbonisation"	2015-2023; Open Access; TAK; Journal Quality 1; Review article	Decarbonisation of seaports: A review and directions for future research	Ateyah Alzahrani, Ioan Petri, Yacine Rezgui, Ali Ghoroghi	2021	Science Direct	Energy Strategy Reviews	World	Qualitative	Yes
"port" AND "decarbonisation"	2015-2023; Open Access; TAK; Journal Quality 1; Review article	Ports' technical and operational measures to reduce greenhouse gas emission and improve energy efficiency: A review	Anas S. Alamoush, Fabio Ballini, Aykut I. Ölçer	2020	Science Direct	Marine Pollution Bulletin	General	Literature Review	Yes
"port" AND "decarbonisation"	2015-2023; Open Access; TAK; Journal Quality 1; Review article	Wave energy converters in low energy seas: Current state and opportunities	Spyros Foteinis	2022	Science Direct	Renewable and Sustainable Energy Reviews	World	Literature Review	No
"port" AND "energy efficiency"	2015-2023; Open Access; TAK; Journal Quality 1; Review article	Ports' technical and operational measures to reduce greenhouse gas emission and improve energy efficiency: A review	Anas S. Alamoush, Fabio Ballini, Aykut I. Ölçer	2020	Science Direct	Marine Pollution Bulletin	General	Literature Review	Yes
"port" AND "energy efficiency"	2015-2023; Open Access; TAK; Journal Quality 1; Review article	A review of energy efficiency in ports: Operational strategies, technologies and energy management systems	Çağatay Iris, Jasmine Siu Lee Lam	2019	Science Direct	Renewable and Sustainable Energy Reviews	World	Literature Review	Yes
"port" AND "energy efficiency"	2015-2023; Open Access; TAK; Journal Quality 1; Review article	Shore power as a first step toward shipping decarbonization and related policy impact on a dry bulk cargo carrier	Hugo Daniel, Joao Pedro F. Trovao, David Williams	2022	Science Direct	eTransportation	North America	Quantitative	Yes
"port" AND "energy efficiency"	2015-2023; Open Access; TAK; Journal Quality 1; Review article	Planning zero-emissions ports through the nearly zero energy port concept	Nikolaos Sifakis, Theocharis Tsoutsos	2021	Science Direct	Journal of Cleaner Production	General	Literature Review	Yes
"port" AND "energy efficiency"	2015-2023; Open Access; TAK; Journal Quality 1; Review article	Solution for RTG crane power supply with the use of a hybrid energy storage system based on literature review	Dimitrios Vlahopoulos , Aggelos S. Bouhouras	2022	Science Direct	ustainable Energy Technologies and Assessment	General	Qualitative and quantitative	Yes
"port" AND "energy efficiency"	2015-2023; Open Access; TAK; Journal Quality 1; Review article	Symbiotic technology-based potential for energy saving: A case study in China's iron and steel industrial parks	Zongguo Wen, Jinjing Xu, Jason C.K. Lee, Cuiping Rena	2017	Science Direct	Renewable and Sustainable Energy Reviews	Asia	Qualitative and quantitative	No
"port" AND "energy efficiency"	2015-2023; Open Access; TAK; Journal Quality 1; Review article	The environmental Kuznets curve, economic growth, renewable and non-renewable energy, and trade in Tunisia	Mehdi Ben Jebli, Slim BenYoussef	2015	Science Direct	RenewableandSustainableEnergyReviews	Africa	Quantitative	No
"port" AND "CO2"	2015-2023; Open Access; TAK; Journal Quality 1; Review article	Energy-related approach for reduction of CO2 emissions: A critical strategy on the port-to-ship pathway	Anh Tuan Hoang, Aoife M. Foley, Sandro Nizeti, Zuohua Huang, Hwai Chyuan Ong, Aykut I. Ölçer, Van Viet Pham, Xuan Phuong Nguyen	2022	Science Direct	Journal of Cleaner Production	General	Literature Review	Yes
"port" AND "CO2"	2015-2023; Open Access; TAK; Journal Quality 1; Review article	Ports' technical and operational measures to reduce greenhouse gas emission and improve energy efficiency A review			Science Direct				Yes
"port" AND "CO2"	2015-2023; Open Access; TAK; Journal Quality 1; Review article	Reduction in CO2 emissions in RoRo/Pax ports equipped with automatic mooring systems	Emma Díaz-Ruiz-Navamuel a, b, *, Andres Orte	2018	Science Direct	Environmental Pollution	General	Qualitative and quantitative	
"port" AND "sustainability"	2015-2023; Open Access; TAK; Journal Quality 1; Review article	Energy-related approach for reduction of CO2 emissions: A critical strategy on the port-to-ship pathway	Anh Tuan Hoang, Aoife M. Foley, Sandro Nizeti, Zuohua Huang, Hwai Chyuan Ong, Aykut I. Ölçer, Van Viet Pham, Xuan Phuong Nguyen	2022	Science Direct	Journal of Cleaner Production	General	Literature Review	Yes
"port" AND "sustainability"	2015-2023; Open Access; TAK; Journal Quality 1; Review article	A review of energy efficiency in ports: Operational strategies, technologies and energy management systems	Çağatay Iris, Jasmine Siu Lee Lam	2019	Science Direct	Renewable and Sustainable Energy Reviews	World	Literature Review	Yes
"port" AND "sustainability"	2015-2023; Open Access; TAK; Journal Quality 1; Review article	The management in response to marine oil spill from ships in China: A systematic review	Shangao Xiong, Hualou Long, Guoping Tang, Ju	2015	Science Direct	Marine Pollution Bulletin	Asia	Qualitative and quantitative	No
"port" AND "sustainability"	2015-2023; Open Access; TAK; Journal Quality 1; Review article	Analysis of factors affecting microwave heating of natural gas hydrate combined with numerical simulation method	Huohai Yang, Xuanyu Liu, Jie Yue, Xinrui Tang	2022	Science Direct	Petroleum	Asia	Quantitative	No
"port" AND "sustainability"	2015-2023; Open Access; TAK; Journal Quality 1; Review article	Analysis of the interrelations between biogeographic systems and the dynamics of the Port-Waterfront Cities: Cartagena de Indias, Colombia	Grace Andreas Montoya-Rojas, Margui Almario García, Shirly Bello-Escobar, Kushal Pal Singh	2020	Science Direct	Ocean and Coastal Management	South America	Qualitative	No
"port" AND "sustainability"	2015-2023; Open Access; TAK; Journal Quality 1; Review article	Assessment of suitable shrimp farming site selection using geographical information system based Analytical Hierarchy Process in Turkey	Halil Burak Akdeniz, Sukran Yalpir, Saban Inan	2023	Science Direct	Ocean and Coastal Management	Asia	Qualitative and quantitative	No
"port" AND "sustainability"	2015-2023; Open Access; TAK; Journal Quality 1; Review article	Combining sediment management and bioremediation in muddy ports and harbours: A review	A. Polrot, J.R. Kirby, J.W. Birkett, G.P. Sharple	2021	Science Direct	Environmental Pollution	General	Qualitative	No
"port" AND "sustainability"	2015-2023; Open Access; TAK; Journal Quality 1; Review article	Cropland degradation and nutrient overload on Hainan Island: A review and synthesis	Tingyu Li, Xiuyang Hong, Shuoran Liu, Xiaoqiao Wu, Shan Fu, Ye Liang, Jinghua Li, Ran Li, Chong Zhang, Xiaotong Song, Hongwei Zhao, Dengfeng Wang, Fengliang Zhao, Yunze Ruan, Xiaotang Ju	2022	Science Direct	Environmental Pollution	Asia	Qualitative and quantitative	No
"port" AND "sustainability"	2015-2023; Open Access; TAK; Journal Quality 1; Review article	Dual injection: An effective and efficient technology to use renewable fuels in spark ignition engines	Yuhan Huang, Nic C. Surawski, Yuan Zhuang, Jo	2021	Science Direct	Renewable and Sustainable Energy Reviews	Asia	Quantitative	No
"port" AND "sustainability"	2015-2023; Open Access; TAK; Journal Quality 1; Review article	Effects of blending C3-C4 alcohols on motor gasoline properties and performance of spark ignition engines: A review	Saeid Aghahossein Shirazi, Bahareh Abdollahipoor, Bret Windom, Kenneth F. Reardon, Thomas D. Foust	2020	Science Direct	Fuel Processing Technology	General	Quantitative	No
"port" AND "sustainability"	2015-2023; Open Access; TAK; Journal Quality 1; Review article	Environmental pollution with antifouling paint particles: Distribution, ecotoxicology, and sustainable alternatives	Fernando G. Torres, Gabriel E. De-la-Torre	2021	Science Direct	Marine Pollution Bulletin	General	Quantitative	No
"port" AND "sustainability"	2015-2023; Open Access; TAK; Journal Quality 1; Review article	Impact of the COVID-19 pandemic on food production and animal health	Parastoo Rahimi, Md Saiful Islam, Phelipe Magalhaes Duarte, Sina Salajegheh Tazerji, Md Abdus Sobur, Mohamed E. El Zowalaty, Hossam M. Ashour, Md Tanvir Rahman	2022	Science Direct	Trends in Food Science & Technology	General	Qualitative	No
"port" AND "sustainability"	2015-2023; Open Access; TAK; Journal Quality 1; Review article	Novel and investigational therapies for wet and dry age-related macular degeneration	Aira Sarkar, Srushti Jayesh Sodha, Vijayabhaskarreddy Junnuthula, Praveen Kolimi, Sathish Dyawanapelly	2022	Science Direct	Drug Discovery Today	General	Qualitative	No
"port" AND "sustainability"	2015-2023; Open Access; TAK; Journal Quality 1; Review article	Overcoming the Law of the Hidden in Cyberinfrastructures	Alexander Bucksch, Abhiram Das, Hannah Schneider, Nirav Merchant and Joshua S. Weitz	2017	Science Direct	Trends in Plant Science	General	Qualitative	No
"port" AND "sustainability"	2015-2023; Open Access; TAK; Journal Quality 1; Review article	Review on the contamination and remediation of polycyclic aromatic hydrocarbons (PAHs) in coastal soil and sediments	Chaomeng Dai, Yueming Han, Yanping Duan, Xiaoying Lai, Rongbing Fu, Shuguang Liu, Kah Hon Leong, Yaojen Tu, Lang Zhou	2022	Science Direct	Environmental Research	General	Qualitative	No
"port" AND "sustainability"	2015-2023; Open Access; TAK; Journal Quality 1; Review article	Sediment management in coastal infrastructures: Techno-economic and environmental impact assessment of alternative technologies to dredging	A. Bianchini, F. Cento, A. Guzzini, M., Pellegrini, C. Saccani	2019	Science Direct	Journal of Environmental Management	General	Quantitative	No
"port" AND "sustainability"	2015-2023; Open Access; TAK; Journal Quality 1; Review article	Selecting the most viable renewable energy source for Brazilian ports using the FITradeoff method	Dayla Karolina Fossile, Eduarda Asfora Frej, Sergio E. Gouvea da Costa, Edson Pinheiro de Lima, Adiel Teixeira de Almeida	2020	Science Direct	Journal of Cleaner Production	South America	Qualitative	Yes
"port" AND "sustainability"	2015-2023; Open Access; TAK; Journal Quality 1; Review article	A sustainable electrical interface to mitigate emissions due to power supply in ports	T.Coppola, M.Fantauzzi, D.Lauria, C.Pisani, F.Quarant	2016	Science Direct	RenewableandSustainableEnergyReviews	World	Quantitative	Yes
"port" AND "sustainability"	2015-2023; Open Access; TAK; Journal Quality 1; Review article	Challenges for the future of ports. What can be learnt from the Spanish Mediterranean ports?	Nuria Nebot, Carlos Rosa-Jiménez, Ricard Pié Ninot, Beatriz Perea-Medina	2017	Science Direct	Ocean & Coastal Management	Europe	Qualitative	No
"port" AND "sustainability"	2015-2023; Open Access; TAK; Journal Quality 1; Review article	C-Ports: A proposal for a comprehensive standardization and implementation plan of digital services offered by the “Port of the Future”	Paolo Pagano, Silvia Antonelli, Alexandr Tardo	2022	Science Direct	Computers in Industry	Europe	Quantitative	Yes
"port" AND "sustainability"	2015-2023; Open Access; TAK; Journal Quality 1; Review article	Solution for RTG crane power supply with the use of a hybrid energy storage system based on literature review	Dimitrios Vlahopoulos , Aggelos S. Bouhouras	2022	Science Direct	ustainable Energy Technologies and Assessment	General	Qualitative and quantitative	Yes
"port" AND "sustainability"	2015-2023; Open Access; TAK; Journal Quality 1; Review article	Synergy of green hydrogen sector with offshore industries: Opportunities and challenges for a safe and sustainable hydrogen economy	Sumit Kumar, Til Baalisampang, Ehsan Arzaghi, Vikram Garaniya, Rouzbeh Abbassi, Fatemeh Salehi	2023	Science Direct	Journal of Cleaner Production	General	Qualitative	Yes
"port" AND "sustainability"	2015-2023; Open Access; TAK; Journal Quality 1; Review article	The role of fuel cells in port microgrids to support sustainable goods movement	Michael Mac Kinnon, Ghazal Razeghi, Scott Samuelsen	2021	Science Direct	Renewable and Sustainable Energy Reviews	General	Literature Review	Yes

Red = Outside the fixed scope

Orange = Duplicate

Annex 2: Contact list of the port and port association employees of the European Union

Country	Port/Port association	Name	Position	E-Mail or Link
Austria	Port of Linz	General adress	General adress	info@linzag.at
Austria	Port of Enns	Werner Auer	Management	w.auer@ennshafen.at
Austria	Port of Enns	Jörg Praher	Management	ennshafen@ecoplus.at
Austria	Port of Enns	Christina Eckmayr	Marketing, Press	c.eckmayr@ennshafen.at
Austria	Port of Enns	Karin Voglsam	Project management	k.voglsam@ennshafen.at
Austria	Port of Vienna	Doris Pulker-Rohrhofer	Managing Director	doris.pulker-rohrhofer@hafenwien.com
Austria	Port of Vienna	Henrike Bauer	Deputy Head of Business Development and International Affairs	henrike.bauer@hafenwien.com
Austria	Port of Vienna	Michaela Pfneiszl	Quality and Environmental Manager	michaela.pfneiszl@hafenwien.com
Austria	Port of Vienna	Mark Miller	Head of Finance and Strategy	mark.miller@hafenwien.com
Austria	Port of Vienna	Friedrich Lehr	Managing Director	friedrich.lehr@hafenwien.com
Belgium	Port of Nieuwpoort	General adress	General adress	info@vynieuwpoort.be
Belgium	Port of Oostende	General adress	General adress	info@portofoostende.be
Belgium	Port of Oostende	Dirk Declerck	CEO	dirk.declerck@portofoostende.be
Belgium	Port of Oostende	Steve Declercq	Director of Business Development	steve.declercq@portofoostende.be
Belgium	Port of Oostende	Jan Allaert	Commercial Director	jan.allaert@portofoostende.be
Belgium	Port of Antwerp-Bruges	Tomas Thiels	Expert Shore Power for Sea Shipping	Tomas.Thiels@portofantwerpbruges.com
Belgium	Port of Antwerp-Bruges	Jan Cuyt	Business Development Advisor	jan.cuyt@portofantwerpbruges.com
Belgium	Port of Antwerp-Bruges	Arne Strybos	Program Manager Fuel Transition	arne.strybos@portofantwerpbruges.com
Belgium	Port of Antwerp-Bruges	Jan Goemaere	Port Infrastructure Manager Zeebrugge	Jan.Goemaere@portofantwerpbruges.com
Belgium	Port of Antwerp-Bruges	Pieter Vandermeeren	Coordinator Masterplanning Green Ports	pieter.vandermeeren@portofantwerpbruges.com
Belgium	Port of Antwerp-Bruges	Maxime Peeters	Program Manager Hydrogen	maxime.peeters@portofantwerpbruges.com
Belgium	Port of Antwerp-Bruges	Didier Van Osselaer	Sustainable Transition Manager	didier.vanosselaer@portofantwerpbruges.com
Belgium	Port of Antwerp-Bruges	Camille Lubon	Mobility Advisor	camille.lubon@portofantwerpbruges.com
Belgium	Port of Antwerp-Bruges	Philippe Le Petit	Port Representative France	philippe.lepetit@portofantwerpbruges.com
Belgium	Port of Antwerp-Bruges	Rob Smeets	Chief Operations Officer	rob.smeets@portofantwerpbruges.com
Belgium	Port of Antwerp-Bruges	Koen Cuypers	Port Area Development Expert	Koen.cuypers@portofantwerpbruges.com
Belgium	Port of Antwerp-Bruges	Martin Hubeňák	Port Representative Poland/Slovakia/Czech Republic	martin.hubenak@portofantwerpbruges.com
Belgium	Port of Antwerp-Bruges	Walter Holzhammer	Port Representative Austria/Hungary	walter.holzhammer@portofantwerpbruges.com
Belgium	Port of Antwerp-Bruges	Nils Van Vliet	CEO Railport	nils.vanvliet@railport.be
Belgium	Port of Liège	General adress	General adress	https://www.portdeliege.be/fr/contact-liege-port-autonome
Belgium	Port of Brussels	General adress	General adress	info@port.brussels
Bulgaria	Bulgarian Ports Infrastructure Company	Mariela Ganchovska	Head of Public Relations and Protocol Department	m.ganchovska@bgports.bg
Bulgaria	Bulgarian Ports Infrastructure Company	General adress Bourgas	General adress Bourgas	office.bourgas@bgports.bg
Bulgaria	Bulgarian Ports Infrastructure Company	General adress Varna	General adress Varna	office.varna@bgports.bg
Bulgaria	Bulgarian Ports Infrastructure Company	General adress Lom	General adress Lom	office.lom@bgports.bg
Bulgaria	Bulgarian Ports Infrastructure Company	General adress Vtmis	General adress Vtmis	office.vtmis@bgports.bg
Bulgaria	Bulgarian Ports Infrastructure Company	General adress Bulris	General adress Bulris	office.bulris@bgports.bg

Bulgaria	Bulgarian Ports Infrastructure Company	General adress Ruse	General adress Ruse	office_portruse@bgports.bg
Croatia	Croatian Ports Association	General adress	General adress	dozvole@portauthority.hr
Croatia	Croatian Ports Association	General adress	General adress	rijeka.gateway@portauthority.hr
Croatia	Port of Rijeka	Maja Trtanj	Head of the Office of the President of the Management Board	maja.trtanj@lukarijeka.hr
Croatia	Port of Rijeka	Procurement department	Procurement department	nabava@lukarijeka.hr
Croatia	Port of Rijeka	PR specialist	PR specialist	press@lukarijeka.hr
Croatia	Port of Rijeka	Development and asset management	Development and asset management	razvoj@lukarijeka.hr
Croatia	Port of Rijeka	Sales and marketing sector	Sales and marketing sector	commercial@lukarijeka.hr
Croatia	Port of Rijeka	Operations sector	Operations sector	operativa@lukarijeka.hr
Croatia	Port of Rijeka	Terminal Rijeka	Terminal Rijeka	rukovoditeljtr@lukarijeka.hr
Croatia	Port of Rijeka	Terminal Škrljevo	Terminal Škrljevo	skrljevo@lukarijeka.hr
Croatia	Port of Rijeka	Terminal Bakar	Terminal Bakar	bakar@lukarijeka.hr
Croatia	Port of Rijeka	Terminal Silos	Terminal Silos	silos@lukarijeka.hr
Croatia	Port of Rijeka	Terminal Bršica	Terminal Bršica	brsica@lukarijeka.hr
Croatia	Port of Split	Port Authority	Port Authority	lusplit@portsplit.hr
Croatia	Port of Split	Operations Centre	Operations Centre	operativa@portsplit.hr
Croatia	Port of Vukovar	Port Authority	Port Authority	office@luv.hr
Cyprus	Cyprus Ports Authority	General adress	General adress	cpa@cpa.gov.cy
Cyprus	Cyprus Ports Authority	Michalis Kefalonitis	Larnaca Port Manager	michalis.kefalonitis@cpa.gov.cy
Cyprus	Cyprus Ports Authority	Panayiotis Agathocleous	Limassol Port Manager	panayiotis.agathocleous@cpa.gov.cy
Cyprus	Cyprus Ports Authority	Miltos Savva	Accountant	miltos.savva@cpa.gov.cy
Cyprus	Cyprus Ports Authority	Neophytos Vichas	VTS Operator	neophytos.vichas@cpa.gov.cy
Cyprus	Cyprus Ports Authority	Stelios Pittakas	Chief Accountant	stelios.pittakas@cpa.gov.cy
Cyprus	Cyprus Ports Authority	Andreas Parmaklis	Administrative (Procurement, Project Management) Officer	andreas.parmaklis@cpa.gov.cy
Cyprus	Cyprus Ports Authority	Xanthos Matsoukas	Re Appointed Board Member	xanthos.matsoukas@cpa.gov.cy
Cyprus	Cyprus Ports Authority	Panayiotis Kypri	Internal Accountant	panayiotis.kypri@cpa.gov.cy
Cyprus	Cyprus Ports Authority	Katerina Dokou	Environmental Officer	katerina.dokou@cpa.gov.cy
Cyprus	Cyprus Ports Authority	Evros Maliotis	Port Officer	evros.maliotis@cpa.gov.cy
Cyprus	Cyprus Ports Authority	Stavros Stavrou	Marine Pilot	stavros.stavrou@cpa.gov.cy
Cyprus	Cyprus Ports Authority	Charis Theocharous	Deputy PFSO	charis.theocharous@cpa.gov.cy
Denmark	ADP - Associated Danish Ports A/S	Tine Kirk	Director	tkp@danskehavne.dk
Denmark	ADP - Associated Danish Ports A/S	Marianne Winther	International Chef	mw@danskehavne.dk
Denmark	ADP - Associated Danish Ports A/S	Søren Søndergaard	Head of Press and Communication	ss@danskehavne.dk
Denmark	ADP - Associated Danish Ports A/S	Karina Lyngbak Sørensen	Enterprise Policy Adviser	kls@danskehavne.dk
Denmark	ADP - Associated Danish Ports A/S	Camilla Rosenhagen	Head of Climate and Environment	cr@danskehavne.dk
Denmark	ADP - Associated Danish Ports A/S	Henriette Obitsø Mølgaard	Industrial Policy Adviser / Executive Assistant	hom@danskehavne.dk
Denmark	ADP - Associated Danish Ports A/S	Frederikke Aa	Student assistant	fa@danskehavne.dk
Denmark	Port of Aalborg	General adress	CEO	ktd@portofaalborg.com
Denmark	Port of Aalborg	Betina C. Mose Nielsen	CFO, CIO & Head of Administration	bcn@portofaalborg.com
Denmark	Port of Aalborg	Jesper Raakjær	Group Chief Visionary Officer, Professor	jr@portofaalborg.com
Denmark	Port of Aalborg	Mette Schmidt	Chief Technical & Sustainability Officer	ms@portofaalborg.com
Denmark	Port of Aalborg	Henrik Lybæk	Head of Real Estate & Property Management	hly@portofaalborg.com
Denmark	Port of Aalborg	Claus Rosenbeck	Harbourmaster	cr@portofaalborg.com

Denmark	Port of Aalborg	Søren Bæk Christensen	Director of Operation	sbc@portofaalborg.com
Denmark	Port of Aalborg	Brian D. Rasmussen	Engineer, Environment & Port Facilities	bdr@portofaalborg.com
Denmark	Port of Aalborg	Anda Varna	Junior Engineer, Digital & Environmental Design	av@portofaalborg.com
Denmark	Port of Aalborg	Dennis Bossen	Junior Specialist, Energy & Environmental Technology	dbo@portofaalborg.com
Denmark	Port of Aalborg	Mark Tholstrup	Senior Engineer & Project Manager	mat@portofaalborg.com
Denmark	Port of Aalborg	Mette Kromann Mandrup	Senior Engineer & Project Manager	mkm@portofaalborg.com
Denmark	Port of Aalborg	Ole Svendsen	Chief Consultant Operation	os@portofaalborg.com
Denmark	Port of Aalborg	Peter Bjerg Olesen	Technology & Logistics Specialist	pbo@portofaalborg.com
Denmark	Port of Aalborg	Maja Thordahl Schou	Head of Communications	mts@portofaalborg.com
Denmark	Port of Aalborg	Anne Sivesgaard Jensen	Sustainability Consultant	asj@portofaalborg.com
Denmark	Port of Aalborg	Rikke Drustrup	Sustainability Consultant	rdr@portofaalborg.com
Denmark	Port of Aalborg	Leonie Schlüter	PhD Student	lsc@portofaalborg.com
Denmark	Port of Aalborg	Bjarke Møller	Development Consultant	bmo@portofaalborg.com
Denmark	Port of Aalborg	Rasmus Munk Kolind	Senior Commercial Manager, Container & Rail	rmk@portofaalborg.com
Denmark	Port of Esbjerg	Dennis Jul Pedersen	CEO	djp@portesbjerg.dk
Denmark	Port of Esbjerg	Jesper Bank	Chief Commercial Officer	jba@portesbjerg.dk
Denmark	Port of Esbjerg	Henrik Theilgaard	Chief Operating Officer	hth@portesbjerg.dk
Denmark	Port of Esbjerg	Jane Behrens von Qualen	HSEQ Manager	jbq@portesbjerg.dk
Denmark	Port of Esbjerg	Rasmus Ager	Project Developer	ra@portesbjerg.dk
Denmark	Port of Esbjerg	Ishita Sharma	Research Manager	issh@portesbjerg.dk
Denmark	Port of Esbjerg	Lærke Skov Jensen	Business Development Junior	lsj@portesbjerg.dk
Denmark	Port of Esbjerg	Jesper Jørgensen	Engineer	jej@portesbjerg.dk
Denmark	Port of Esbjerg	Lone Arendt Rasmussen	Engineer	lar@portesbjerg.dk
Denmark	Port of Esbjerg	Michael Fries	Harbour Master	mf@portesbjerg.dk
Denmark	Port of Stavanger	Eivind Hornnes	Business Development Manager	eivind.hornnes@stavanger.havn.no
Denmark	Port of Stavanger	Magne Fjell	Port Director	magne.fjell@stavanger.havn.no
Denmark	Port of Stavanger	General adress	General adress	post@stavanger.havn.no
Denmark	ADP Nyborg Terminal	General adress	General adress	post@adp-as.dk
Denmark & Sweden	Port of Copenhagen Malmö	Jens Andersson	Operations Manager	jens.andersson@cmport.com
Denmark & Sweden	Port of Copenhagen Malmö	Jonatan Stoltz	Head of Environment	jonatan.stoltz@cmport.com
Denmark & Sweden	Port of Copenhagen Malmö	Jessika Cansund	Environmental strategist	jessika.cansund@cmport.com
Denmark & Sweden	Port of Copenhagen Malmö	Ulrika Prytz Rugfelt	Chief Communications & Sustainablity Officer	ulrika.prytz@cmport.com
Denmark & Sweden	Port of Copenhagen Malmö	Felicia Boudrée	PR & Communications Coordinator	felicia.boudree@cmport.com
Denmark & Sweden	Port of Copenhagen Malmö	Lennart Viðbjørg	Commercial Manager	lennart.viobjorg@cmport.com
Denmark & Sweden	Port of Copenhagen Malmö	Nikolaj Haubroe	Project Manager	nikolaj.haubroe@cmport.com
Denmark & Sweden	Port of Copenhagen Malmö	Malthe Mulvad	Public Affairs Lead	malthe.mulvad@cmport.com
Denmark & Sweden	Port of Copenhagen Malmö	Jens Bloch	Market Intelligence Manager	jens.bloch@cmport.com
Denmark & Sweden	Port of Copenhagen Malmö	Torben Lind	Business Development Director	torben.lind@cmport.com
Denmark & Sweden	Port of Copenhagen Malmö	Jesper Posth	Project Manager	jesper.posth@cmport.com
Denmark & Sweden	Port of Copenhagen Malmö	Gert Nørgaard	Manager	gert.norgaard@cmport.com
Denmark & Sweden	Port of Copenhagen Malmö	Frida Ängskulle	Sustainable Strategy Execution Specialist	frida.angskulle@cmport.com

Estonia	Port of Taillin	General adress	General adress	portoftallinn@portoftallinn.com
Estonia	Port of Taillin	Old City Harbour	Old City Harbour	vanasadam@portoftallinn.com
Estonia	Port of Taillin	Muuga Harbour	Muuga Harbour	muuga@portoftallinn.com
Estonia	Port of Taillin	Paldiski South Harbour	Paldiski South Harbour	paldiski@portoftallinn.com
Estonia	Port of Taillin	Saaremaa Harbour	Saaremaa Harbour	saaremaa@portoftallinn.com
Europe	ESPO	Isabelle Ryckbost	Secretary General	isabelle.ryckbost@espo.be
Europe	ESPO	Danique de Jonge	Senior advisor Intermodal & Logistics, Port Governance, Economic Analysis	danique.dejonge@espo.be
Europe	ESPO	Valter Selén	Senior Policy Advisor Sustainable Development, EcoPorts Coordinator, Dialogue	valter.selen@espo.be
Europe	ESPO	Piotr Krasnicki	Senior policy advisor on trade facilitation, marine affairs, customs and security	piotr.krasnicki@espo.be
Europe	ESPO	Anaëlle Boudry	Policy Advisor Energy and Blue Growth	anaelle.boudry@espo.be
Europe	ESPO	Turi Fiorito	Senior Advisor	turi.fiorito@espo.be
Europe	ESPO	Pernelle Picat	Communication, Administration and Event Assistant	pernelle.picat@espo.be
Europe	ESPO	Saran Touré	Personal Assistant and Events Manager	secretariat@espo.be
Europe	ESPO	Cécile Overlau	Finance and Office Manager	cecile.overlau@espo.be
Europe	ESPO	Anne Stuhlmann	Unknown	portinsights@espo.be
Finland	Finnish Port Association	Helmiina Latvanen	Communications	helmiina.latvanen@satamaliitto.fi
Finland	Port of Helsinki	Ville Haapasaari	CEO	ville.haapasaari@portofhelsinki.fi
Finland	Finnish Port Association	Kirsti Tarnanen-Sariola	Deputy Director	kirsti.tarnanen-sariola@satamaliitto.fi
Finland	Finnish Port Association	Aili Lampilinna	Preparedness Manager / NESO	aili.lampilinna@satamaliitto.fi
Finland	Finnish Port Association	General adress	General adress	info@satamaliitto.fi
Finland	Port of Kokkola	Torbjörn Witting	CEO & Logistics Services	torbjorn.witting@portofkokkola.fi
Finland	Port of Kokkola	Tomas Mikkola	Harbour Master	tomas.mikkola@portofkokkola.fi
Finland	Port of Kokkola	Jyrki Roukala	Development Manager	jyrki.roukala@portofkokkola.fi
Finland	Port of Kokkola	Dick Fraser	Marketing Representative	office@madicco.com
Finland	Port of Jakobstad Pietarsaari	Juha Hakala	Managing director	juha.hakala@portofpietarsaari.fi
Finland	Port of Jakobstad Pietarsaari	Katja Högnabba	Finance and Administration Secretary	katja.hognabba@portofpietarsaari.fi
Finland	Port of Jakobstad Pietarsaari	General adress	General adress	office@portofpietarsaari.fi
Finland	Port of Rauma	General adress	General adress	office@portofrauma.com
Finland	Port of Turku	Erik Söderholm	Managing Director	erik.soderholm@portofturku.fi
Finland	Port of Turku	Antti Pekanheimo	Chief Operating Officer	antti.pekanheimo@portofturku.fi
Finland	Port of Turku	Marjo Saviranta	Marketing and Communication Director	marjo.saviranta@portofturku.fi
Finland	Port of Turku	Teemu Aaltonen	Deputy Harbour Master	teemu.a.aaltonen@portofturku.fi
Finland	Port of Turku	Aija Kallio	Marketing Coordinator	aija.kallio@portofturku.fi
Finland	Port of Hamina-Kotka	Jari Kontunen	Project Director	jari.kontunen@haminakotka.fi
Finland	Port of Hamina-Kotka	Kimmo Naski	CEO, Managing Director	kimmo.naski@haminakotka.fi
Finland	Port of Hamina-Kotka	Eija Rossi	Commercial Director	eija.rossi@haminakotka.fi
Finland	Port of Hamina-Kotka	Petra Kuitunen	Marketing Manager	petra.kuitunen@haminakotka.fi
Finland	Port of Hamina-Kotka	Antii Lallukka	Sales Manager	antti.lallukka@haminakotka.fi
Finland	Port of Helsinki	Jussi Malm	Development Manager	jussi.malm@portofhelsinki.fi
Finland	Port of Helsinki	Petteri Nieminen	Project Manager	petteri.nieminen@portofhelsinki.fi
Finland	Port of Helsinki	Staffan Teromaa	Harbour Master	staffan.teromaa@portofhelsinki.fi
Finland	Port of Helsinki	Andreas Slotte	Head of Sustainable Development	andreas.slotte@portofhelsinki.fi
Finland	Port of Helsinki	Anton Airas	Environmental Specialist	anton.airas@portofhelsinki.fi
Finland	Port of Helsinki	Hanna van der Stehen	Manager, EU Projects	hanna.vanderstehen@portofhelsinki.fi
Finland	Port of Helsinki	Ville Haapasaari	CEO	ville.haapasaari@portofhelsinki.fi

Finland	Port of Helsinki	Eeva Hietanen	Head of Communications	eeva.hietanen@portofhelsinki.fi
France	Union des Ports de France	General adress	General adress	portsdefrance@port.fr
France	Union des Ports de France	Mathilde Pollet	Responsable des affaires économiques et européennes	mathilde.pollet@port.fr
France	Union des Ports de France	Christina Peron	Chargée de communication et d'information	christina.peron@port.fr
France	Union des Ports de France	Emilie Preat	Responsable Affaires juridiques et sociales	emilie.preat@port.fr
France	Union des Ports de France	Magali Massuyeau-Lemaire	Assistante Administrative	magali.massuyeau@port.fr
France	Administração dos Portos de Sines e do Algarve, S.A.	General adress	General adress	geral@apsinesalgarve.pt
France	Port of Dunkerque	Emmanuelle Verger	Chairman of the Supervisory Board	http://www.dunkerque-port.fr/fr/contact-fiche/?formParam%5 BreceiverIds%5D=6600
France	Port of Dunkerque	Frédéric Barra	President of the Development Council	http://www.dunkerque-port.fr/fr/contact-fiche/?formParam%5BreceiverIds%5D=6613
France	Port of Dunkerque	Maurice Georges	President of the Management Board	http://www.dunkerque-port.fr/fr/contact-fiche/?formParam%5BreceiverIds%5D=70121
France	Port of Dunkerque	Daniel Deschodt	Member of the Management Board	http://www.dunkerque-port.fr/fr/contact-fiche/?formParam%5BreceiverIds%5D=6489
France	Port of Dunkerque	Christian Minet	Director of Operations and Member of the Management Board	http://www.dunkerque-port.fr/fr/contact-fiche/?formParam%5BreceiverIds%5D=58747
France	Port of Dunkerque	David Lefranc	Director of Planning and Environment	http://www.dunkerque-port.fr/fr/contact-fiche/?formParam%5BreceiverIds%5D=23713
France	Port of Dunkerque	Joël Floch	Port Captain	http://www.dunkerque-port.fr/fr/contact-fiche/?formParam%5BreceiverIds%5D=36104
France	Port of Dunkerque	Philippe Laguionie	Second Port Captain	http://www.dunkerque-port.fr/fr/contact-fiche/?formParam%5BreceiverIds%5D=2423
France	Port of Dunkerque	Frédéric Caron	Port infrastructure division	http://www.dunkerque-port.fr/fr/contact-fiche/?formParam%5BreceiverIds%5D=12213
France	Port of Dunkerque	Gwennaëlle Cotonnec	Development, Foresight and Environment Unit	http://www.dunkerque-port.fr/fr/contact-fiche/?formParam%5BreceiverIds%5D=47180
France	Port of Dunkerque	François Lapere	Civil Engineering	http://www.dunkerque-port.fr/fr/contact-fiche/?formParam%5BreceiverIds%5D=61497
France	Port of Dunkerque	Stéphane Gavaud	Purchasing Markets	http://www.dunkerque-port.fr/fr/contact-fiche/?formParam%5BreceiverIds%5D=15635
France	Port of Dunkerque	Marie-Elizabeth Bogucki	Communication and Public Relations	http://www.dunkerque-port.fr/fr/contact-fiche/?formParam%5BreceiverIds%5D=5564
France	Port of Dunkerque	Guy Bourbonnaud	Marketing and Transport	http://www.dunkerque-port.fr/fr/contact-fiche/?formParam%5BreceiverIds%5D=5565
France	Port of Dunkerque	Yvan Gomel	Commercial prospecting	http://www.dunkerque-port.fr/fr/contact-fiche/?formParam%5BreceiverIds%5D=5566
France	Port of Dunkerque	Nicolas Forain	Logistics and Industrial Development	http://www.dunkerque-port.fr/fr/contact-fiche/?formParam%5BreceiverIds%5D=5582
France	Port of Dunkerque	Philippe Carpentier	Deputy Operations Manager	http://www.dunkerque-port.fr/fr/contact-fiche/?formParam%5BreceiverIds%5D=1687
France	Port of Dunkerque	Nicolas Godart	Nautical Access and Infrastructure	http://www.dunkerque-port.fr/fr/contact-fiche/?formParam%5BreceiverIds%5D=5749
France	Port of Dunkerque	Eric Seynave	West Port Development and Operations	http://www.dunkerque-port.fr/fr/contact-fiche/?formParam%5BreceiverIds%5D=5750
France	Port of Dunkerque	Pascal Caloone	IT and Networks	http://www.dunkerque-port.fr/fr/contact-fiche/?formParam%5BreceiverIds%5D=5586
France	Port of Dunkerque	Pierre Defrance	Management of the operation and maintenance of the port rail network	http://www.dunkerque-port.fr/fr/contact-fiche/?formParam%5BreceiverIds%5D=47181
France	Port of Marseille	General adress	General adress	https://www.marseille-port.fr/nous-contacter
France	Port of Marseille	Michael Parra	Head of Energy Transition	https://www.linkedin.com/in/michael-parra-a8559165/
France	Port of Boulogne Calais	General adress	General adress	contact@portboulognecalais.fr
France	Port of Boulogne Calais	Gaëtan Saitzek	Communication Manager	gaetan.saitzek@portboulognecalais.fr
France	Port of Boulogne Calais	Anthony Pétillon	Head of Strategy and Development	anthony.petillon@portboulognecalais.fr
France	Port of Boulogne Calais	Eric Lacointe	Senior	eric.lacointe@portboulognecalais.fr
France	Port of Boulogne Calais	Benoit Rochet	General director	benoit.rochet@portboulognecalais.fr
France	Port of Boulogne Calais	James Fontaine	Communication assistant	james.fontaine@portboulognecalais.fr
France	Port of Caen	General adress	General adress	https://www.caen.port.fr/contact/

France	Port of Cherbourg	General adress	General adress	info@cherbourgport.fr
France	Port of Cherbourg	Yannick Millet	General director	yannick.millet@cherbourgport.fr
France	Port of Cherbourg	Virginie Lepetit	Virginie Lepetit	virginie.lepetit@cherbourgport.fr
France	Port of Cherbourg	Stéphane Monnet	Deputy operations manager	stephane.monnet@cherbourgport.fr
France	Port of Cherbourg	General adress	General adress	port.exploitation@cherbourgport.fr
France	Port of Cherbourg	Stéphane Lobbedey	Manager & Developer	https://www.linkedin.com/in/st%C3%A9phane-lobbedey-5886a569/
France	Port of Lorient	General adress	General adress	port-lorient@sellor.com
France	Port of Lorient	Lionel Hériquet	Harbor Master	lionel.heriquet@sellor.com
France	Port of Lorient	Brieuc Morin	Port Director	brieuc.morin@sellor.com
France	Port of Karnéval	Florent Le Moigno	Harbor Master	florent.lemoigno@sellor.com
France	Port of Karnéval	General adress	General adress	port-kernevel@sellor.com
France	Port of Port-Louis	Leplatois Bruno	Harbor Master	bruno.leplatois@sellor.com
France	Port of Port-Louis	General adress	General adress	port-portlouis@sellor.com
France	Port of Guidel	William Vilain	Harbor Master	william.vilain@sellor.com
France	Port of Guidel	General adress	General adress	port-guidel@sellor.com
France	Port of Gâvres	General adress	General adress	port-paysdelorient@sellor.com
France	Lorient Dry port	General adress	General adress	lorient-portasec@sellor.com
France	Lorient Dry port	Julien Bothuan	Dry Port Manager	julien.bothuan@sellor.com
France	Port of Lorient The Base	General adress	General adress	port-lorientlabase@sellor.com
France	Port of Loemeur	General adress	General adress	port-lomener@sellor.com
France	Port of Hennebont	General adress	General adress	port-hennebont@sellor.com
France	Port of Nantes-St. Nazaire	Generel adress	Generel adress	https://www.nantes.port.fr/fr/contactez-nous
France	Atlantic Port of La Rochelle	Louis Billon	Ecological transition assistant	louis.billon@larochelle.port.fr
France	Atlantic Port of La Rochelle	Bernard Plisson	Strategy and Ecological Transition Director	bernard.plisson@larochelle.port.fr
France	Atlantic Port of La Rochelle	Ludivine Robin	Communication and Event Manager	ludivine.robin@larochelle.port.fr
France	Atlantic Port of La Rochelle	Isabelle Dumondin	Public Procurement Assistant	isabelle.dumondin@larochelle.port.fr
France	Atlantic Port of La Rochelle	Flavien Bertin	Project manager	flavien.bertin@larochelle.port.fr
France	Atlantic Port of La Rochelle	Betsy Dubois	Quality, Security, Environment (QSE) Coordinator	betsy.dubois@larochelle.port.fr
France	Atlantic Port of La Rochelle	Jocelyn Gras	Operations Manager	jocelyn.gras@larochelle.port.fr
France	Atlantic Port of La Rochelle	General adress	General adress	https://www.larochelle.port.fr/contacts/contact-de-l-autorite-portuaire/?vars=contacts%2Fcontact-de-l-autorite-portuaire%2F&formConfirm=1-nous-contacter
France	Port of Bordeaux	General adress	General adress	postoffice@bordeaux-port.fr
France	Port of Bordeaux	Service Environnement	Service Environnement	https://www.bordeaux-port.fr/fr/contact
France	Port of Bayonne	General adress	General adress	https://www.bayonne.port.fr/fr/contact/
France	Port of Bayonne	J. Bedere	Legal Officer	j.bedere@bayonne.cci.fr
France	Port of Bayonne	Carlota Ocampo	Industrial Ecology Officer	c.ocampo@bayonne.cci.fr
France	Port of Bayonne	Olivier Fayola	Sales Manager	o.fayola@bayonne.cci.fr
France	Port of Bayonne	Alex Bernard	Port officer	a.bernard@bayonne.cci.fr
France	Port of Bayonne	General adress	Port Operation	operation@pln-port.com
France	Port of Bayonne	General adress	Commercial	commercial@pln-port.com
France	Port of Saint Louis du Rhone	General adress	General adress	https://www.portsaintlouis.fr/contact/
France	Port of Marsielle Fos	General adress	General adress	ecoute.clients@marseille-port.fr
France	Port of Marsielle Fos	Michael Parra	Head of Energy Transition	michael.parra@marseille-port.fr
France	Port of Marsielle Fos	Daphné Lécole	Mobility advisor	daphne.lecole@marseille-port.fr
France	Port of Marsielle Fos	Fabrice Beyer	Project Manager	fabrice.beyer@marseille-port.fr
France	Port of Marsielle Fos	Amandine Luciani	Head of Environment and Operational Planning Department	amandine.luciani@marseille-port.fr
France	Port of Marsielle Fos	Frédéric Rychen	Smart Port Referent	frédéric.rychen@marseille-port.fr
France	Port of Marsielle Fos	Nicolas Bouchevreau	Port Officer	nicolas.bouchevreau@marseille-port.fr

France	Port of Marsielle Fos	Hugo Caparros	Water and waste treatment	hugo.caparros@marseille-port.fr
France	Port of Marsielle Fos	Vanessa Rigat	Business Development and International Solutions Department	vanessa.rigat@marseille-port.fr
France	Port of Marsielle Fos	Bernard Giraldi	Head of the Railway Division	bernard.giraldi@marseille-port.fr
France	Port of Marsielle Fos	Nicolas Sire	Director of Communications	nicolas.sire@marseille-port.fr
France	Port of Marsielle Fos	Philippe Bion	Director of Maritime Infrastructure and Engineering	philippe.bion@marseille-port.fr
France	Port of Marsielle Fos	Georges Oberlé	Business Development Manager	georges.oberle@marseille-port.fr
France	Port of Marsielle Fos	Fabienne Hanauer	Statistics & Indicators Manager	fabienne.hanauer@marseille-port.fr
France	Port of Marsielle Fos	Christophe Lacôte	Business Development & Intermodal Solutions	christophe.lacote@marseille-port.fr
France	Port of Marsielle Fos	Audrey Grech	PhD	audrey.grech@marseille-port.fr
France	HAROPA Port	Generel adress	Generel adress	environnement@havre-port.fr
France	HAROPA Port	Jérôme Lacroix	Environmental Officer	jerome.lacroix@havre-port.fr
France	HAROPA Port	Florian Maraine	Head of the industrial and logistics sector development department	florian.maraine@haropaport.com
France	HAROPA Port	François-Xavier Marie	Development Manager Retail / Manufactured Products	francois-xavier.marie@haropaport.com
France	HAROPA Port	Grégory Legendre	Development Manager Chemicals / Industries	gregory.legendre@haropaport.com
France	HAROPA Port	Stéphane Leydier	Reefer Development Manager / Food / Health Products	stephane.leydier@haropaport.com
France	HAROPA Port	Charlotte Bellanger	Head of Development Deep Sea / ro-ro / ferry / cruise	charlotte.bellanger@haropaport.com
France	HAROPA Port	Renaud Bouillon	Analysis and Development Officer	renaud.bouillon@haropaport.com
France	HAROPA Port	Pierre Sanlis	Environmental researcher	pierre.sanlis@haropaport.com
France	HAROPA Port	Eugénie Nagy	Operations Officer	eugenie.nagy@haropaport.com
France	HAROPA Port	Juliette Gallien	Institutional Relations Officer	juliette.gallien@haropaport.com
France	HAROPA Port	Jean Plateau	Directeur du Port de Gennevilliers	jean.plateau@haropaport.com
France	HAROPA Port	Céline Montes	Head of the Equipment Department	celine.montes@haropaport.com
France	HAROPA Port	Yann Baranger	Secretary General	yann.baranger@haropaport.com
France	HAROPA Port	Sandrine Samson	Director of the ecological transition project	sandrine.samson@haropaport.com
France	HAROPA Port	Franck Bruger	Director of Operations	franck.bruger@haropaport.com
France	HAROPA Port	Marine Paillaud	Environment and Quality Officer	marine.paillaud@haropaport.com
France	HAROPA Port	Antoine Berbain	Deputy Director General	antoine.berbain@haropaport.com
France	HAROPA Port	Chaimaa Ayad	Environmental officer	chaimaa.ayad@haropaport.com
France	HAROPA Port	Frédérique Guilbert	Head of CSR Department	frederique.guilbert@haropaport.com
France	HAROPA Port	Sébastien Moro	Industrial Environment Manager	sebastien.moro@haropaport.com
France	HAROPA Port	Thomas Leveque	Railway Development Officer	thomasleveque@haropaport.com
France	HAROPA Port	Erwan Graviou	Head of the Electricity Division	erwan.graviou@haropaport.com
France	HAROPA Port	Richard Bruny	Access and Marine Environment Works Manager	richard.bruny@haropaport.com
Germany	Hafenwirtschaftsgemeinschaft Cuxhaven e.V.	General adress	General adress	info@hafenwirtschaftsgemeinschaft.de
Germany	Zentralverband der deutschen Seehafenbetriebe e. V.	General adress	General adress	info@zds-seehaefen.de
Germany	Zentralverband der deutschen Seehafenbetriebe e. V.	Leonard Kuntscher	Policy, Analysis and Communications Advisor	leonard.kuntscher@zds-seehaefen.de

Germany	Zentralverband der deutschen Seehafenbetriebe e. V.	Christine Magdalena Lutzer	Assistant to the Chief Executive Officer	christine.lutzer@zds-seehaefen.de
Germany	Cuxport GmbH	Hans-Peter Zint	Managing Director and Senior Expert on Port Management and Port Operation	https://www.linkedin.com/in/hans-peter-zint-0162901b/
Germany	Port of Rostock	General adress	General adress	https://www.rostock-port.de/kontakt
Germany	Port of Rostock	Christian Hardt	Head of Department Corporate Communications	c.hardt@rostock-port.de
Germany	Port of Rostock	Liam Schreckenberg	Project Development Sales	l.schreckenberg@rostock-port.de
Germany	Port of Rostock	Hannes Mielke	Project Engineer Traffic Infrastructure	h.mielke@rostock-port.de
Germany	Port of Rostock	Martina Wieland	Project Development Sales	m.wieland@rostock-port.de
Germany	Port of Rostock	Tino Lüth	Business Development - Intermodal Logistics	t.lueth@rostock-port.de
Germany	Port of Rostock	Jens Scharner	Managing Director	j.scharner@rostock-port.de
Germany	Port of Rostock	Daniel Krampikowski	Head Of Sales	d.krampikowski@rostock-port.de
Germany	Port of Rostock	Goetz Strahl	Head of Logistics	g.strahl@rostock-port.de
Germany	Port of Lübeck	Natascha Blumenthal	Press and public relations	natascha.blumenthal@lhg.com
Germany	Port of Lübeck	Karsten Brüning	Terminals Division Management	karsten.bruening@lhg.com
Germany	Port of Lübeck	Inga Clasen	Marketing & Distribution Sales	inga.clasen@lhg.com
Germany	Port of Lübeck	Marcus Clasen	Terminal Skandinavienkai Operations management	marcus.clasen@lhg.com
Germany	Port of Lübeck	Ortwin Harms	Management	ortwin.harms@lhg.com
Germany	Port of Lübeck	Sebastian Jürgens	Management Speaker	sebastian.juergens@lhg.com
Germany	Port of Lübeck	Tobard Jan Klemke	Head of Department Marketing & Sales	tobard-jan.klemke@lhg.com
Germany	Port of Lübeck	Manfred Sydow	Quality management	manfred.sydow@lhg.com
Germany	Port of Hamburg	Axel Mattern	Board of Directors	mattern@hafen-hamburg.de
Germany	Port of Hamburg	Katharina Weidemann	Assistant to the Board of Directors	weidemann@hafen-hamburg.de
Germany	Port of Hamburg	Mathias Schulz	Head of Communication	schulz@hafen-hamburg.de
Germany	Port of Hamburg	Ralf Johanning	Press officer	johanning@hafen-hamburg.de
Germany	Port of Hamburg	Saskia Haßkam	Press and public relations	hasskamp@hafen-hamburg.de
Germany	Port of Hamburg	Marina Basso Michael	Regional Director Europe	basso-michael@hafen-hamburg.de
Germany	Port of Hamburg	Stefan Breitenbach	Head of Project Department	breitenbach@hafen-hamburg.de
Germany	Port of Hamburg	Adina Cailliaux	Deputy Head of Project Department	cailliaux@hafen-hamburg.de
Germany	Port of Hamburg	Johannes Betz	Project Manager	betz@hafen-hamburg.de
Germany	Port of Hamburg	John Fischer	Project Manager	fischer@hafen-hamburg.de
Germany	Port of Hamburg	Tim Reincke	Working Student	reincke@hafen-hamburg.de
Germany	Port of Hamburg	Christian Ulken	Manager Market Research, Port	ulken@hafen-hamburg.de
Germany	Port of Hamburg	Jens Schlegel	Manager Market Research, Shipping and Hinterland	schlegel@hafen-hamburg.de
Germany	Port of Hamburg	Stefan Kunze	Head of the Representative Office East Germany	kunze@hafen-hamburg.de
Germany	Port of Hamburg	Antje Göhler	Assistant of the Representative Office East Germany	goehler@hafen-hamburg.de
Germany	Port of Hamburg	Markus Heinen	Head of the Representative Office West Germany	heinen@hafen-hamburg.de
Germany	Port of Hamburg	Lena Püttschneider	Assistant of the Representative Office West Germany	Puettschneider@hafen-hamburg.de
Germany	Port of Hamburg	Karin Lengenfelder	Head of the Representative Office South Germany	lengenfelder@hafen-hamburg.de
Germany	Port of Hamburg	Tony Michaela Mark	Assistant of the Representative Office South Germany	mark@hafen-hamburg.de
Germany	Port of Hamburg	Alexander Till	Head of the Representative Office Austria	till@hafen-hamburg.de

Germany	Port of Hamburg	Nicole Bauer	Assistant of the Representative Office Austria	bauer@hafen-hamburg.de
Germany	Port of Hamburg	Vladimir Dobos	Head of the Representative Office Czech Republic and Slovakia	dobos@hafen-hamburg.de
Germany	Port of Hamburg	Petra Vlachova	Assistant of the Representative Office AustriaCzech Republic and Slovakia	vlachova@hafen-hamburg.de
Germany	Port of Hamburg	Krisztina Kovács	Head of the Representative Office Hungary	kovacs@hafen-hamburg.de
Germany	Port of Hamburg	Zsuzsanna Lőrincz	Assistant of the Representative Office Hungary	loerincz@hafen-hamburg.de
Germany	Port of Hamburg	Maciej Brzozowski	Head of the Representative Office Poland	Brzozowski@hafen-hamburg.de
Germany	Port of Hamburg	Emilia Przybyl	Assistant of the Representative Office Poland	przybyl@hafen-hamburg.de
Germany	Port of Bremerhaven	General adress	General adress	https://www.bremenports.de/kontakt
Germany	Port of Bremerhaven	Klaus Bartels	Port Strategy Management	klaus.bartels@bremenports.de
Germany	Port of Bremerhaven	Henry Behrends	Port Operations Management	henry.behrends@bremenports.de
Germany	Port of Bremerhaven	Holger Bruns	Press officer	holger.bruns@bremenports.de
Germany	Port of Bremerhaven	Anne Brüggen	Head of Environmental Planning	anne.brueggen@bremenports.de
Germany	Port of Bremerhaven	Stefan Färber	Head of Port Development and Innovation	stefan.faerber@bremenports.de
Germany	Port of Bremerhaven	Christian Hein	Port development management	christian.hein@bremenports.de
Germany	Port of Bremerhaven	Robert Howe	Managing Director	office@bremenports.de
Germany	Port of Bremerhaven	Lutz Jankowsky	Management Technical Facilities	lutz.jankowsky@bremenports.de
Germany	Port of Bremerhaven	Uwe Plewa	Port construction management	uwe.plewa@bremenports.de
Germany	Port of Bremerhaven	G. Carsten Rogge	Port railway line	carsten.rogge@bremenports.de
Germany	Port of Bremerhaven	Ronald Schwarze	Head of Marketing	ronald.schwarze@bremenports.de
Germany	Port of Bremerhaven	Lars Stemmler	Head of International Projects	lars.stemmler@bremenports.de
Germany	Port of Bremerhaven	Uwe von Bargen	Director of Environment and Sustainability Strategy	uwe.von.bargen@bremenports.de
Germany	Port of Duisburg	Marc Holstein	Project Manager Terminals	marc.holstein@duisport.de
Germany	Port of Duisburg	Christian Bach	Assistant to the CEO	christian.bach@duisport.de
Germany	Port of Duisburg	Vanessa Bohnen	Junior Project Manager	vanessa.bohnen@duisport.de
Germany	Port of Duisburg	Tomaž Daneu	Project Manager	tomaz.daneu@duisport.de
Germany	Port of Duisburg	Christian Kasel	Operation / Projects	christian.kasel@duisport.de
Germany	Port of Duisburg	Anna Xu	Operations	anna.xu@duisport.de
Germany	Port of Duisburg	Jannes Hörning	Apprenticeship as industrial clerk	jannes.hoerning@duisport.de
Germany	Port of Duisburg	Guido Martens	fleet and e-fleet management	guido.martens@duisport.de
Germany	Port of Duisburg	Robert Beer	Project Manager	robert.beer@duisport.de
Germany	Port of Duisburg	Markus Bangen	CEO	markus.bangen@duisport.de
Germany	Port of Duisburg	Christina Rubach	Project Manager - Sustainability & PMO	christina.rubach@duisport.de
Germany	Port of Duisburg	Alexander Garbar	Head of Corporate Development and Strategy	alexander.garbar@duisport.de
Germany	Port of Duisburg	Miriam Keine	Project Assistance Business Development	miriam.kiene@duisport.de
Germany	Port of Wismar	Michael Kremp	Managing Director	mkremp@hafen-wismar.de
Germany	Port of Wismar	Heidi Burke	Assistance to the management	hburke@hafen-wismar.de
Germany	Port of Wismar	Sven Siegert	Key Account Manager	ssiegert@hafen-wismar.de
Germany	Port of Wismar	Ralf Gonschorek	Sales Manager	rgonschorek@hafen-wismar.de
Germany	Port of Wismar	Claudia Schlutow	Office Managerin Marketing / Sales	cschlutow@hafen-wismar.de
Germany	Port of Wismar	Arne Leu	Manager Port Operations	aleu@hafen-wismar.de

Germany	Port of Wismar	Michael Brüggemann	Port Operations Manager	mbrueggemann@hafen-wismar.de
Germany	Port of Wismar	Manfred Hamann	Port Operations Manager	mhamann@hafen-wismar.de
Germany	Port of Wismar	Anja Deckert-Marx	Port Operations Manager	adeckert-marx@hafen-wismar.de
Germany	Port of Wismar	Udo Tegler	Port Operations Manager	utegler@hafen-wismar.de
Germany	Port of Wismar	Frank Peters	Railway Operations Manager	frank.peters@petersrail.eu
Germany	Port of Wismar	Nicole Husen	Quality, environmental and occupational health and safety management	nhusen@hafen-wismar.de
Germany	Port of Kiel	Airi Uuna	Baltic States Office	airi.uuna@ahk-balt.org
Germany	Port of Kiel	Jan Immel	Lituania Office	jan.immel@ahk-balt.org
Germany	Port of Kiel	Petra Ginta	Estonia Office	info.lv@ahk-balt.org
Germany	Port of Kiel	Dirk Claus	Managing Director	d.claus@portofkiel.com
Germany	Port of Kiel	Martina Dahm	Marketing, Sales	marketing@portofkiel.com
Germany	Port of Kiel	Eva Kampe	Marketing, Sales & Intermodal	marketing@portofkiel.com
Germany	Port of Kiel	Julia Reichel	Press officer	presse@portofkiel.com
Germany	Port of Brunsbüttel	Frank Schnabel	Management	f.schnabel@schrammgroup.de
Germany	Port of Brunsbüttel	Hans Helmut Schramm	Management	h-h.schramm@schrammgroup.de
Germany	Port of Brunsbüttel	Sven Hargens	Director Sales / Marketing	s.hargens@schrammgroup.de
Germany	Port of Brunsbüttel	Björn Hoffmann	Sales / Marketing	b.hoffmann@schrammgroup.de
Germany	Port of Brunsbüttel	Inga Carstens	Sales / Marketing	i.carstens@schrammgroup.de
Germany	Port of Brunsbüttel	Jendrik Johnson	Sales / Marketing	j.johnson@schrammgroup.de
Germany	Port of Brunsbüttel	Lars Sell	Port Captain	l.sell@schrammgroup.de
Germany	Port of Brunsbüttel	Jörg Mittag	Purchasing Manager	j.mittag@schrammgroup.de
Germany	Port of Emden	Claas Mauritz Brons	Unknown	mauritz.brons@seaport-emden.de
Germany	Port of Dortmund	Sebastian Koch	Harbour Master	koch@dortmunder-hafen.de
Germany	Port of Dortmund	Max Brandenburger	Harbour Master	brandenburger@dortmunder-hafen.de
Germany	Port of Dortmund	Bettina Brennenstuhl	Executive Board	brennenstuhl@dortmunder-hafen.de
Germany	Port of Dortmund	Pascal Frai	Press officer	frai@dortmunder-hafen.de
Germany	Port of Dortmund	Martin Nowak	Unknown	nowak@dortmunder-hafen.de
Germany	Port of Neuss Düsselsorf	Sascha Odermatt	Management	sodermatt@nd-haefen.de
Germany	Port of Neuss Düsselsorf	Andreas Hamm	Assistant to the Management	ahamm@nd-haefen.de
Germany	Port of Neuss Düsselsorf	Karin Juretzka	Railway infrastructure	kjuretzka@nd-haefen.de
Germany	Port of Neuss Düsselsorf	Alexander Voigt	Real estate management	avoigt@nd-haefen.de
Germany	Port of Neuss Düsselsorf	Thorsten Harlizius	Commercial department	tharlizius@nd-haefen.de
Germany	Port of Neuss Düsselsorf	Thomas Düttchen	Corporate Communications	tduettchen@nd-haefen.de
Germany	Port of Neuss Düsselsorf	Tobias Pannhorst	Quality management	tpannhorst@nd-haefen.de
Germany	Port of Francfort	Thomas Nowara	Harbour Master	thomas.nowara@hfm-frankfurt.de
Germany	Port of Francfort	Tanja Mollin	Harbour Master	tanja.mollin@hfm-frankfurt.de
Germany	Port of Francfort	Bianca Winkel	Port Authority	bianca.winkel@hfm-frankfurt.de
Germany	Port of Karlsruhe	Patricia Erb-Korn	Managing Director	erb-korn@rheinhafen.de
Germany	Port of Karlsruhe	Jens-Jochen Roth	Project management	roth@rheinhafen.de
Germany	Port of Karlsruhe	Nadine Bauer	Marketing and organisation	bauer@rheinhafen.de
Germany	Port of Karlsruhe	Manuela Gasthauer	Commercial department	gasthauer@rheinhafen.de
Germany	Port of Karlsruhe	Klaus Focke	Head of Operational Ship Operations	focke@rheinhafen.de
Germany	Port of Karlsruhe	Bernd Ertel	First harbour master	ertel@rheinhafen.de
Germany	Port of Kehl	General adress	General adress	info@hafen-kehl.de
Germany	Port of Magdeburg	Heiko Maly	Managing Director	gf@magdeburg-hafen.de
Germany	Port of Magdeburg	Ralf-Dieter Riehl	Commercial management	gf@magdeburg-hafen.de
Germany	Port of Magdeburg	Felix Montag	Management: Operations/Sales/Logistics	logistik@magdeburg-hafen.de
Germany	Port of Magdeburg	Boris Zufelde	Management: Railway operations	hafenbahn@magdeburg-hafen.de
Germany	Havelport Berlin	Klaus Pietack	Managing Director	k.pietack@havelport.de

Germany	Havelport Berlin	A. Böttcher	Operations Manager	a.boettcher@havelport.de
Germany	Niedersachsen Ports	General adress	General adress	wilhelmshaven@nports.de
Germany	Port of Wilhelmshaven	General adress	General adress	info@whv-wilhelmshaven.de
Germany	JadeWeserPort	General adress	General adress	info@jadeweserport.de
Greece	Hellenic Ports Association	General adress	General adress	elime@elime.gr
Greece	Port of Thessaloniki	T. Liagkos	Chairman of the BoD & Managing Director	tliagkos@thpa.gr
Greece	Port of Thessaloniki	T. Riga	Chief Commercial Officer	triga@thpa.gr
Greece	Port of Thessaloniki	Public Relations & CSR	Public Relations & Corporate Social Responsibility Department	pr@thpa.gr
Greece	Port of Thessaloniki	EU Projects	EU Projects	euprojects@thpa.gr
Greece	Port of Thessaloniki	Health, Safety & Environment Unit	Health, Safety & Environment Unit	evafaki@thpa.gr
Greece	Port of Thessaloniki	Container Terminal Division	Container Terminal Division	dosbert@thpa.gr
Greece	Port of Thessaloniki	Conventional Cargo Terminal Division	Conventional Cargo Terminal Division	abaltasis@thpa.gr
Greece	Port of Thessaloniki	Equipment & Maintenance, Cranes & High Voltage	Equipment & Maintenance Division, Cranes & High Voltage Department	kkontogiannis@thpa.gr
Greece	Port of Thessaloniki	Information & Communication Technologies	Information & Communication Technologies Department	ict@thpa.gr
Greece	Port of Thessaloniki	Athens Offices	Athens Offices	athensoffices@thpa.gr
Greece	Port of Thessaloniki	Sofia Dry Port	Sofia Dry Port	sofia@thpa.eu
Greece	Port of Volos	General adress	General adress	admin@port-volos.gr
Greece	Port of Volos	Environmental Department	Environmental Department	environment@port-volos.gr
Greece	Port of Patras	General adress	General adress	info@patrasport.gr
Greece	Port of Corinth Canal	Administration	Administration	info@aedik.gr
Greece	Port of Corinth Canal	Administration	Administration	corinth_canal@aedik.gr
Greece	Port of Corinth Canal	Marketing and Sales	Marketing and Sales	sales@aedik.gr
Greece	Port of Eleusis	General adress	General adress	grammatia@olesa.gr
Greece	Port of Keratsini	Port authority	Port authority	kera@yen.gr
Greece	Piraeus Port of Athens	Ioanna Farantaki	Strategic Development and Marketing	ioanna.farantaki@piraeus.org
Greece	Piraeus Port of Athens	Evangelos Tsantas	Yard Planner	evangelos.tsantas@piraeus.org
Greece	Piraeus Port of Athens	Christos Tsakalogiannis	Risk Management Manager	christos.tsakalogiannis@piraeus.org
Greece	Piraeus Port of Athens	Despoina Kouvatsou	Strategic Development and Marketing	despoina.kouvatsou@piraeus.org
Greece	Piraeus Port of Athens	Mike Voudigaris	Administrator	mike.voudigaris@piraeus.org
Greece	Piraeus Port of Athens	Evgenia Lagkadinou	Environmental Officer	evgenia.lagkadinou@piraeus.org
Greece	Piraeus Port of Athens	Giannis Chaskis	Strategic Development & Marketing	giannis.chaskis@piraeus.org
Greece	Piraeus Port of Athens	Lazaros Thomaidis	Chemical Engineer - Environmental Sector	lazaros.thomaidis@piraeus.org
Greece	Piraeus Port of Athens	Dimitris Spyrou	Consultant	dimitris.spyrou@piraeus.org
Greece	Piraeus Port of Athens	Giouli Kommata	Strategic Development & Marketing Manager	giouli.kommata@piraeus.org
Hungary	Port of Budapest	General adress	General adress	kikoto@mahartpassnave.hu
Ireland	Irish Maritime Development Office	General adress	General adress	General adress
Ireland	Irish Maritime Development Office	Liam Lacey	Director	liam.lacey@imdo.ie
Ireland	Irish Maritime Development Office	Kate McHugh	Personal Assistant to the Director	kate.mchugh@imdo.ie
Ireland	Irish Maritime Development Office	Edel O'Connor	Business Development Manager	edel.oconnor@imdo.ie
Ireland	Irish Maritime Development Office	Holly Faulkner	Marketing & Communications Manager	holly.faulkner@imdo.ie
Ireland	Irish Maritime Development Office	Kate Farrell	Unknown	kate.farrell@marine.ie
Ireland	Port of Drogheda	Paul Fleming	Chief Executive	paulfleming@droghedaport.ie

Ireland	Port of Drogheda	Laurence Kirwan	Harbour Master	laurencekirwan@droghedaport.ie
Ireland	Port of Drogheda	Joan Wiseman	Corporate Administrator	joanwiseman@droghedaport.ie
Ireland	Port of Drogheda	Nessa Lally	Corporate Administrator	nessalally@droghedaport.ie
Ireland	Port of Dublin	General adress	General adress	https://www.dublinport.ie/contact/
Ireland	Port of Bantry Bay	Harbour Master	Harbour Master	harbourmaster@bantrybayport.com
Ireland	Port of Shannon Foynes	Harbour Office	Harbour Office	info@sfpc.ie
Ireland	Port of Shannon Foynes	Jerry Hallissey	Business Development	jhallissey@sfpc.ie
Ireland	Port of Shannon Foynes	Engineering and Port Services	Engineering and Port Services	engineering@sfpc.ie
Ireland	Port of Shannon Foynes	Marine Operations	Marine Operations	marineops@sfpc.ie
Ireland	Port of Galway	Brian Sheridan	Unknown	brian.sheridan@theportofgalway.ie
Ireland	Port of Galway	General adress	General adress	info@theportofgalway.ie
Italy	Associazione Porti Italiani (Assoporti)	Daniele Rossi	Presidente	daniele.rossi@assoporti.it
Italy	Associazione Porti Italiani (Assoporti)	Tiziana Murgia	Press Executive	tiziana.murgia@assoporti.it
Italy	Port of Trieste	Management Secretary	Management Secretary	segreteria@trieste-marine-terminal.com
Italy	Port of Trieste	Operation Department	Operation Department	operation@trieste-marine-terminal.com
Italy	Port of Trieste	Intermodal Department	Intermodal Department	intermodal@trieste-marine-terminal.com
Italy	Port of Trieste	Sales & Marketing Department	Sales & Marketing Department	sales@trieste-marine-terminal.com
Italy	Port of Venice	Marta Citron	Environment officer	marta.citron@port.venice.it
Italy	Port of Venice	Valentina Zambetti	Project and finance manager & EU environment projects	valentina.zambetti@port.venice.it
Italy	Port of Venice	Riccardo Novello	Maritime Trade Development, Logistics and Intermodality	riccardo.novello@port.venice.it
Italy	Port of Venice	Andrea Bucella	Port Management and Business Development	andrea.bucella@port.venice.it
Italy	Port of Ravenna	General adress	General adress	port.ravenna@legalmail.it
Italy	Port of Brindisi	Harbour Master	Harbour Master	brindisi@guardiacostiera.it
Italy	Port of Brindisi	Hercules Haralambides	President	presidente@portodibrindisi.it
Italy	Port of Brindisi	Pasquale Fischetto	Infrastructure Services Department Manager	dirigenteareat@portodibrindisi.it
Italy	Port of Brindisi	Renata Sartorio	General Affairs Department	protocollo@portodibrindisi.it
Italy	Port of Taranto	Port Authority	Port Authority	authority@port.taranto.it
Italy	Port of Gioia Tauro	Port Authority	Port Authority	autoritaportuale@pec.portodigioiatauro.it
Italy	Port of Gioia Tauro	General adress	General adress	info@portodigioiatauro.it
Italy	Port of Messina	Port Authority	Port Authority	protocollo@pec.adspstretto.it
Italy	Port of Augusta	Antipollution	Antipollution	info@ternullocristoforo.it
Italy	Port of Augusta	Recovery and waste disposal	Recovery and waste disposal	info@gruppogespi.com
Italy	Port of Augusta	Recovery of sludge and liquid waste	Recovery of sludge and liquid waste and navigation waste	operations.arg@augustea.com
Italy	Port of Augusta	OPS	OPS	ops@portinfo.it
Italy	Port of Palermo	Pasqualino Monti	President	presidenza@portpalermo.it
Italy	Port of Palermo	Flora Albano	Community Policies & Project Management	flora.albano@portpalermo.it
Italy	Port of Palermo	Simona D'Amato	Community Policies & Project Management	simona.damato@portpalermo.it
Italy	Port of Palermo	Luciano Caddemi	Operational area and Safety Executive	luciano.caddemi@portpalermo.it
Italy	Port of Palermo	Fiora Sodo	Environment and Safety Office	fiora.sodo@portpalermo.it
Italy	Port of Salermo	Port Authority	Port Authority	autportsa@pec.porto.salerno.it
Italy	Port of Salermo	General adress	General adress	info@porto.salerno.it
Italy	Port of Civitavecchia Rome	General adress	General adress	ask@civitavecchiaport.org
Italy	Port of Spezia	General adress	General adress	protocollo@pec.porto.laspezia.it
Italy	Port of Genoa	Port Authority	Port Authority	info@portsofgenoa.com
Italy	Port of Genoa	General adress	General adress	segreteria.generale@pec.portsofgenoa.com

Italy	Port of Oristano	General adress	General adress	info@adspmaredisardegna.it
Italy	Port of Cagliari	General adress	General adress	amministrazione@cagliaricruiseport.it
Latvia	Port of Riga	Kaspars Tiesnesis	Head of the business	kaspars.tiesnesis@rop.lv
Latvia	Port of Riga	Inga Sabovica	Communications Specialist	inga.sabovica@rop.lv
Latvia	Port of Riga	Martins Ziemanis	Deputy Chief Executive Officer	martins.ziemanis@rop.lv
Latvia	Port of Riga	Deniss Bickovs	Project Manager	deniss.bickovs@rop.lv
Latvia	Port of Riga	Viesturs Zeps	Chairman of the Board	viesturs.zeps@rop.lv
Latvia	Port of Riga	Edgars Priede	Project Manager	edgars.priede@rop.lv
Latvia	Port of Riga	Darja Uspenska	Environment and Development Department	darja.uspenska@rop.lv
Lithuania	Port of Klaipeda	Vidmantas Paukštė	Infrastructure Director	v.paukste@port.lt
Lithuania	Port of Klaipeda	Vladas Motiejūnas	Harbor Master	v.motiejunas@port.lt
Lithuania	Port of Klaipeda	Saulius Staponkus	Head of the Public Procurement department	s.staponkus@port.lt
Lithuania	Port of Klaipeda	Arūnas Astrauskas	Head of Railway Infrastructure Department	a.astrauskas@port.lt
Lithuania	Port of Klaipeda	Algimantas Kungys	Head of the Department of Development and Environmental Protection	a.kungys@port.lt
Lithuania	Port of Klaipeda	Gedeminas Sakutis	Deputy Head of Department of Development and Environmental Protection	g.sakutis@port.lt
Lithuania	Port of Klaipeda	Kubiliūtė Aistė	Environmental Coordinator	a.kubiliute@port.lt
Lithuania	Port of Klaipeda	Razma Martynas	Environmental Protection Specialist	m.razma@port.lt
Lithuania	Port of Klaipeda	Audinga Jokūbauskienė	Head of the Economics and Strategic Planning Department	a.jokubauskiene@port.lt
Lithuania	Port of Klaipeda	Agnė Ruikienė	Deputy Head of the Department of Economics and Strategic Planning	a.ruikiene@port.lt
Lithuania	Port of Klaipeda	Džiugas Šaulys	Head of Communications and Marketing Department	d.saulys@port.lt
Lithuania	Port of Klaipeda	Dalia Gun	Head of the Commercial Group	d.gun@port.lt
Malta	Palau International Ship Registry	Răzvan Moise	Marine Consultant	https://www.linkedin.com/in/razvan-moise/
Malta	Port of Freeport	Security/Safety	Security/Safety	hogan@portfreeport.com
Malta	Port of Freeport	Missy Bevers	Administrative	bevers@portfreeport.com
Malta	Port of Freeport	Jason Miura	Business & Economic Development	miura@portfreeport.com
Malta	Port of Freeport	Al Durel	Operations	durel@portfreeport.com
Malta	Port of Valetta	Operations	General adress	info@vallettacruiseport.com
Netherlands	Port of Amsterdam	Giulia Fiori	Master Transport and SCM; Supply Chain Analysis	giulia.fiori@portofamsterdam.com
Netherlands	Port of Amsterdam	Reinoud Botman	Project Manager	reinoud.botman@portofamsterdam.com
Netherlands	Port of Amsterdam	Kaz de Bruijn	Strategic Advisor	kaz.debruijn@portofamsterdam.com
Netherlands	Port of Amsterdam	Eric Warners	Energy transition	eric.warners@portofamsterdam.com
Netherlands	Port of Amsterdam	Ellen Van Der Veer	Senior Strategic Advisor Energy Transition	ellen.vanderveer@portofamsterdam.com
Netherlands	Port of Amsterdam	Jan Egbertsen	Innovation Manager	jan.egbertsen@portofamsterdam.com
Netherlands	Port of Amsterdam	Ruben Vrijhoef	Professor, researcher, consultant, entrepreneur	ruben.vrijhoef@portofamsterdam.com
Netherlands	Port of Amsterdam	Mark Hoolwerf	Deputy Director	mark.hoolwerf@portofamsterdam.com
Netherlands	Port of Amsterdam	Niels Broekhoff	Projectmanager Infrastructure	niels.broekhoff@portofamsterdam.com
Netherlands	Port of Amsterdam	Imco Dieke	Operations Manager	imco.dieke@portofamsterdam.com
Netherlands	Port of Amsterdam	Allard Klinkers	Commercial Manager Offshore & Logistics	allard.klinkers@portofamsterdam.com
Netherlands	Port of Amsterdam	Rob Beets	Port Officer	rob.beets@portofamsterdam.com
Netherlands	Port of Amsterdam	Jaap Bleumink	Agile Transformation	jaap.bleumink@portofamsterdam.com
Netherlands	Port of Amsterdam	Joost Zuidema	Innovation Lead	joost.zuidema@portofamsterdam.com

Netherlands	Port of Amsterdam	Jos Timans	Port Officer	jos.timans@portofamsterdam.com
Netherlands	Port of Amsterdam	Marc Oomen	Unknown	marc.oomen@portofamsterdam.com
Netherlands	Port of Scheveningen	Anita Verwoest	Project Director	anita.verwoest@denhaag.nl
Netherlands	Port of Scheveningen	Cees Duvekot	Harbour master	havenbedrijf@denhaag.nl
Netherlands	Port of Dordrecht	Bram Voncken	Area manager	https://www.portofrotterdam.com/en/form/standard-contact?nid=1273
Netherlands	Port of Moerdijk	General address	General address	https://www.portofmoerdijk.nl/en/contact/
Netherlands	Port of Moerdijk	Location and commerce	Location and commerce	commercie@portofmoerdijk.nl
Netherlands	Port of Moerdijk	Port service	Port service	havendienst@portofmoerdijk.nl
Netherlands	Port of Moerdijk	Administration	Administration	administratie@portofmoerdijk.nl
Netherlands	Port of Zeeland	General adress	General adress	port@zeelandseaports.com
Netherlands	Port of Rotterdam	Maaike Grevelink	Press Officer	https://www.portofrotterdam.com/en/form/standard-contact?nid=2854
Netherlands	Port of Rotterdam	Tie Schellekens	Spokesperson between the city, port and environmental issues	https://www.portofrotterdam.com/en/form/standard-contact?nid=452
Netherlands	Port of Rotterdam	Sjaak Poppe	Spokesperson for CEO Allard Castelein regarding energy transition	https://www.portofrotterdam.com/en/form/standard-contact?nid=1327
Norway	Oslo Harbour Authority	Ingvar M. Mathisen	Director of the Port	ingvar.m.mathisen@oslohavn.no
Norway	Norske Havner	Kjell-Olav Gammelsæter	Director	kjell-olav.gammelsater@havn.no
Norway	Norske Havner	Arnt-Einar Litsheim	Technical Director	arnt-einar.litsheim@havn.no
Norway	Norske Havner	Bernt C. Lind-Aaby	Head of Division	bernt.aaby@havn.no
Poland	Port of Szczecin Swinoujscie	Beata Płatkowska	Environment Protection	beata.platkowska@port.szczecin.pl
Poland	Port of Szczecin Swinoujscie	Environment Protection	Environment Protection	environment@port.szczecin.pl
Poland	Port of Szczecin Swinoujscie	Emil Cyraniak	Laboratory of Work Environment Research	emil.cyraniak@port.szczecin.pl
Poland	Port of Szczecin Swinoujscie	Anna Dudra	Marketing	anna.dudra@port.szczecin.pl
Poland	Port of Szczecin Swinoujscie	Monika Woźniak-Lewandowska	Press	monika.wozniak-lewandowska@port.szczecin.pl
Poland	Port of Szczecin Swinoujscie	Monika Gadomska	Public procurement	monika.gadomska@port.szczecin.pl
Poland	Port of Szczecin Swinoujscie	Krzysztof Kwiecień	Infrastructure	krzysztof.kwiecien@port.szczecin.pl
Poland	Port of Szczecin Swinoujscie	Piotr Krahel	Development of Ports, EU funds and research and development projects	piotr.krahel@port.szczecin.pl
Poland	Port of Gdynia	Port Authority	Port Authority	info@port.gdynia.pl
Poland	Port of Gdynia	Baltic Bulk Terminal Ltd.	Baltic Bulk Terminal Ltd.	bbm@bbm.gdynia.pl
Poland	Port of Gdynia	Baltic Container Terminal Ltd.	Baltic Container Terminal Ltd.	bct@bct.gdynia.pl
Poland	Port of Gdynia	OT Port Gdynia Ltd.	OT Port Gdynia Ltd.	info@otpg.pl
Poland	Port of Gdynia	Baltic Grain Terminal Ltd.	Baltic Grain Terminal Ltd.	sekretariat@btz.gdynia.pl
Poland	Port of Gdynia	Gdynia Container Terminal	Gdynia Container Terminal	handlowy@gct.pl
Poland	Port of Gdynia	HES Gdynia Bulk Terminal Sp. z o.o.	HES Gdynia Bulk Terminal Sp. z o.o.	gdynia@hesinternational.eu
Poland	Port of Gdynia	Koole Tankstorage Gdynia Ltd.	Koole Tankstorage Gdynia Ltd.	m.kruszynski@koole.com
Poland	Port of Gdynia	Aalborg Portland Polska Ltd.	Aalborg Portland Polska Ltd.	office@alpetrol.pl
Poland	Port of Gdynia	Morski Terminal LPG	Morski Terminal LPG	terminal.gdynia@alpetrol.pl
Poland	Port of Gdynia	Speed Ltd.	Speed Ltd.	speed@speed.gdynia.pl
Poland	Port of Gdansk	Kamil Tarczewski	Vice President Infrastructure	kamil.tarczewski@portgdansk.pl
Poland	Port of Gdansk	Aleksandra Dubiela	EU Funds Specialist	aleksandra.dubiela@portgdansk.pl
Poland	Port of Gdansk	Lech Paszkowski	Director of Development and Investment at the Maritime Board Company	lech.paszkowski@portgdansk.pl
Poland	Port of Gdansk	Piotr Bura	Head of the Marketing and Communications Department	piotr.bura@portgdansk.pl
Poland	Port of Gdansk	Bartosz Bloch	Manager Business Development	bartosz.bloch@portgdansk.pl
Poland	Port of Gdansk	Brigitte Cheong	Business Developer	brigitte.cheong@portgdansk.pl
Poland	Port of Gdansk	Anna Drozd	Spokesperson	anna.drozd@portgdansk.pl

Portugal	Associação dos Portos de Portugal	General adress	General adress	geral@portosdeportugal.pt
Portugal	Port of Leixoes	Diogo Vaz Marecos	Board of Directors	diogo.marecos@yilport.com
Portugal	Port of Leixoes	Nuno David Silva	General Manager, Administrative Department, Commercial Department	nuno.david@yilport.com
Portugal	Port of Leixoes	Susana Boloto	Board Secretary	susana.boloto@yilport.com
Portugal	Port of Leixoes	Ismael Maia	HSE Specialist	ismael.maia@yilport.com
Portugal	Port of Leixoes	Rodrigo Pedrosa	HSE Specialist	rodrigo.pedrosa@yilport.com
Portugal	Port of Leixoes	Filipe Santos	Operations Department	filipe.santos@yilport.com
Portugal	Port of Leixoes	Eulália Castro	Operations Department	eulalia.carvalho@yilport.com
Portugal	Port of Leixoes	Fernando Machado	Operations Department	fernando.machado@yilport.com
Portugal	Port of Leixoes	Fernando Pinto	Operations Department	fernando.pinto@yilport.com
Portugal	Port of Aveiro	Carla Macedo	Business Development	carla.macedo@portodeaveiro.pt
Portugal	Port of Aveiro	Rolanda Fontes	Marketing technology	rolanda.fontes@portodeaveiro.pt
Portugal	Port of Aveiro	Sofia Ventura	Strategy Office	sofia.ventura@portodeaveiro.pt
Portugal	Port of Aveiro	Sérgio Dias	Port Administration	sergio.dias@portodeaveiro.pt
Portugal	Port of Aveiro	Pedro Pereira	Management Control	pedro.pereira@portodeaveiro.pt
Portugal	Port of Figueira Da Foz	Joaquim Sotto Maior	Port Coordinator	joaquim.sotto@portofigueiradafoz.pt
Portugal	Port of Figueira Da Foz	General adress	General adress	geral.apff@portofigueiradafoz.pt
Portugal	Port of Lisbon	Fernanda Pereira da Silva	Media and events	comunicacao@portodelisboa.pt
Portugal	Port of Lisbon	Carlos Correia	Board Chairman	ccorreia@portodelisboa.pt
Portugal	Port of Lisbon	Carla Ribeiro	Member Board of directors	cribeiro@portodelisboa.pt
Portugal	Port of Lisbon	Ricardo Roque	Member Board of directors	rroque@portodelisboa.pt
Portugal	Port of Lisbon	José Rocha	Infrastructures, environment and construction works	iao@portodelisboa.pt
Portugal	Port of Lisbon	Manuela Patrício	Port Terminals and Logistics	tp@portodelisboa.pt
Portugal	Port of Lisbon	Sandra Viegas	Public procurement	contratacaopublica@portodelisboa.pt
Portugal	Port of Setubal	General adress	General adress	geral@portodesetubal.pt
Portugal	Port of Portimao	General adress	General adress	info@marinadeportimao.com.pt
Portugal	Port of Sines	Joana Góis	Transport and Logistics Management	joana.gois@apsinesalgarve.pt
Portugal	Port of Sines	Eduardo Moutinho	Civil Engineering - Land Sort Manager	eduardo.moutinho@apsinesalgarve.pt
Portugal	Port of Sines	Cláudio Pinto	Innovation and Information Systems Director	claudio.pinto@apsinesalgarve.pt
Portugal	Port of Sines	Rodrigo Pinela	Safety, Security and Environment	rodrigo.pinela@apsinesalgarve.pt
Portugal	Port of Sines	Paulo Silva	Economista	paulo.silva@apsinesalgarve.pt
Portugal	Port of Sines	Helena Silva	Director	helena.silva@apsinesalgarve.pt
Portugal	Port of Sines	Gonçalo Pereira	Quality, Environment and Safety Department	goncalo.pereira@apsinesalgarve.pt
Romania	Administrația Porturilor Maritime S.A.	General adress	General adress	apmc@constantza-port.ro
Romania	Port of Constantza	Environment Office	Environment Office	apmc_mediu@constantza-port.ro
Romania	Port of Constantza	Marketing	Marketing	apmc_marketing@constantza-port.ro
Romania	Port of Constantza	Port Operations Service	Port Operations Service	sep@constantza-port.ro
Romania	Port of Constantza	Press relations	Press relations	apmc_presa@constantza-port.ro
Slovakia	Port of Bratislava	General News	General News	vpas@vpas.sk
Slovakia	Port of Bratislava	Property	Property	sprava@vpas.sk
Slovakia	Port of Bratislava	Project Management	Project Management	rozvoj@vpas.sk
Slovakia	Port of Bratislava	Media	Media	hovorca@vpas.sk
Slovenia	Port of Kopper	General adress	General adress	portkoper@luka-kp.si
Slovenia	Port of Varna	General adress	General adress	headoffice@port-varna.bg
Spain	Puertos del Estado	Emilio Gómez Fernández	Press Officer	egomez@puertos.es
Spain	Puertos del Estado	Rocío Ramos Díez	Head of Infrastructure	rramos@puertos.es
Spain	Puertos del Estado	Alvaro Rodriguez Dapena	President	arodrieguez@puertos.es

Spain	Puertos del Estado	Jaime Luezas	Head of Port Community Services Area	jluezas@puertos.es
Spain	Puertos del Estado	Cristina Blas Miranda	Marketing & Ministry of Transport, Mobility and Urban Agenda	cblas@puertos.es
Spain	Puertos del Estado	Ana María García	Chief Advisor to the President	amgarcia@puertos.es
Spain	Puertos del Estado	Begoña Pérez Gómez	Head of Harbour Oceanography Department	bego@puertos.es
Spain	Puertos del Estado	María Jesús Calvo	Economist	mjcalvo@puertos.es
Spain	Puertos del Estado	Beatriz Zafra Sánchez	Responsable de Servicios Portuarios	bzafra@puertos.es
Spain	Puertos del Estado	Armando López Rodríguez	PhD	arodriguez@puertos.es
Spain	Puertos del Estado	José Llorca	Head of Innovation	jllorca@puertos.es
Spain	Puertos del Estado	Enrique Tortosa	Head of Port Services Area	etortosa@puertos.es
Spain	Puertos del Estado	Pilar Parra Serrano	Corporate Director	pparra@puertos.es
Spain	Puertos del Estado	Jaime Seijas	Working Group Coordinator	jseijas@puertos.es
Spain	Puertos del Estado	Manuel Arana Burgos	Director of Planning and Development	m.arana@puertos.es
Spain	Port of Santander	General adress	General adress	info@puertosantander.es
Spain	Port of Aviles	General adress	General adress	info@puertoaviles.com
Spain	Port of Ferrol	General adress	General adress	ferrol@apfsc.es
Spain	Port of Ferrol	Debora Acea Escrich	Sustainability Manager	dacea@apfsc.es
Spain	Port of A Coruna	Irene Souto Blázquez	Port Development and Commercial Manager	isouto@puertocoruna.com
Spain	Port of A Coruna	Manuel Fuertes Carballeira	Secretary General	mfuertes@puertocoruna.com
Spain	Port of A Coruna	Martin Fernandez Prado	President	mfernandez@puertocoruna.com
Spain	Port of A Coruna	José Luis Suárez Doval	Port Operations Manager and IT Development Manager	jsuarez@puertocoruna.com
Spain	Port of A Coruna	Samanta García-Carro de la Colina	Head of Commercial Unit	sgarcia@puertocoruna.com
Spain	Port of A Coruna	Andrés Guerra	Head of Sustainability Department	aguerra@puertocoruna.com
Spain	Port of A Coruna	Ramón Castro González	Head of Communication and External Relations	rcastro@puertocoruna.com
Spain	Port of A Coruna	Sebastián García Orro	Environment Technician	sgarcia@puertocoruna.com
Spain	Port of Villagarcia	General adress	General adress	sac@portovilagarcia.es
Spain	Port of Vigo	General adress	General adress	apvigo@apvigo.es
Spain	Port of Huelva	General adress	General adress	aph@puertohuelva.com
Spain	Port of La Carraca	General adress	General adress	orpflota@fn.mde.es
Spain	Port of Cadiz	General adress	General adress	cadiz@papba@apba.esuertocadiz.com
Spain	Port of Algeciras Bay	General adress	General adress	apba@apba.es
Spain	Port of Malaga	General adress	General adress	sac@puertomalaga.com
Spain	Port of Almeria	General adress	General adress	atencionalpublico@apalmeria.com
Spain	Port of Almeria	General adress	General adress	presidencia@apalmeria.com
Spain	Port of Almeria	Generl Secretary	Generl Secretary	jm-sanchez@apalmeria.com
Spain	Port of Almeria	Port Services	Port Services	serviciosportuarios@apalmeria.com
Spain	Port of Cartagena	General adress	General adress	cartagena@apc.es
Spain	Port of Alicante	General adress	General adress	secretaria.apa@puertoalicante.com
Spain	Port of Alicante	Environement	Environement	https://www.puertoalicante.com/medioambiente/contacto-medioambiente/
Spain	Port of Alicante	Sustainable innovation	Sustainable innovation	innovacion@puertoalicante.com
Sweden	Ports of Sweden	General adress 1	General adress 1	sjofartsverket@sjofartsverket.se
Sweden	Ports of Sweden	General adress 2	General adress 2	info@sjofartsverket.se
Sweden	Port of Gavle	Linda Astner	Head of sustainability	linda.astner@gavlehamn.se
Sweden	Port of Gavle	Henrik Rosengren	Environmental Engineer	henrik.rosengren@gavlehamn.se
Sweden	Port of Gavle	Torbjörn Henriksson	Project Manager	torbjorn.henriksson@gavlehamn.se
Sweden	Port of Gavle	Ingemar Johansson	Operations manager, Energy Port	ingemar.johansson@gavlehamn.se

Sweden	Port of Gavle	Daniel Karlsson	Head of infrastructure	daniel.karlsson@gavlehamn.se
Sweden	Port of Gavle	Natalie Gerami	Head of Marketing and Business development	natalie.gerami_wallner@gavlehamn.se
Sweden	Port of Gavle	Fredrik Svanbom	Chief Executive Officer	fredrik.svanbom@gavlehamn.se
Sweden	Port of Stockholm	Charlotta Solerud	Environmental Department	charlotta.solerud@portsofstockholm.com
Sweden	Port of Stockholm	Nicklas Ebersson	Container Department	nicklas.ebersson@portsofstockholm.com
Sweden	Port of Stockholm	Per Rydberg	Procurement	per.rydberg@portsofstockholm.com
Sweden	Port of Stockholm	General adress	General adress	info@portsofstockholm.com
Sweden	Port of Norrkoping	Jenny Ericson	Human Resources and Sustainability Manager	jenny.ericson@nhs.se
Sweden	Port of Norrkoping	Eva Egertz	Environmental & Quality Manager	eva.egertz@nhs.se
Sweden	Port of Norrkoping	Linda Jonsson Melin	Communications Manager	linda.jonsson.melin@nhs.se
Sweden	Port of Norrkoping	Hans Karlsson	Operations Manager	hans.karlsson@nhs.se
Sweden	Port of Norrkoping	Joakim Pettersson	Harbour Master	joakim.pettersson@nhs.se
Sweden	Port of Norrkoping	Eva-Lotte Wondollek	Head of Project Department	eva-lotte.wondollek@nhs.se
Sweden	Port of Norrkoping	Eric Gustavsson	Project Manager, port development	eric.gustavsson@nhs.se
Sweden	Port of Norrkoping	Magnus Grimhed	Marketing & Sales Manager	magnus.grimhed@nhs.se
Sweden	Port of Norrkoping	Henrik Åkerström	CEO	henrik.akerstrom@nhs.se
Sweden	Port of Karlskrona	Anna Lindblad	Head of Communication	anna.lindblad@karlskrona.se
Sweden	Port of Karlskrona	General adress	General adress	karlskrona.kommun@karlskrona.se
Sweden	Port of Ahus	Roberto Zigante	Head of Environmental and Security	roberto.zigante@ahushamn.se
Sweden	Port of Ahus	Fredrik Åsare	CEO	fredrik.asare@ahushamn.se
Sweden	Port of Ahus	Stefan Hallström	Production manager	stefan.hallstrom@ahushamn.se
Sweden	Port of Helsingborg	Communication	Communication	communication@port.helsingborg.se
Sweden	Port of Helsingborg	Conny Rosén	Operation Manager	conny.rosen@port.helsingborg.se
Sweden	Port of Helsingborg	Pär Kraft	Logistics Projects	par.kraft@port.helsingborg.se
Sweden	Port of Helsingborg	Bart Steijaert	Managing Director	bart.steijaert@port.helsingborg.se
Sweden	Port of Helsingborg	Maria Hägg	Marketing Director & Chairwoman of the board	maria.hagg@port.helsingborg.se
Sweden	Port of Falkenbergs	Peter Sevholt	MANAGING DIRECTOR	peter.sevholt@falkenbergs-terminal.se
Sweden	Port of Falkenbergs	Ulf Johansson	Forwarding	ulf.johansson@falkenbergs-terminal.se
Sweden	Port of Falkenbergs	Sandra Wetterlöv	Forwarding	sandra.wetterlov@falkenbergs-terminal.se
Sweden	Port of Goteborg	Edvard Molitor	Head of Sustainability	edvard.molitor@portgot.se
Sweden	Port of Goteborg	Åsa Kärnebro	Harbour Master	harbourmasteroffice@portgot.se
Sweden	Port of Goteborg	Cecilia Lööf	Head of Marketing & Communications	cecilia.loof@portgot.se
Sweden	Port of Goteborg	Martin Adatec	Sustainability agent	martin.adeteg@portgot.se
Sweden	Port of Goteborg	Elvir Dzanic	CEO	elvir.dzanic@portgot.se
Sweden	Port of Goteborg	Malin Collin	Vice President Business Strategy, Deputy CEO	malin.collin@portgot.se
Sweden	Port of Wallhamn	General adress	General adress	https://wallhamn.com/en/

Annex 3: Multilingual contact sheet for questionnaire participation

English

Subject: "Green Ports" - support request

Dear Madam or Sir,

I am Marielle Sorge, currently in my last semester of studies for my binational double Master's degree in "Supply Chain Management" at ESCE Paris and in "International Consulting" at HWR Berlin.

As part of my Master's thesis on "Green Ports", I am currently conducting a survey on emission reduction measures for the decarbonisation of ports. You can access the survey via the following link: https://www.q-set.de/q-set.php?sCode=SZYKJTSASZNQ

I would be very grateful if you could take about 15 minutes to answer the questions by 31st May 2023 with your expert knowledge. Do not hesitate to forward the survey to other contacts in the port industry, that would be a great help. Since the European port environment is a small world, it is fundamental to get as many answers as possible from different people's point of view, to ensure reliability of the results.

I am happy to share the results of the survey with you in the aftermath.

Thank you in advance for your valuable support!

Kind regards,

Marielle Sorge

French

Sujet : Les "ports verts" - demande de soutien

Madame, Monsieur,

Je suis Marielle Sorge, actuellement dans mon dernier semestre d'études pour mon double Master binational en "Supply Chain Management" à l'ESCE Paris et en "International Consulting" à la HWR Berlin.

Dans le cadre de mon mémoire de fin d'études sur les "Ports Verts", je mène actuellement une enquête sur les mesures de réduction des émissions pour la décarbonation des ports. Vous pouvez accéder à l'enquête via le lien suivant : https://www.q-set.de/q-set.php?sCode=SZYKJTSASZNQ

Je vous serais très reconnaissante si vous pouviez prendre environ 15 minutes pour répondre aux questions d'ici le 31 mai 2023 en faisant appel à vos connaissances d'expert. N'hésitez pas à transmettre l'enquête à d'autres contacts dans l'industrie portuaire, ce serait d'une grande aide. Comme l'environnement portuaire européen est un petit monde, il est essentiel d'obtenir le plus grand nombre de réponses possibles du point de vue de différentes personnes, afin de garantir la fiabilité des résultats.

Je serai par la suite heureuse de partager les résultats de l'enquête avec vous.

Je vous remercie d'avance pour votre précieux soutien !

Bien cordialement,

Marielle Sorge

German

Betreff: „Grüne Häfen“ - Bitte um Unterstützung

Sehr geehrte Damen und Herren,

Ich bin Marielle Sorge, aktuell in meinem letzten Studiensemester für meinen doppelten, binationalen Masterabschluss in „Supply Chain Management“ an der ESCE Paris und in „International Consulting“ an der HWR Berlin.

Im Rahmen meiner Masterarbeit (auf Englisch) zum Thema „Grüne Häfen“ führe ich aktuell eine Umfrage zu Emissionsminderungsmaßnahmen für die Dekarbonisierung von Häfen durch. Zur Umfrage kommen Sie über folgenden Link: https://www.q-set.de/q-set.php?sCode=SZYKJTSASZNQ

Ich wäre Ihnen sehr dankbar, wenn Sie sich bis zum 31. Mai 2023 etwa 15 Minuten Zeit nehmen würden, um die Fragen zu beantworten. Gerne können Sie die Umfrage an weitere Kontakte aus dem Hafenbereich weiterleiten, das wäre eine große Hilfe. Da die Welt der europäischen Häfen klein ist, ist es von grundlegender Bedeutung, so viele Antworten wie möglich aus den verschiedenen Blickwinkeln zu erhalten, um die Zuverlässigkeit der Ergebnisse zu gewährleisten.

Gerne kann ich Ihnen die Ergebnisse der Umfrage im Nachgang zukommen lassen.

Ich bedanke mich im Voraus für Ihre wertvolle Unterstützung!

Mit freundlichen Grüßen,

Marielle Sorge

Spanish

Asunto: "Puertos Verdes" - solicitud de ayuda

Estimada señora, estimado señor,

Soy Marielle Sorge, actualmente cursando el último semestre de mi doble máster binacional en "Supply Chain Management" en la ESCE París y en "International Consulting" en la HWR Berlín.

Como parte de mi tesis de máster sobre "Puertos Verdes" (en inglés), estoy actualmente realizando una encuesta sobre medidas de reducción de emisiones para la descarbonización de los puertos. Puede acceder a la encuesta a través del siguiente enlace: https://www.q-set.de/q-set.php?sCode=SZYKJTSASZNQ

Le estaría muy agradecida si pudiera dedicar unos 15 minutos a responder a las preguntas antes del 31 de mayo de 2023 con sus conocimientos especializados. No dude en reenviar la encuesta a otros contactos del sector portuario, sería de gran ayuda. Dado que el entorno portuario europeo es un mundo pequeño, es fundamental obtener el mayor número posible de respuestas desde el punto de vista de diferentes personas, para garantizar la fiabilidad de los resultados.

Me complacerá compartir con ustedes los resultados de la encuesta a continuación.

Gracias de antemano por su valioso apoyo.

Un cordial saludo,

Marielle Sorge

Portuguese

Assunto: "Portos Verdes" - pedido de assistência

Caras senhoras e senhores,

Chamo-me Marielle Sorge e estou actualmente no último semestre do meu duplo mestrado binacional em "Supply Chain Management" na ESCE Paris e em "International Consulting" na HWR Berlin.

Como parte da minha tese de mestrado sobre "Portos Verdes", estou actualmente a realizar um inquérito sobre medidas de redução de emissões para a descarbonização dos portos. Pode aceder ao inquérito através da seguinte ligação: https://www.q-set.de/q-set.php?sCode=SZYKJTSASZNQ

Ficaria muito grato se pudesse dispensar 15 minutos para responder às perguntas antes de 31 de Maio de 2023 com a sua experiência. Não hesite em enviar o inquérito a outros contactos no sector marítimo, pois seria de grande ajuda. Como o ambiente portuário europeu é um mundo pequeno, é essencial obter o maior número possível de respostas de diferentes pontos de vista, para garantir a fiabilidade dos resultados.

Terei todo o prazer em partilhar convosco os resultados do inquérito.

Agradeço desde já o vosso valioso apoio.

Com os melhores cumprimentos,

Marielle Sorge

*This message was translated online from English

Italian

Oggetto: "Porti verdi" - richiesta di supporto

Gentile Signora o Signore,

sono Marielle Sorge, attualmente all'ultimo semestre di studi per il mio doppio master binazionale in "Supply Chain Management" presso l'ESCE di Parigi e in "International Consulting" presso l'HWR di Berlino.

Nell'ambito della mia tesi di Master su "Green Ports", sto conducendo un'indagine sulle misure di riduzione delle emissioni per la decarbonizzazione dei porti. È possibile accedere al sondaggio tramite il seguente link: https://www.q-set.de/q-set.php?sCode=SZYKJTSASZNQ

Vi sarei molto grato se poteste dedicare circa 15 minuti per rispondere alle domande entro il 31 maggio 2023 con le vostre conoscenze specialistiche. Non esitate a inoltrare il sondaggio ad altri contatti nell'industria portuale, sarebbe di grande aiuto. Poiché l'ambiente portuale europeo è un mondo piccolo, è fondamentale ottenere il maggior numero possibile di risposte dal punto di vista di persone diverse, per garantire l'affidabilità dei risultati.

Sarò lieto di condividere con voi i risultati dell'indagine in seguito.

Vi ringrazio in anticipo per il vostro prezioso supporto!

Cordiali saluti,

Marielle Sorge

*This message was translated online from English

Romanian

Subiect: "Porturi verzi" - cerere de sprijin

Stimată doamnă sau domnule,

Mă numesc Marielle Sorge și sunt în prezent în ultimul semestru de studii pentru un dublu masterat binațional în "Supply Chain Management" la ESCE Paris și în "International Consulting" la HWR Berlin.

În cadrul tezei mele de masterat privind "Porturile verzi", realizez în prezent un studiu privind măsurile de reducere a emisiilor pentru decarbonizarea porturilor. Puteți accesa sondajul prin intermediul următorului link: https://www.q-set.de/q-set.php?sCode=SZYKJTSASZNQ

V-aș fi foarte recunoscător dacă ați putea să vă acordați aproximativ 15 minute pentru a răspunde la întrebări până la 31 mai 2023 cu cunoștințele dumneavoastră de specialitate. Nu ezitați să transmiteți sondajul și altor contacte din industria portuară, acest lucru ar fi de mare ajutor. Deoarece mediul portuar european este o lume mică, este fundamental să obținem cât mai multe răspunsuri din punctul de vedere al diferitelor persoane, pentru a asigura fiabilitatea rezultatelor.

Sunt bucuros să vă împărtășesc rezultatele sondajului în perioada următoare.

Vă mulțumesc anticipat pentru sprijinul dumneavoastră valoros!

Cu stimă,

Marielle Sorge

*This message was translated online from English

Lithauan

Tema: "Žalieji uostai" - paramos užklausa

Gerbiama ponia arba ponas,

Esu Marielle Sorge, šiuo metu paskutinį semestrą studijuoju ESCE Paryžiuje ir HWR Berlyne dvigubą magistro laipsnį "Tiekimo grandinės valdymas" ir "Tarptautinės konsultacijos".

Šiuo metu rašydama magistro darbą tema "Žalieji uostai" atlieku apklausą apie išmetamųjų teršalų mažinimo priemones, skirtas uostų anglies dioksido išmetimo mažinimui. Su apklausa galite susipažinti naudodamiesi šia nuoroda: https://www.q-set.de/q-set.php?sCode=SZYKJTSASZNQ

Būčiau labai dėkingas, jei iki 2023 m. gegužės 31 d., remdamiesi savo ekspertinėmis žiniomis, skirtumėte apie 15 minučių ir atsakytumėte į klausimus. Nedvejodami persiųskite šią apklausą kitiems jūrininkystės sektoriaus atstovams, tai būtų didelė pagalba. Kadangi Europos uostų aplinka yra mažas pasaulis, siekiant užtikrinti rezultatų patikimumą, labai svarbu gauti kuo daugiau atsakymų iš skirtingų žmonių požiūrio taškų.

Džiaugiuosi, kad apklausos rezultatais galėsiu pasidalyti su jumis vėliau.

Iš anksto dėkoju už vertingą paramą!

Su maloniais linkėjimais,

Marielle Sorge

*This message was translated online from English

Latvian

Temats: "Green Ports" - atbalsta pieprasījums

Cienījamā kundze vai kungs,

Es esmu Marielle Sorge, pašlaik pēdējā studiju semestrī studēju dubultā maģistra grāda iegūšanai "Piegādes ķēdes vadībā" ESCE Parīzē un "Starptautiskajās konsultācijās" HWR Berlīnē.

Savā maģistra darbā par tēmu "Zaļās ostas" es pašlaik veicu pētījumu par emisiju samazināšanas pasākumiem ostu dekarbonizācijai. Apsekojumam var piekļūt, izmantojot šādu saiti: https://www.q-set.de/q-set.php?sCode=SZYKJTSASZNQ

Būšu ļoti pateicīgs, ja veltīsiet aptuveni 15 minūtes, lai līdz 2023. gada 31. maijam atbildētu uz jautājumiem, izmantojot savas ekspertu zināšanas. Nevilcinieties pārsūtīt aptauju citiem jūrniecības nozares pārstāvjiem, tas būtu liels atbalsts. Tā kā Eiropas ostu vide ir maza pasaule, ir būtiski iegūt pēc iespējas vairāk atbilžu no dažādu cilvēku viedokļa, lai nodrošinātu rezultātu ticamību.

Es labprāt dalīšos ar aptaujas rezultātiem ar jums pēc tam.

Jau iepriekš pateicos jums par vērtīgo atbalstu!

Ar cieņu,

Marielle Sorge

*This message was translated online from English

Polish

Przedmiot : "Zielone porty" - prośba o wsparcie

Szanowna Pani lub Szanowny Panie,

Nazywam się Marielle Sorge i obecnie jestem na ostatnim semestrze studiów magisterskich na kierunku "Zarządzanie łańcuchem dostaw" w ESCE w Paryżu oraz "International Consulting" w HWR w Berlinie.

W ramach mojej pracy magisterskiej na temat "Zielonych portów" przeprowadzam obecnie ankietę na temat środków redukcji emisji w celu dekarbonizacji portów. Dostęp do ankiety można uzyskać pod następującym linkiem: https://www.q-set.de/q-set.php?sCode=SZYKJTSASZNQ

Byłbym bardzo wdzięczny, gdybyś mógł poświęcić około 15 minut na udzielenie odpowiedzi na pytania do 31 maja 2023 r., korzystając ze swojej wiedzy eksperckiej. Nie wahaj się przekazać ankiety innym kontaktom w branży morskiej, byłoby to bardzo pomocne. Ponieważ europejskie środowisko portowe jest małym światem, fundamentalne znaczenie ma uzyskanie jak największej liczby odpowiedzi z punktu widzenia różnych osób, aby zapewnić wiarygodność wyników.

Z przyjemnością podzielę się z Państwem wynikami ankiety w późniejszym terminie.

Z góry dziękuję za cenne wsparcie!

Pozdrawiam serdecznie,

Marielle Sorge

*This message was translated online from English

Estonian

Teema: "Rohelised sadamad" – toetusetaotlus

Lugupeetud proua või härra,

Ma olen Marielle Sorge, kes praegu õpib viimasel semestril oma kahepoolse magistrikraadi "Tarneahela juhtimine" ESCE Pariisis ja "Rahvusvaheline nõustamine" HWR Berliinis.

Oma magistritöö "Rohelised sadamad" raames viin praegu läbi uuringut heitkoguste vähendamise meetmete kohta sadamate süsinikdioksiidiheite vähendamiseks. Uuringuga saab tutvuda järgmise lingi kaudu: https://www.q-set.de/q-set.php?sCode=SZYKJTSASZNQ

Oleksin väga tänulik, kui võtaksite umbes 15 minutit, et vastata küsimustele 31. maiks 2023 oma ekspertteadmistega. Ärge kartke edastada küsitlust teistele kontaktisikutele merendussektoris, see oleks suureks abiks. Kuna Euroopa sadamakeskkond on väike maailm, on tulemuste usaldusväärsuse tagamiseks väga oluline saada võimalikult palju vastuseid erinevate inimeste vaatenurgast.

Mul on hea meel, kui ma saan uuringu tulemusi teiega pärast seda jagada.

Tänan teid juba ette väärtusliku toetuse eest!

Lugupidamisega,

Marielle Sorge

*This message was translated online from English

Greek

Θέμα: "Πράσινοι λιμένες" - αίτημα υποστήριξης

Αγαπητή κυρία ή κύριε,

Είμαι η Marielle Sorge, και αυτή τη στιγμή διανύω το τελευταίο εξάμηνο των σπουδών μου για το διπλό μεταπτυχιακό μου δίπλωμα στη "Supply Chain Management" στο ESCE Paris και στη "International Consulting" στο HWR Berlin.

Στο πλαίσιο της μεταπτυχιακής μου διατριβής με θέμα "Πράσινοι λιμένες", διεξάγω επί του παρόντος μια έρευνα σχετικά με τα μέτρα μείωσης των εκπομπών για την απαλλαγή των λιμένων από τον άνθρακα. Μπορείτε να έχετε πρόσβαση στην έρευνα μέσω του ακόλουθου συνδέσμου: https://www.q-set.de/q-set.php?sCode=SZYKJTSASZNQ

Θα σας ήμουν πολύ ευγνώμων αν μπορούσατε να αφιερώσετε περίπου 15 λεπτά για να απαντήσετε στις ερωτήσεις μέχρι τις 31 Μαΐου 2023 με τις εξειδικευμένες γνώσεις σας. Μη διστάσετε να προωθήσετε την έρευνα και σε άλλες επαφές στη ναυτιλιακή βιομηχανία, αυτό θα ήταν μεγάλη βοήθεια. Δεδομένου ότι το ευρωπαϊκό λιμενικό περιβάλλον είναι ένας μικρός κόσμος, επικοινώνησα επίσης με ορισμένους συναδέλφους σας, καθώς είναι θεμελιώδες να λάβουμε όσο το δυνατόν περισσότερες απαντήσεις από την οπτική γωνία διαφορετικών ανθρώπων, ώστε να διασφαλιστεί η αξιοπιστία των αποτελεσμάτων.

Είμαι στην ευχάριστη θέση να μοιραστώ μαζί σας τα αποτελέσματα της έρευνας στη συνέχεια.

Σας ευχαριστώ εκ των προτέρων για την πολύτιμη υποστήριξή σας!

Με εκτίμηση,

Marielle Sorge

*This message was translated online from English

Slovakian

Predmet: "Zelené porty" - žiadosť o podporu

Vážená pani alebo pán,

Som Marielle Sorge, momentálne som v poslednom semestri štúdia dvojnásobného magisterského titulu v odbore "Supply Chain Management" na ESCE Paris a v odbore "International Consulting" na HWR Berlin.

V rámci svojej magisterskej práce na tému "Zelené prístavy" (v angličtine) v súčasnosti vykonávam prieskum opatrení na zníženie emisií v rámci dekarbonizácie prístavov. K prieskumu sa môžete dostať prostredníctvom tohto odkazu: https://www.q-set.de/q-set.php?sCode=SZYKJTSASZNQ

Bola by som vám veľmi vďačná, keby ste si našli približne 15 minút a do 31. mája 2023 odpovedali na otázky s vašimi odbornými znalosťami. Neváhajte a prepošlite prieskum ďalším kontaktom v námornom priemysle, bola by to veľká pomoc. Keďže európske prístavné prostredie je malý svet, kontaktoval som aj niektorých vašich kolegov, pretože je nevyhnutné získať čo najviac odpovedí z pohľadu rôznych ľudí, aby sa zabezpečila spoľahlivosť výsledkov.

Rád sa s vami následne podelím o výsledky prieskumu.

Vopred vám ďakujem za vašu cennú podporu!

S láskavým pozdravom,

Marielle Sorge

*This message was translated online from English

Hungarian

Tárgy: "Zöld kikötők" - támogatási kérelem

Tisztelt Hölgyem vagy Uram,

Marielle Sorge vagyok, jelenleg az utolsó félévemet töltöm a párizsi ESCE "Supply Chain Management" és a berlini HWR "International Consulting" mesterképzésén.

A "Zöld kikötők" témájú diplomamunkám részeként jelenleg a kikötők szén-dioxid-mentesítését célzó kibocsátáscsökkentő intézkedésekről készítek felmérést. A felmérés a következő linken érhető el: https://www.q-set.de/q-set.php?sCode=SZYKJTSASZNQ

Nagyon hálás lennék, ha szánna kb. 15 percet arra, hogy 2023. május 31-ig szakértelmével válaszoljon a kérdésekre. Ne habozzon továbbítani a felmérést a tengerészeti ágazatban dolgozó más kapcsolattartóknak is, ez nagy segítség lenne. Mivel az európai kikötői környezet egy kis világ, felvettem a kapcsolatot néhány kollégájával is, mivel alapvető fontosságú, hogy minél több válasz érkezzen különböző emberek nézőpontjából, hogy az eredmények megbízhatósága biztosított legyen.

Örömmel osztom meg Önökkel a felmérés eredményeit a későbbiekben.

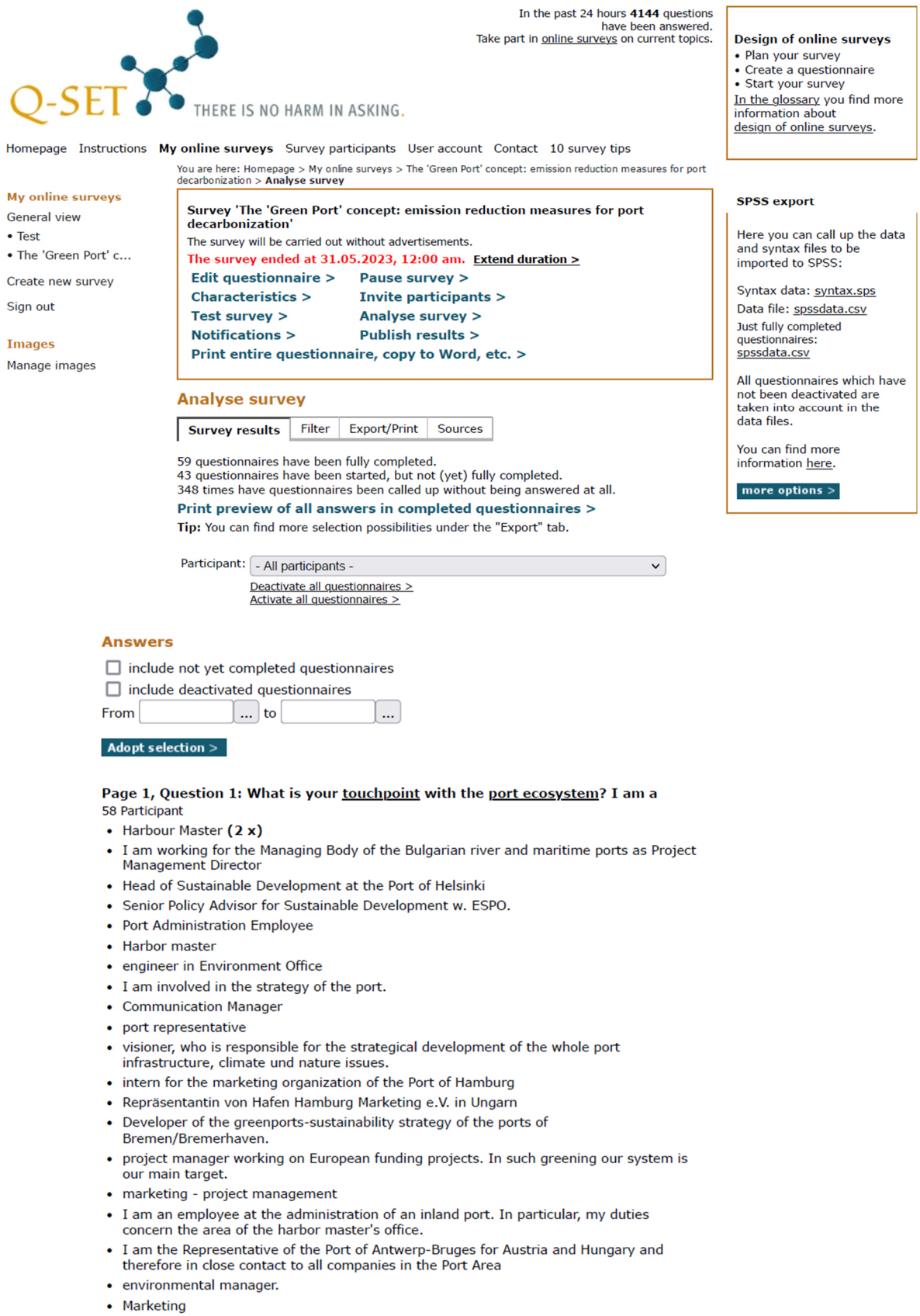
Előre is köszönöm értékes támogatását!

Üdvözlettel,

Marielle Sorge

*This message was translated online from English

Annex 4: Raw questionnaire data



Q-SET THERE IS NO HARM IN ASKING.

In the past 24 hours **4144** questions have been answered.
Take part in online surveys on current topics.

Design of online surveys
- Plan your survey
- Create a questionnaire
- Start your survey

In the glossary you find more information about design of online surveys.

Homepage Instructions **My online surveys** Survey participants User account Contact 10 survey tips

You are here: Homepage > My online surveys > The 'Green Port' concept: emission reduction measures for port decarbonization > **Analyse survey**

My online surveys
General view
- Test
- The 'Green Port' c...

Create new survey

Sign out

Images
Manage images

Survey 'The 'Green Port' concept: emission reduction measures for port decarbonization'
The survey will be carried out without advertisements.
The survey ended at 31.05.2023, 12:00 am. Extend duration >

Edit questionnaire > Pause survey >
Characteristics > Invite participants >
Test survey > Analyse survey >
Notifications > Publish results >
Print entire questionnaire, copy to Word, etc. >

SPSS export

Here you can call up the data and syntax files to be imported to SPSS:

Syntax data: syntax.sps
Data file: spssdata.csv
Just fully completed questionnaires: spssdata.csv

All questionnaires which have not been deactivated are taken into account in the data files.

You can find more information here.

more options >

Analyse survey

Survey results | Filter | Export/Print | Sources

59 questionnaires have been fully completed.
43 questionnaires have been started, but not (yet) fully completed.
348 times have questionnaires been called up without being answered at all.

Print preview of all answers in completed questionnaires >

Tip: You can find more selection possibilities under the "Export" tab.

Participant: - All participants -

Deactivate all questionnaires >
Activate all questionnaires >

Answers

☐ include not yet completed questionnaires
☐ include deactivated questionnaires
From ... to ...

Adopt selection >

Page 1, Question 1: What is your touchpoint with the port ecosystem? I am a
58 Participant

- Harbour Master **(2 x)**
- I am working for the Managing Body of the Bulgarian river and maritime ports as Project Management Director
- Head of Sustainable Development at the Port of Helsinki
- Senior Policy Advisor for Sustainable Development w. ESPO.
- Port Administration Employee
- Harbor master
- engineer in Environment Office
- I am involved in the strategy of the port.
- Communication Manager
- port representative
- visioner, who is responsible for the strategical development of the whole port infrastructure, climate und nature issues.
- intern for the marketing organization of the Port of Hamburg
- Repräsentantin von Hafen Hamburg Marketing e.V. in Ungarn
- Developer of the greenports-sustainability strategy of the ports of Bremen/Bremerhaven.
- project manager working on European funding projects. In such greening our system is our main target.
- marketing - project management
- I am an employee at the administration of an inland port. In particular, my duties concern the area of the harbor master's office.
- I am the Representative of the Port of Antwerp-Bruges for Austria and Hungary and therefore in close contact to all companies in the Port Area
- environmental manager.
- Marketing

- Project Manager Research & Innovation in the biggest inland port in Europe
- The Environmental Manager of the Port Authority of Aveiro (Port Administration)
- Inland port operator
- I an an expert in Company in the port sector
- member of the boards of 2 ports: APSS- Administração dos Portos de Setúbal e Sesimbra e da APL - Administração do Porto de Lisboa
- Expert in Projects management directorate, Bulgarian Ports Infrastructure Company
- Environmental manager
- Port authority worker
- Director of Sustainability and Environmental Strategy Department of ThPA SA
- Head of the business and customer support unit
- I am an employee of the port authority
- Port Authority Environmental Department manager
- I have been Head of port and maritime activities in two French public authorities for 15 years. My education is related to coastal and maritime developments and management.
- Head of sustaianbility at a port authority.
- HSE Specialist
- Project manager for port expansion project.
- Senior Environmental Advisor
- Business Development Advisor - within Customer Relations (department that link the port with the Shipowners - Ship Operators - Traders
- head of local marketing unit
- business developer of hydrogen infrastructures, proposing cold ironing solutions
- Head of the Environment and Energy Efficiency Division at APDL,SA (Port Authority)
- Researcher in sustainable logistics systems, who is involved in two EU projects focsuing on the "Greening of Port Operations".
- project manager sustainable transition
- Container terminal operator
- Deputy operations manager in France
- I am an assistant for ecological transition
- Head of International Projects
- Senior Strategic Advisor Energy Transition
- I am part of the project management team
- Environmental Officer
- PhD Student for port sustainability

- EU Funds Specialist
- I work as the Head of department for Sustainable Development
- Sustainability Manager
- Manager for Environmental Protection
- Director of Business Development
- Advisor Renewable Energy in the Sustainable Transition team of the Port Authority

Page 1, Question 2: What is your nationality?
59 Participant

- German **(15 x)**
- French **(5 x)**
- Portuguese **(4 x)**
- Bulgarian **(3 x)**
- Austria **(3 x)**
- Belgian **(3 x)**
- Polish **(3 x)**
- Finnish **(2 x)**
- Romanian **(2 x)**
- Austrian **(2 x)**
- Swedish **(2 x)**
- Swedish.
- Japanese
- French.
- ungarisch
- German.
- PT
- Greek
- Latvian
- Finland
- Italian
- Dutch
- Greece
- Danish
- Spanish
- Belgium

Page 1, Question 3: Do you believe there is currently enough research focussing on port decarbonization measures to support and guide the transition towards green ports?

59 Participant

Yes	23
No	36

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Page 1, Question 4: Which of the following measures for port decarbonization do you consider the most urgent ones?

Please rank from 1 = most urgent to 8 = least urgent from today's perspective.

59 Participant

Regulation and Policy development	30	4	3	3	6	1	3	4	5	**3,27** (193 / 59 Answers)
Green Port Management	4	11	2	3	4	17	6	5	7	**5,27** (311 / 59 Answers)
Onshore Power Supply (cold ironing)	4	7	6	9	9	9	5	4	6	**4,95** (292 / 59 Answers)
Electrification of port equipment	3	5	5	11	13	10	5	6	1	**4,90** (289 / 59 Answers)
Smart information measures and automation	2	4	2	3	6	7	8	22	4	**6,34** (368 / 58 Answers)
Ship arrival/stay/departure optimization	2	1	4	4	3	2	7	10	26	**7,15** (422 / 59 Answers)
Use of alternative fuels	5	7	23	8	5	4	3	2	2	**3,80** (224 / 59 Answers)
Use of renewable energy sources	7	20	7	8	5	3	7	2	0	**3,53** (208 / 59 Answers)
Energy Management Systems	2	0	7	10	8	6	15	4	7	**5,75** (339 / 59 Answers)

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Page 1, Question 5: Into which lifecycle category would you range the current development status of the following measures for decarbonization of ports in the European Union?

59 Participant

	Preparation	Scale-up	Growth	Maturity	Decline
Regulation and Policy development	11	21	23	3	0
Green Port Management	13	18	20	6	0
Onshore Power Supply (cold ironing)	10	18	25	5	1
Electrification of port equipment	13	26	17	3	0
Smart information measures and automation	8	15	21	13	1
Ship arrival/stay/departure optimization	9	13	15	21	0
Use of alternative fuels	29	17	9	2	2
Use of renewable energy sources	6	21	28	2	2
Energy Management Systems	7	27	18	6	0

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Page 2, Question 6: Which kind of framework do you consider the most effective one for implementation of port decarbonization measures?

59 Participant

Compulsory regulations and policies	4
Voluntary initiatives by port authorities and related stakeholders	1
Both, equally	14
Both, with stronger focus on compulsory regulations and policies	30
Both, with stronger focus on voluntary initiatives by port authorities and related stakeholders	10

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Page 2, Question 7: How would you categorize the following stakeholders regarding their responsibility for port decarbonization?

59 Participant

	Very responsible	Responsible	Less responsible	Not responsible
EU	34	23	2	0

National Government	39	17	3	0
Institutions	6	33	17	3
Port authorities/administrators	41	17	1	0
Shipping companies	33	18	7	1
Local industry	13	33	10	3
Local organizations	2	18	31	8
Citizens	5	11	25	18

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Page 2, Question 8: Through which types of incentives should emission reduction measures in ports best be promoted?

59 Participant

Reward measures	16
Punishment measures	2
Both, equally	9
Both, with stronger focus on reward measures	26
Both, with stronger focus on punishment measures	6

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Page 2, Question 9: Should ports employ specialized and dedicated managers or agents for the process of port greenification?

59 Participant

Yes	51
No	8

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Page 2, Question 10: Should ports use a green marketing strategy to promote their decarbonization efforts?

59 Participant

Yes	55
No	4

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Page 3, Question 11: How significant do you consider the following barriers for Onshore Power Supply (cold ironing) implementation?

59 Participant

	Very significant	Significant	Less significant	Not significant
Costs	43	13	1	2
Technical specifications	20	30	7	2
Standards and regulation	24	29	4	2
Integration into port operation	16	32	9	2
Stakeholder collaboration	18	32	7	2

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Page 3, Question 12: How suitable do you consider the following power supply options for Onshore Power Supply (cold ironing) in view of port decarbonization?

58 Participant

	Very suited	Suited	Less suited	Not suited
Direct connection to the national grid	35	21	2	0
Direct connection to local micro grid	20	29	6	3
Fuel cell on barge	11	17	22	6
LNG on barge	2	12	18	25
Turbine on barge	0	8	26	21

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Page 3, Question 13: Which of the following options regarding operation equipment should be the primary focus in view of port decarbonization?

59 Participant

Working efficiency improvement	1
Equipment transformation/replacement/retrofit	14
Both, equally	21
Both, with stronger focus on working efficiency improvement	10
Both, with stronger focus on equipment transformation/replacement/retrofit	13

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Page 3, Question 14: Which of the following port operation technologies do you consider the most urgent ones to be addressed in order to reduce emissions in ports?
Please rank from 1 = most urgent to 5 = least urgent from today's perspective.
59 Participant

Trucks	41	8	6	1	3	**1,59** (94 / 59 Answers)
Cranes	11	30	10	2	6	**2,36** (139 / 59 Answers)
Cooling and heating of port buildings	3	9	22	20	5	**3,25** (192 / 59 Answers)
Dust pollution	2	4	18	23	12	**3,66** (216 / 59 Answers)
Lightning	2	8	3	13	33	**4,14** (244 / 59 Answers)

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Page 3, Question 15: Which digitalization tool do you believe has the biggest impact to contribute to operational efficiency and thus emission reduction in ports?
Please rank from 1 = biggest impact to 4 = smallest impact.
58 Participant

Big Data (BD)	25	15	17	1	**1,90** (110 / 58 Answers)
Internet of Thing (IoT)	16	26	13	3	**2,05** (119 / 58 Answers)
Artificial Intelligence (AI)	15	15	22	6	**2,33** (135 / 58 Answers)
3D printing	2	2	6	48	**3,72** (216 / 58 Answers)

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Page 3, Question 16: Will ports which do not implement automation processes into their daily operation stay environmentally and economically competitive in the middle and long term?
59 Participant

Yes	6
No	53

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Page 3, Question 17: Have you identified success factors or best practices for the implementation of Onshore Power Supply, port equipment measures and/or port information measures?
35 Participant

- No **(2 x)**
- Yes **(2 x)**
- We are in a process of research these factors within EALING project financed by CEF
- OPS in liner traffic is by far the easiest to start with. That in turn build in-house know how the helps in tackling the more difficult OPS cases, eg. container and cruise segments
- https://www.espo.be/practices?tag=climate-air
- Involvement of the port stakeholders in UE funded dedicated projects
- European funding programs
- Swapping batteries are the most relevant way to reduce costs and to improve the life cycle of the batteries so as of the grid components. Especially for short sea shipping.
- n the port of hamburg, the cruseships are already supplied by onshore power
- Renewable powered ships would help decarbonisation at 100 % of ship-operation-time; OPS will help max. 5 % of ship-operation-time; OPS is a systematical risk for local port grids.
- Strong Port Community network
  Clear strategy and focus on key objectives
  Technical knowledge
  Funding
  Innovation
- Yes, OPS is a success factor to the relation ports/cities (cruise ships etc)
- Yes, the Company elaborated studies related to port equipment, infrastructure, performance and safety in order to implement OPS in the ports.
- Grid stability, incoming vessels that support the technology
- costs and suitable technical options
- stakeholder dialogue, Funding, validate data of own operations but also of port community
- ----

- no yet
- Cooperation and access to sufficient funding
- Engaged stuff and management
- Donot consider it as a classic business case - consider the environmental return as the most important one, and the economical ROI in the longer run
  Look also into energy efficiency - no need to build solutions that cover all possible exceptions
- The existence of a port service company that can undertake the sell of electricity and thus financial guarantees to develop OPS
- Port of Duisburg (Best practice)
  Port of Rotterdam & Hamburg (Altenwerder) - port equipment & no lightning
- OPS infrastructure responsability of terminal operator
- Closer collaboration of ports with private companies but difficult for us to get the overview of technology providers and the right partners: We have engaged some consultants of that regard but they were rather expensive and thus not viable for everyone
- The Port of Rotterdam established the start-up PortXchange, a collaborative planning platform for encouraging ports and shipping companies to collaborate to achieve just-in-time sailing to reduce emissions.
- The new workboat of the Port of Bergen, which is running on a battery pack. It can carry out harbour operation like maintenance or towing, all emission-free.
- The use of disruptive technologies like IoT, 5G, data analytics for traffic management etc. can highly contribute to optimize capacity and traffic/congestion, with resulting extra benefits for the environemnt.
- A combination of OPS and automooring systems can be applied, this reduces the emissions from the ships at berth and also reduces the time of each ship (plus the necessary power for OPS)
- Port Environmental Performance IT platform for entry of real-time data captured from a sensors network of port and ship equipment. Gives information about the real emissions and enables to tackle the main emission sources first.
- Digital platform for tracking emissions in the port
- Coordination of environmental activities helps overcome some barriers, for example the ports of Stockholm, Helsinki, and Tallinn in the Baltic Sea have decided to set same standards for cold ironing for the ships operating in all three ports. This might however not be possible everywhere and for every shipping company.
- Share information among port authorities
  Subsidies/grants are vital in early stage adoption

Page 4, Question 18: Should ports impose an immediate reduction of vessel speed and auxiliary time at berth as short-term applicable measures to reduce emissions?

58 Participant

	Yes	No
Vessel speed	21	37
Auxiliary time at berth	25	32

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Page 4, Question 19: How do you evaluate the responsibility of ports regarding the development of alternative fuel use?

59 Participant

Very responsible	11
Responsible	38
Less responsible	7
Not responsible	3

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Page 4, Question 20: Which alternative fuel do you believe is the most suited for the decarbonization of ship propulsion and port operation?

Please rank from 1 = most suited to 5 = least suited.

57 Participant

LNG	13	5	6	4	29	**3,54** (202 / 57 Answers)
Hydrogen	17	15	11	9	2	**2,33** (126 / 54 Answers)
Methanol	11	11	18	12	3	**2,73** (150 / 55 Answers)
Ammonia	6	12	9	14	14	**3,33** (183 / 55 Answers)
Biofuels	9	12	11	16	8	**3,04** (170 / 56 Answers)

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Page 4, Question 21: Which role play ports for the deployment of renewable electricity technologies for assisted ship propulsion?

59 Participant

Very important role	12

Important role	26
Less important role	19
No important role	2

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Page 4, Question 22: How crucial is the integration of the hinterland for contribution to port decarbonization?

58 Participant

Very crucial	31
Crucial	26
Less crucial	1
Not crucial	-

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Page 4, Question 23: Have you identified success factors or best practices for the implementation of energy efficiency measures for ships, alternative fuel use, renewable electricity for ship propulsion and/or hinterland integration?

30 Participant

- No **(5 x)**
- not yet **(2 x)**
- We hope that the shipping lanes will be equipted and obliged to use OPS when they are in ports
- Traditional energy reducing measures in ports (buildings, lighting etc) are still under utilized options. Smart energy management reduces the peak load on the port grid
- https://www.espo.be/practices?tag=energy-fuels
- Cooperation between European ports
- The operators need a robust supply process in all the ports of call. The process can be validated if all the operators agree on the methods and systems.
- LNG Terminal will be operated in Brunsbüttel/Wilhelmshaven/Lubmin
  Construction of a hydrogen pipeline network is to begin in Hamburg in 2023.
  Air Products and Mabanaft announced plans to develop Germany's first large-scale, green energy import terminal at Mabanaft's existing tank terminal in the Port of Hamburg.
- Environmental Ship Index (ESI), "greenports-Awards" for green ships and shipping companies, our greenports-Strategy
- Biofuel (B15) using in the Port of Aveiro - tests in port equipment and boat of bar Pilots
  Mobility modelling and study of alternatives

- Yes, with the proposal of creat energy comunities
- A study and analysis of the feasibility and conditions for the construction of photovoltaic power plants at the ports is being carried out and an analysis of the studied alternatives and a proposal for implementation, follow-up actions and recommendations are being prepared, according to the results of the study on the feasibility of renewable energy production at the Bulgarian river ports.
- -----

- Regulation, regulation, and regulation
- Partnerships and collaboration- due to higher safety risks for the alternative fuels, involve port terminals early in the stage
- speed up the operation around ships to minimize berthing time. Closer collaboration of local port industry for alternative fuel development and availability. integration of railway and river transport for hinterland
- efficiency: The automooring system optimises ship speed and reducing the time spent waiting, which also contributes to CO2 emissions reduction.

  Fuels/energy: ports and private energy companies need to work together to build and operate the infrastructure; financing could be splitted in that way
- Explore all possible energy production options, like the Port of Marseille which will locally produce bioLNG from household wastesof the region
- Close cooperation with customers, like automated traffic management for trucks and ships, onshore power supply, offering eco-incentives for environmntally friendly actions of customers, etc.
- Ports and local industry should closely work together for the use of clean fuels to eliminate local natural gas use which pollutes a lot and threatens the health of workers and residents.
- Feasibility of new fuels needs to be analyzed and tested, both in terms of operation and cost-effectiveness
  The same accounts for retroffitting ships and equipment

- In Hamburg, a hybrid workboat is acquired for more eco-friendliness for local operational work; building those kind of new boats on a multi-purpose basis will have greater benefits on the long term.

- Cooperation between ports is crucial, which has already been done through strategic agreements or momerandums of understanding. Coop can have numerous advantages: setting up logistic chains, share expertise, share costs, use synergies, strengthen competitiveness, etc.

- For the hinterland, rail shuttles can be set up to distribute the goods in bulks, but railway infrastructure will be needed. River transport is another option, too.
- Procedures for letters of intent or expressions of interest need to be set up for both alternative fuels and electricity supply (OPS for instance) in order to get a clear vision of the needed capacity, in order to integrate the volumes already in the infrastructure planning to match the future demand and supply.

Page 5, Question 24: Which power supply path should ports take to cover their overall electricity need while considering port decarbonization?

57 Participant

Reliance on the national electricity grid	5
Self-supply electricity system	5
Both, equally	12
Both, with stronger focus on reliance on the national electricity grid	23
Both, with stronger focus on self-supply electricity system	12

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Page 5, Question 25: From a macro point of view, in which order would you advise a port to prioritize the following renewable energy sources when opting for a (partly) self-supply electricity system?

Please rank from 1 = most prioritized to 4 = least prioritized.

58 Participant

Geothermal energy	3	6	12	35	**3,41** (191 / 56 Answers)
Wind energy	23	27	7	1	**1,76** (102 / 58 Answers)
Marine energy	4	6	28	18	**3,07** (172 / 56 Answers)
Solar energy	28	18	9	2	**1,74** (99 / 57 Answers)

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Page 5, Question 26: Do you believe fuel cells will play a mayor role in balancing intermittencies for (partly) self-reliant ports in the near future?

55 Participant

Yes	38
No	17

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Page 5, Question 27: Do ports need to install Energy Management Systems to control and optimize their (future) energy demand and supply?

58 Participant

Yes	52
No	6

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Page 5, Question 28: Have you identified success factors or best practices for the implementation of renewable energy sources and/or energy management systems in ports?

27 Participant

- No **(6 x)**
- Not yet **(2 x)**
- None
- The use of locally produce renewable energy is very dependent on the actual port layout. In some cases own production can be very feasible, but eg. in our case the reliance on the massive development of the national renewable energy production is a better option
- https://www.espo.be/practices?tag=energy-fuels
- Solar panels installed on the sea water surface inside port area
- European projects
- Hamburg Port Authority is already using port energiy management system
- Our greenports-Strategy
- Building a Port Community Renewable Community, based on renewables sources inside the Port, complemented with an intelligent energy management system.
- An analysis of the studied alternatives and a proposal for implementation, follow-up actions and recommendations are being prepared, according to the results of the study on the feasibility of renewable energy production at the Bulgarian river ports.
- subsidation policy
- implementation of energy management systems is crucial
- ------
- Collaboration with energy sector
- it really depends on the exact geographic and meteorologic conditions of a port. Put PV could be installed everywhere I guess, rooftops are a good solution, but it requires cooperation with the local building owners

- Photovoltaic panels can be installed on roofs of port buildings to overcome the space availability issues
- As mentioned just before, expressions of interest would help get an idea of the capacity needed.
- When installing wind turbines or PV panels, repowering should be considered after a certain time of operation, usually between 20 and 30 years. In that way, more output electricity can be produced within the same available space.

- Seaports are great locations for instaling offshore wind parcs but the planning of those parcs must including the routing of ships approaching the port.
- For successful implementation of renewable electricity sources, close cooperation between the port, energy companies and local transmission system operators is unavoidable

Page 6, Question 29: Is there <u>further information</u> you would like to share and highlight regarding <u>emission reduction measures for port decarbonization</u>?

30 Participant

- No **(5 x)**
- 1.Need for cooherence vis-à-vis existing European and national legislation, and with the recently defined policy initiatives and objectives set out in the European Green Deal, the RepowerEU plan and the Net-Zero Industry Act
  2.Ports are increasingly taking up a role in the energy supply and provision and are now also being recognised as hubs of energy by EU policy makers. In the review of the 2013 TEN-T guidelines, which is currently taking place, the Transport Council has agreed on a text which provides that ports which have a "minimum annual cargo volume of 500.000 tonnes and contribute to diversification of energy supplies and acceleration of renewable energy as main activity of the port" can become part of the TEN-T comprehensive network. Moreover, many supportive policies for the deployment of renewable energy in Europe are being developed, in which ports as hubs of energy can play an important role. In view of this, it seems appropriate to think how to measure a port not merely in terms of tonnes and TEU, but also as energy hub.
- The investments needed for high powered OPS are massive, and the burden of that needs to be shared with the rest of society. This is especially true regarding the needed strengthening of the grid around the port.
- Not at this stage.
- Our port tends to go for electric supply of ships and vehicles. The amount of energy is huge (over 2 GWh/day). The energy needs to be there. Who can assure that ?
- Ports are also Gateways for any energy carrier and goods that can be relevant for decarbonisation technologies. Ports are of systematic relevance for national & international economies. Ports need a resilient and self-sufficient energy supply from renewables. Ports are organised in different ways but they need the necessary ressources (human ressources, regulation, finances) to develop the necessary changes
- we need a global approach for this. Vessels are still running on two types of Diesel - one in shore area and another (more dirty) on the sea. This should be solved immediately.
- I answered the questions from the inland port perspective. Therefore the view, e.g. on shore power supply, can be much different to the seaport point of view.
- Not for the moment
- good luck
- first you hhave to set up a validate database, all meausures depend on that
- -----

  Please note that I am the only Harbour Master in my country so please make necessary arrangements for my anonymity. Thank you and good luck.
- Interesting survey. Important topic :)
  I hope you will share results.
- Do not forget the landside. Ports have enormous impact also on the truck side.
- Could you pls. send the results of your study to me?
  Luisa.Kempf@eurogate.eu.
  Thanks
  :-)
- incentive schemes for pro-environmental actions of stakeholders
- Environmental assessment schemes and why not certifications to motivate the management of ports to take action. Reports on emissions and measures are very important for transparency
- We need to take care of the surrounding marine ecosystem, too. Gor example by limiting oil spills from bunkering, for example by setting higher safety measures
- The treatment of hazardous goods is a challenge because the content does not belong to ports, however we have to unload, store anddistribute it and are therefore responsible for possible toxic pollutions and risks. Emergency plans are needed to be set up and known by the port workers. The explosion in the port of Beirut showed an extreme case of that issue, including environment and communities around.
- Reception of ship waste needs to be managed well without direct spill to the water and with including recycling. Legislation pushing shipping companies towards more eco-friendly materials would take off some burden of ports in that regard. The same accounts for sewage and waste waters, which are of great amount especially for passengr ships. Corresponding facilities are needed.
- Agreements between ports, their mother cities and shipping companies need urgently to be made. Greening ports is an urgent matter!
- Strategic roadmaps need to be set up and priorities fixed. These priorities might be highly dependent of regulation and funding options

- The management of every port needs to make the first steps. "Not having the time and resources" is a reason for unsufficient environmental action but being aware of this gives the opportunity to change it.
- Noise prevention is crucial as well. This could be done via new equipment, OPS or installing noise zones.
  Also, dust pollution is another topic which could be adressed by dust pollution monitoring system for air quality, for instance,and combined instant reduction measures (water sprays).
- More than just the focus on emission is important. I'm thinking of other environmental topics like reducing ballast water (new technologies needed for the treatment), dredging for port expansion (use clean sediment as a further resource) and garbage from ships (provide reception facilities)...
- EU research and funding projects are important to us

Annex 5: Interview transcripts

Interview 1:
Green Port Masterplanner at Port of Antwerp-Bruges

Interviewer:

What is your definition of a green port?

Interviewee 1:

The more generally accepted way of talking about a green port is focusing on CO2 emissions, right? But I think it's also about biodiversity, about social aspects. So it's not just the focus on CO2 alone, but really on the broader framework gap.

Interviewer:

And what are recommendable practices for the integration of port related stakeholders into the transition towards green points?

Interviewee 1:

We have more of a culture of managing stakeholders. I wouldn't say there's a lot of trust in between all parties in the sector. The shipping industry is what I call a self-organised ecosystem, so it's got many, many parties that play a small role in a very large chain of events or a very large supply chain without having really one single responsible for the entire chain, right? So, the actor field in the port is very complex, very diverse. And then having port authorities being more of managing stakeholders, I think we need to move more towards a participation approach where we really co-create, cooperate - and we are actually doing that on various fronts but more like on an operational level, setting up all kinds of corporations. But if it's about strategy, thinking about desired futures and co-creating a definition, for instance of a green port, that's what we really need to focus on. Into some kind of a co-creation level. That's not part of the culture yet, but we are working on that.

Interviewer:

And speaking of strategy, policy and management, are there also other practises that you've heard of that are successful to implement certain management structures or policies?

Interviewee 1:

We're trying to make the dynamic within the system visible. So, there is some leadership, some stewardship within the Port Community, private companies that actually do invest in sustainability. And what we tried to do is to make that visible, to inspire the community to make that also part of the mainstream, like to create a sense of urgency also with all of the others. Having them become aware of their peers will make people more tempted to move themselves as well or act, that's a psychological thing. We usually call that a lighthouse project, in which we invest. So, all kind of projects that are iconic and have an impact in a way, foremost operational, and bring a systemic change or innovation. By doing this, we think we will inspire others. I see that happening virtually in most European ports. So, demonstration projects are important.

Interviewer:

And what could ports do to accelerate the application of onshore power supply despite all the known barriers or how can they be overcome? Maybe you have heard something about that as well because it is used already in some ports.

Interviewee 1:

One of the major barriers is the clarity of roles and responsibilities when it comes to OPS. So you have the terminal operator, the shipping line or ship owner, the labour, the Port Authority, and there are all kinds of agencies of federal or regional governments. There's the distribution system operator. There's the energy provider. So, all kinds of parties involved and none of them is really taking the leadership. To overcome that, you could either do that on a policy level like making a regulation that sets out the roles and responsibilities. However, I'm pretty sure that this kind of regulation will be debated a lot and unless Europe would define all roles and responsibilities and being very directive in that, it is difficult to implement - but that's not how the democratic process in Europe works, right.

So, it's going to face a lot. It's actually a bit of a chicken and egg problem, a paradoxical situation in which the sector calls for clarity on roles and responsibilities. But I would think that once the policymakers in Europe take an initiative and make clear what the roles and responsibilities are, they will face a lot of resistance from the sector.

Interviewer:

In ports eyes, are smart and automation measures more applied for economic or for ecologic reasons?

Interviewee 1:

More for economic reasons.

Interviewer:

Between new, replaced or retrofitted operation equipment – how could ports make the right choice? How can the assessment be done? On which criteria could it be based?

Interviewee 1:

The way you could approach the issue is by using the merit order, which helps making decisions.

Interviewer:

And regarding the reduction of vessel speed and birthing time, no, or go and why?

Interviewee 1:

Well, 80% of the ship's emissions in port are during berthing time. So reducing that time would mean there's less emissions. It's however part of an entire operational chain, so I don't really see how reducing the birthing time in itself could be a measure. The only way would be if you could increase efficiency of the container terminal, for instance. But then, reducing berthing time is rather some kind of a consequence of another measure, being improving efficiency of the terminal. In Antwerp, we are definitely working on all kinds of digital tools to optimise the vessel

traffic and so on, because we do believe it will have an mere impact by optimising the current status quo. I truly believe there will be this fields where you can optimise and increase efficiencies and as such, reduce energy consumption and CO2 emissions.

Interviewer:

What about vessel speed? Is that something that you believe should ports do or is it also linked to other measures?

Interviewee 1:

Yeah, but it's not the ports that reduce the speed, right? It's the vessels. Since it's open water, the ports are not responsible for the speed that the ship is taking, but you should be aware that for the port of Antwerp, we are a port that's 80 kilometres inland. So, we are dependent on the tides of the river, the river shelter, which rises and falls every day a few metres, which is why some ships can only approach the port in certain time windows. If you have a port that's at the sea, I wouldn't see why reducing the vessel speeds would be a problem. In the end, that should be part of the strategy of the shipping line. They're also saving fuel. But the operational situation in our port makes entering quite particular.

Interviewer:

The next question would be, which positioning should ports take in the development of alternative fuels?

Interviewee 1:

Well, it's first and foremost providing a framework, because a port is responsible for safeguarding safety in the port. So, bunkering operations, at least in Europe, fall under the European Port Services Regulation, which demands the creation of an additional framework to make bunkering activities safe and efficient. And that's definitely a responsibility for ports to have such a framework, to make sure that also companies that want to provide this kind of services can have licences to do so. The port could also provide land where intermediate storage of these compounds can happen. I think ports should include options for all these fuels. LNG, hydrogen, ammonia. Methanol. I'm not too big of a fan of biofuels. There is plenty of storage capacity today for conventional, fossil fuels in the port, and since these fuels in a way chemically and physically very comparable, there is no need to have specific infrastructure for that.

Interviewer:

And then why would ports consider themselves responsible or not for renewable electricity technologies for assisted ship propulsion?

Interviewee 1:

Ports gain money by quoting ships visiting the port. What we do is give reductions on the part dues for green ships. This could be a reason. But apart from that, I don't really see how a Port Authority has the responsibility this on, it's up to the ships.

Interviewer:

What are possible approaches for ports to successfully integrate the hinterland into their operation?

Interviewee 1:

As a Part Authority, we don't really operate the hinterland part. But I do think it's partly within the port's responsibility since we are providing employment for many people that also live around the areas of the port. Also, in the port there's quite some emissions of nitrogen oxide, a particular matter, and also Sox. These also put pressure on the communities surrounding the port, so we definitely should take some responsibility there as well.

Interviewer:

How are common bottlenecks in clean energy supply for ports usually addressed?

Interviewee 1:

There's a very high focus on technology today. I would say we need more focus also on different ways of thinking and different ways of organising. You also asked like engaging with stakeholders, how do we do that? It's very stakeholder management oriented and not so much in co-creation.

Interviewer:

And then, why would it be crucial or not for ports to install energy management systems to stay (environmentally) competitive?

Interviewee 1:

Very crucial. We have a lot of wind turbines and solar PV in the port, so a lot of intermittent energy supply. Then, there's very limited amount of demand side management in the port. In that regard, energy management systems could really help to align these two. But more on an operational level, which is something that terminal operators among themselves could set up. Then, regulating the mentioned intermittencies is really up to the distribution system operator or even the transmission system operator, they have the corresponding responsibility. I think ports can play a role in building the community or something, but that's not our expertise.

Interviewer:

In this interview, the focus within the 'Green Port' was set on emission reduction measures. Are there other important environmental issues to be addressed by "green ports"?

Interviewee 1:

Would you like me to start? We don't only have CO2 emissions, but also emissions of nitrogen oxides and PM, which are key. But also, we are establishing nature and biodiversity and social measures to making the port safe and enjoyable.

Interviewer:

Thank you for you valuable contribution.

Interview 2:
Environmental Strategist at Ports of Stockholm

Interviewer

What is your definition of a green port?

Interviewee 2

The first question is not a very easy question to answer really. I see it mostly as a process because the long-term goal is of course to have a green port that is totally in line with the surrounding environment and has no impact on the climate and no emissions from the port. And I see perhaps that the long-term definition is a zero-emission port but it's quite a long process and at first we can look to becoming more sustainable by going from fossil fuels to renewable fuels, and then in the end perhaps to the use of fuels that are that have no emissions. It's very hard to define but perhaps a zero-emission port for me.

Interviewer

What are recommendable practises for the integration of port related stakeholders into the transition towards green ports?

Interviewee 2

We have in fact several stakeholders and a very active owner of the port, which is the city of Stockholm. So that's a very important stakeholder for us since the city of Stockholm has very ambitious environmental targets, both on the short and long run, and they put quite a lot of environmental demands on us to fulfil. We have a lot of communication and dialogue with our owner. When it comes to the shipping customers, the direct dialogue is mostly done through our market department and those responsible for different shipping segments within our organisation. So they have the dialogue with the customers, but I think that we need to perhaps change that for the future. We need to have a more active dialogue around environmental issues. Since we see this, for example, fit for 55 and the new regulations on the shipping segment and also on the ports, it's very important for us to know: What kind of techniques are our customers investing in? What kind of alternative fuels are they going to use in the future? I don't really have the answer to it today and I don't think that we have a perfect situation today, but we need to be more systematic and more structured in our dialogue with the shipping customers.

Interviewer

Which successful policy and management practises do you know for port greenification?

Interviewee 2

Yes, we have a strategy. We have a long-term environment and climate action plan, and it has been decided of our Board of Port of Stockholm. And I think it's quite good to have it that way because in this action plan, we have decided on long term goals. And for each environmental goal, we have identified a few strategies to work on, to be able to fulfil these environmental targets. Then, each year, every department within the Port of Stockholm implements their budget, including their respective action plan activities for the next year. In that way, the activities and budget can be united.

Interviewer

What could port do to accelerate the application of onshore power supply despite the numerous barriers for OPS implementation?

Interviewer 2

We have a long experience of OPS in Stockholm. But I know that even before I started working here, it has been the hen and the egg problem. Either we had the investment for the installation of OPS in the port but no customers or vice versa. The customers are interested in using it, and I think there has been quite a change in the last years because the customers are much more aware now of higher environmental standards. Today, the customers come to us to have a dialogue around zero emissions in the port, which is key. So, we really see the change, a shift that the customers are more aware and willing to discuss the solutions available in the port. Also, we have been working with incentives for a long time, meaning that when the customers use OPS, they get a rebate on the port fee, an environmental discounted port fee. In that way, we encourage the customers to use OPS and we have also had a contribution of 1,000,000 Swedish crowns to a vessel that is retrofitted to OPS, so that's also an incentive. Also, I think that the fit for 55 package and the FuelEU Maritime legislations will now push OPS further, with the obligation to install OPS in all TEN-T ports until 2030.

Interviewer

In port's eyes are smart and automation measures more applied for economic or for ecologic reasons, maybe also both?

Interviewee 2

I'm not sure that I'm really an expert in that, and I don't think that we have come very far when it comes to this smart and automation measures. But I would say it's not very much for ecologic reasons.

Interviewer

Between new, replaced or retrofitted operation equipment - how could ports might make the right choice?

Interviewee 2

When it comes to our own equipment, I think we mostly have some retrofitting ideas when it comes to our terminal tractors for cargo handling in the ports. Heavy vehicles, for example, can go from diesel fuel to hydrogen, and we are partly converting terminal tractor to dual fuel technique hopefully. Otherwise, I know for when it comes to cranes and so on, we sell it on the market to another port or other business that is interested. And otherwise, I would say when it comes to retrofitting, I think it's most important to put in effort and money to retrofit the existing vessels because we cannot wait just for the new vessels to be environmentally friendly since they have such a long lifetime.

Interviewer

Reduction of vessel speed and berthing time, no or go and why?

Interviewee 2

We are quite in the hands of our customers because they have their time schedules. For example, when it comes to the ferry traffic between Sweden and Finland, I know they have a very tight time schedule. They are only in the port for one hour so. So, this berthing time, I don't know how much we have to say about it, right? And the reduction of vessel speed: yes, I know it could be a good measure for reducing the emissions. But we have quite a long way through the archipelago here in Stockholm, into the port, and it would take quite a long time to come into the port. So, I think it's a difficult question.

Also, we have discussed on OPS installations. Now, if the vessels would use their own batteries, they might need to stay longer at berthing time to charge their batteries. This might also bring up the issue that not enough electricity will be will be available. In these cases, we also need to have a dialogue with the customers.

Interviewer

Which positioning should ports take in the development of alternative fuel use?

Interviewee 2

I think ports will play a bigger role in the coming years and in the future when it comes to this. Also, what kind of fuel will be used? The shipping sector will mainly need the use and today, we as a port are not involved in the bunkering of fuel when it comes to the shipping customers. Today, the shipping companies are responsible for figuring it out, but I think this will change in the future, with the ports being more involved in the supply of fuels and the kind of energy to be used. Ports becoming an energy hub is a topic we are discussing a lot in Sweden at the moment. We look at the port as a hub to be able to provide fuels and energy both for the shipping sector but also for road transport, for example from the port and inlands. This topic of ports becoming energy hubs is very interesting and a growing issue in the future. In order to decide which fuels will be used, we need again the dialogue with the customers and the surrounding society. But I see that we would have actors who can perhaps have a fuelling station close to the port for heavy vehicles and decide with them what kind of fuels we will be able to offer. Will it be electricity? Biodiesel, LNG?

Interviewer

Why would ports consider themselves responsible or not for renewable electricity technologies for assisted ship propulsion?

Interviewee 2

No, I don't think that we are responsible, but we are a support. I mean, the development of what kind of technology and what kind of fuels the ships will use, that's not really where the port is involved in. But we need to be in the dialogue when it comes to it because I know for example one customer that is talking about battery charging for the vessels. And we don't have enough electric power in the port to be able to provide this. And then, vessels cannot just come to us from one day to another and say, hey, now we have this charging on our vessels, we need to charge our batteries in the port. In fact, it's a very long processes to get this electric power from

the grid owner to the port and it costs quite a lot of money as well. So, we need to be involved in the dialogue, but the decision is on the shipping segment.

Interviewer

Then what are possible approaches for ports to successfully integrate the hinterland into their operation?

Interviewee 2

In fact, since we star considering ports becoming an energy hub, we don't only see a responsibility for port activities or for the shipping customers, but also for the transports from the port to the inland. It could be on road and it could be on rail. For successful implementation, we need to connect and have partners that are more experts in that kind of issues, able to provide the fuelling station, for example.

Interviewer

How are the common bottlenecks in clean energy supply of ports usually addressed?

Interviewee 2

I think we have the energy that we need today available, which means we do not yet have energy bottlenecks. But we do use bio diesel HBO 100 in the terminal tractors today, which is a very scarce resource of which we can't get enough. But when everything is getting more electrified in the near future, we will need quite a lot of power reinforcement to our ports. We need to go up to 200 megawatts in 2030 and we now have, I think 70 or 80 megawatts. So we need to have a massive reinforcement in the power to the port. We don't have that today and it's a very long processes to get the power and it's very costly. In the process, we are mainly talking to the grid owner. For one OPS project where we wanted to connect a cruise ship, we have told the grid owner that we need 24 additional megawatts to the port. But the grid owner called and said they are not able to provide that. Since they need five or six years to be able to come up to that power, it takes a lot of time, and it costs us very much. That's the problem, really.

Interviewer

Why would it be crucial or not for ports to install energy management systems to stay competitive?

Interviewee 2

We have an environmental management system. Since we are certified according to ISO 14,000 and we have energy as the major environmental aspect in the management system, it make sense of course. What kind of energy we are using? Which emissions are resulting of this energy use? That's the major environmental aspects of our business and that's why it's crucial for us.

Interviewer

This Master thesis focusses on emission reduction measures for port decarbonization, but are there other environmental aspects which green ports should integrate as well?

Interviewee 2

If you say Green Port, it is a sustainable port, in line with the surrounding environment. I would say that we have this noise aspect since our ports are very close to the surrounding society and people are living quite close to the ports. So, the noise issue is quite crucial.

And then we have, of course the waste, both solid waste and grey water and black water. There need to be treatment methods and processes available, like recycling. Here, they're functioning quite well. We have connexion to the treatment plant in Stockholm. So, the sewage water goes to the treatment plant and then we have also good agreement with the waste management companies, so they take care of the waste and we have quite high sorting what's called.

Interview 3:
Innovation and EU Projects Responsible at Port Authority of Seville

Interviewer

What is your definition of a green port?

Interviewee 3

OK, so a port is the one that is aware of our position for sure. But we think that the green port is the one that is aware of the environmental consequences and effects that could have its activity. And so, one of its priorities is to take measures to reduce the carbon footprint and other harmful emissions as much as possible.

Interviewer

What are recommendable practices for the integration of port related stakeholders into the transition towards green ports?

Interviewee 3

We take measures, for example, for energy efficiency, emissions control, working with nature, philosophy fostering in circular economy, the use of alternative fuels as hydrogen, OPS for sure, where everything is related and needs to be put together. That's more complicated.

Interviewer

Which successful policy and management measures or practises do you know for Port greenification?

Interviewee 3

Well, I think these are all. The ones that we have mentioned before are good policies for greenification and let’s say, the ones that are most successful. Here in the Port of Seville, working with nature is a philosophy.

Interviewer

What could ports do to accelerate the application of onshore power supply despite the numerous barriers for OPS implementation?

Interviewee 3

As you know, we are looking for grants to be able to finance the OPEX because it's so expensive and not only for our infrastructure, but also the modifications in the ships that are needed. So yeah, public funds are needed. And the OPEX we are speaking about are not only our OPEX, but also the ship owners OPEX. There are also other struggles like the energy capacity. We have to deal with the energy infrastructure here in Spain. It's difficult for ports to not only have the electrified infrastructure, but also to have the energy capacity.

Interviewer

In ports eyes, are smart and automation measures more applied for economic or for ecologic reasons?

Interviewee 3

I think to be honest that it's more for efficient resources by being economic at the end. But for sure, there are also ecological reasons. But I think do believe that when a terminal is thinking to automate the terminal, they are thinking about efficiency reasons. It will have other good and ecologic, too, consequences, but I don't think it's the first reason.

Interviewer

Between new, replaced or retrofitted operation equipment, how could ports make the right choice?

Interviewee 3

It's not easy. We are working on different European projects. It's not always the same, but I think to summarise that if vehicles or machines could be easily retrofitted, we would beat on that but the technology is not yet completely tested. Sometimes, it's not economically worthy because the machine is very old or the size isn't viable because the city doesn't fit with the new characteristics of the battery, for example, so it's simply not possible. That's why ports need to think of buying new equipment. But I think that once the technology is fully tested and the current equipment is fully depreciated (amortized), that will be the moment where we should replace the old machines for the new ones.

Interviewer

Reduction of vessel speed and berthing time – no or go and why?

Interviewee 3

Well, the entrance into our port is very constrained by the tidal conditions. It usually takes like 5 hours to go from the sea mouth to the port of Seville. I'm not an expert on that but I have heard that a speed beneath 10 knots is not recommended for safety reasons. And berthing time is usually also very influenced by tidal constraints to go out of the Guadalquivir inland waterway. We think that if there was any margin to reduce the speed and berthing time by taking into account these constraints, we would study it. Still, I don't think it would have a very significant impact in our port. And because of these constraints, I don't think we could slow down very much the ships and I don't think we could reduce very much the berthing time. Seaports however do not have these tidal constraints, they just have to deal with the capacity of the terminals. I have heard that for the capacity of their terminals, it would be very good to reduce the berthing time because they will have a larger available capacity in the port. This is not only an ecological

reason, but also an economic reason. And regarding the speed, I think the same accounts more or less, but it's rather the shipping companies which can save fuel and thus emissions. In general, we will have to do a trade-off between being earlier in ports for whatever reasons and ecologic reasons like fuel saving. They will have to think about it.

Interviewer

Which positioning should ports take in the development of alternative fuel use?

Interviewee 3

There are projects to promote it and we think it's not our scope to develop this but to facilitate it to promote the green ports, the green logistic. We have no people available to develop the use of alternative fuels and it's not our role as I said, but we really think that we should promote it, be in contact with the concerned industry, by mounting common projects and facilitating the installations in the port.

But we do have problems when the energy companies come and say they want to have a lot of space for PV, for green energy production. That's something that we cannot feed them with because you have to reserve your spaces for industry or for logistic. Still, there are several projects going on now in the port that are related to the production of alternative fuels. And we really think that we should give them the area. We work with concessions, which is like an official rent that they have to pay us, it's something by law that if you want to be in the port, you have to pay the port authority some taxes. but. And once that's understood, we do not have a problem, but we promote to have industries of these kinds in the port.

Interviewer

Why would ports consider themselves responsible or not for renewable electricity technologies for assisted ship propulsion?

Interviewee 3

I think it's more or less the same than the question about fuels. We as ports need to foster the development of these technologies and even need to produce green electricity in the port as well. But on ships, it's up to the shipping companies to invest in their own technologies for the propulsion of their ships. We can help with that and we will for sure do it and facilitate the change, make our contribution. These green technologies on ships are something now that falls under innovation projects, which we try to foster and also become a pioneer of. Because it is something that we want to happen. But the main problem is also the funding. And once we have the money, we need to look at all the other resources: people, infrastructure, etc. At the moment, we don't have any promotion programme for ships installing renewable energy on their roofs, but we are right now talking to the government to ask for some eco-incentives.

Interviewer

What are possible approaches for ports to successfully integrate the hinterland into their operation?

Interviewee 3

Well, we really work on that, too. We have tried to foster some European projects that were related with the port community, but also the city. It's not only about the internal but the whole

city of Seville. We are increasingly promoting for example the use of green hydrogen, wherefore you need the contribution of all the parties, not only the companies that are fostering the new technologies for either ship or land transport. It is in fact very necessary that trucks are involved, that trains are involved, that ships are involved, that the port terminals are involved with their cranes and their vehicles.

Interviewer

How are the common (future) bottlenecks in clean energy supply for ports usually addressed?

Interviewee 3

I think the only way is by finding the funds and by overcoming the technical constraints. Meetings for the exchange are important as well. We have signed recently an agreement with the energy supply company that is working in Spain because it is in their hand. We are talking about installing further renewable energy sources since this is our main objective but it's really the data of the energy company and they just give us the connexion to the grid. They're really interested in that. As for us, that's what we really want to do, which is why we are trying to see, for example, what kind of energy grids we could install inside the port. That is not easy because of the legislation. So we are trying to study what can be done and what cannot be done yet.

Interviewer

Why would it be crucial or not for ports to install energy management systems to stay competitive?

Interviewee 3

We think that it's something really, really important, not only for environmental reasons, but also for economic reasons, because nowadays, we don't have any numbers. We just receive the invoices and that's all. But we have to check whether the demand of the invoice matches the availability of the electricity in the port or if there is something that is not working correctly. We have just done a pilot project for now to take into account this energy management in one part of the port and it seems to be working well. So yes, having a large energy management system all over the port, in order to check on the energy capacity and to become more economically efficient by reducing excessive consumption.

Interviewer

Last question: in this master thesis, I focussed on emission reduction measures. But are there maybe other environmental topics or issues that need to be addressed by green ports?

Interviewee 3

Well, promoting circular economy is one other topic. In Seville, we try to promote the recycling of metals, scraps, wind turbines. We also try to boost biomass. Also, I said in the beginning that green ports are about working with nature, which is really important for us in Seville. It goes beyond the traditional idea of respecting the environment, it's a way of tackling the challenge we face, not only by minimising the impacts on the environment or by adopting corrections to these impacts, but also by favouring the environmental development and improving nature in order to achieve mutual benefits between the Port and the Guadalquivir environment. We've

been for example working on regenerating the nearby beaches, or on managing the guidelines for landfills that could be used later as bird breeding sites. These are example that have been very successful, and we have received the environmental award from the government in Andalucía for it.

We have also posted a lot for the knowledge of the estuary and the optimization of the navigation, because our activities are not carry out in an isolated environment. We are located in an incomparable natural setting, of great historical and environmental importance, in which we coexist with various actors.

Together with the universities of Seville, Huelva, Málaga, Cádiz and the Higher Council for Scientific Research (CSIC), we study since more than 10 years the functioning of the Guadalquivir estuary, how the tides behave, where the turbidity comes from and how the saline plug and the biological state of the estuary. In this last part, I would also mention that it's important for us to have a strategic noise map, we have sampling stations in the basin for water quality. We are certified ISO 14001 and also have the ECOPORT Certification. In a nutshell, we promote good environmental practices in the Port Community of Seville.

Interview 4:
Director of Energy Transition and Sustainability at Fundación Valenciaport

Interviewer

What is your definition of a green port?

Interviewee 4

For me, a green port is a port of minimum environmental impact, considering environment, society and nature.

Interviewer

What are recommendable practises for the integration of port related stakeholders into the transition towards green ports?

Interviewee 4

To create spaces. How you create the space will be different from port to port, based on dialogue and agreement. Because transforming a regular port to a green port involves not just the Port Authority, but mainly actually concession companies, truck operators, the city. So, you have to find places of dialogue to convince and to collaborate. The port can support on this trip, but in the end, most of the investments fall on the back of the other companies. For example, in the case of the port of Valencia, there is an initiative called ECO Port which is the space of talking about possibilities and collaboration about how the Port Authority can support. It used to be a website in Spanish, but it’s not very updated today. But anyway, the main objective of ECO port is to promote the initiative by having regular meetings with the participants involved. There are usually a couple of meetings a year. The website is an additional tool which would be nice to have updated, but it is not critical.

Interviewer

Which successful policy and management practices do you know for port greenification?

Interviewee 4

In the case of the port of Valencia, it is related to something called environmental task. Environmental task means purification, so there are concessionaires that have to pay for doing their activity at the port of Valencia, but they get benefits if they invest in environmental actions such as retrofitting RTT fleets into electric ones. Going green is expensive so at some point, financial incentives are necessary.

Then, the promotion of green practices via marketing campaigns are nice to have and will become increasingly important, but they are not critical. Operational and logistical issues are today more important in this balance.

Interviewer

What could ports do to accelerate the application of onshore power supply despite the numerous barriers for OPS implementation?

Interviewee 4

It's difficult because it implies a lot of investment and a lot of upgrading. The aspect which is not clear yet is the business of how the operators will operate in the future. So that opens the issues from the technical point of view, from the financial point of view, and also from the operative point of view. So, depending on the type of issues, the ports can do a different thing. For the technical issues, a constant dialogue with technological providers is necessary and to involve innovation actions. We assume that human support gives support to the Port Authority of Valencia and this type of action, because there will be the need of innovation also in OPS. And from the infrastructure, it has to get ready, but this is different from port to port. The Port of Valencia, for example, is the owner of the electric grid, which means that the port itself is responsible for upgrading the electric grid. Electric grid expansion is something needed in every port before going into providing OPS, and it is more difficult when the Port Authority is not the grid owner. These ports need to start conversations, convincing the transmission or distribution system operators to build the upgrade. In terms of business model, the ports need to talk to everyone possibly involved. But it also depends on the regulation, in which sense the Port Authority can also play a role in which to guide the regulators.

Interviewer

In ports eyes, are smart and automation measures more applied for economic or for ecologic reasons?

Interviewee 4

I think initially, the focus lies on economic reasons because you can increase productivity. But it is true that with automation, the electrification is much easier and you can explore other concepts and other technologies that it will be much more difficult with non-automated terminals. I would say that right now, the economy is first, but there is also an increasing interest for ecological energy transition reasons for this type of measure.

Interviewer

Between new replaced or retrofitted operation equipment, how could ports make the right choice?

Interviewee 4

In the case of the Port of Valencia, the Port Authority is not the owner of any equipment. There is not much the Port Authority can do rather than, for example, support innovation actions. I think, it will highly depend on the specific local conditions. For an RTG crane in which the energy part is not very important, but the global investment cost of the RTG is very high, retrofitting may make a lot of sense. In terminals however, trucks which have a smaller life span and where the weight of the total cost of the energetic use is much higher than the equipment investment, it might make more sense to opt for a newly purchased truck. This, however, will also depend on the technology.

Interviewer

Then reduction of vessel speed and berthing time - no or go and why?

Interviewee 4

From Port of Valencia's point of view, ships are the main source of emissions in the port, about half of all emissions. So from that logic, I would say the shorter the ships are at berth, the better. But it also depends on other aspects such as the number of cranes available, the number of containers that you have to move, etc. In a global sense, you have to be as productive as possible in order to stay as less time as possible at port. And then regarding vessel speed, there is a trend to reduce speed because the impact of the speed is quite high on energy consumption. But it also integrates other factors, not just the environmental ones.

Interviewer

Which positioning should ports take in the development of alternative fuel use?

Interviewee 4

In ports, you have the Port Authority which is the manager of the land. And then, for preparing the terminals, you have the concessionaires who also invest inside the terminal and manage the cargo. If we focus on the Port Authority, I think they should be facilitators. Because in the end, the Port Authority will not be the one providing the fuel. There will be others. There will be third companies that apply for the use of some space on the port land to be able to store and supply the alternative fuel. Also, there is currently a huge uncertainty and difficulty to decide which of the alternative fuels that are currently on the table will prosper. So, I would say ports are facilitators and also open to listen to a lot of people involved. And also, ports need to get prepared for the future because some of the alternative fuels will have implications of risk analysis and training in ports. In fact, Port Authorities' personnel needs to be properly trained and informed about the risks of these alternative fuels in the port environment.

Interviewer

Why would ports consider themselves responsible or not for renewable electricity technologies for assisted ship propulsion?

Interviewee 4

It's the same as for the alternative fuels. Ports have to be facilitators, but they are not the regulators, they're not the International Maritime Organisation. So, ports can support ship owners to transform their fleet to carbon neutral use as far as they can, for example through environmental taxes benefits. Authorities have to be technology neutral, meaning open of any alternative that ship owners have in mind.

Interviewer

What are possible approaches for ports to successfully integrate the hinterland into their operation?

Interviewee 4

There is a general trend to move as far as possible to transport with less impact, which highly depends on the specifics of the ports. For using the train, you need railways outside the port. And road transport is probably the most difficult sector to decarbonize in the port activities because there are not mature enough alternatives. The closest one would be renewable natural gas but I honestly do not know how to best decarbonize road transport. In the same way as before, ports have to be facilitators of, for example, new fuels that can help a lot to decarbonize the transport since they are the intermediate. There needs to be a willingness of ports to deliver low carbon fuels in the close port environment. Since the alternatives are not yet in a very mature state, participation in innovation projects is useful to validate some of the alternatives that are on the table right now. To date, there are pure electric trucks, hydrogen trucks, etc. but they are not yet in a very commercial state.

Interviewer

How are the common bottlenecks in clean energy supply for ports usually addressed?

Interviewee 4

By upgrading and increasing the green production of electricity, with wind or solar energy. Explore new options I important, for example offshore potential, but that will depend on the geographical area of each port. Energy storage will be needed, which is a great challenge but also required for integrating the electrification and reduce the peaks of the supply. Also, intelligent grid management is very crucial. These three are main topics to be dealt with in the coming years.

Interviewer

Why would it be crucial or not for ports to install energy management systems to stay competitive?

Interviewee 4

It will not just be a need for being competitive but also for being positive because we are moving from a pretty straightforward energy management, in which the producer produces and there are a lot of consumers. But the energy value chain will be a more complex one in which you will produce yourself electricity at the terminal, you will buy from your neighbour, and you will have surplus all at once. We have to be prepared and foresee the energy demand required.

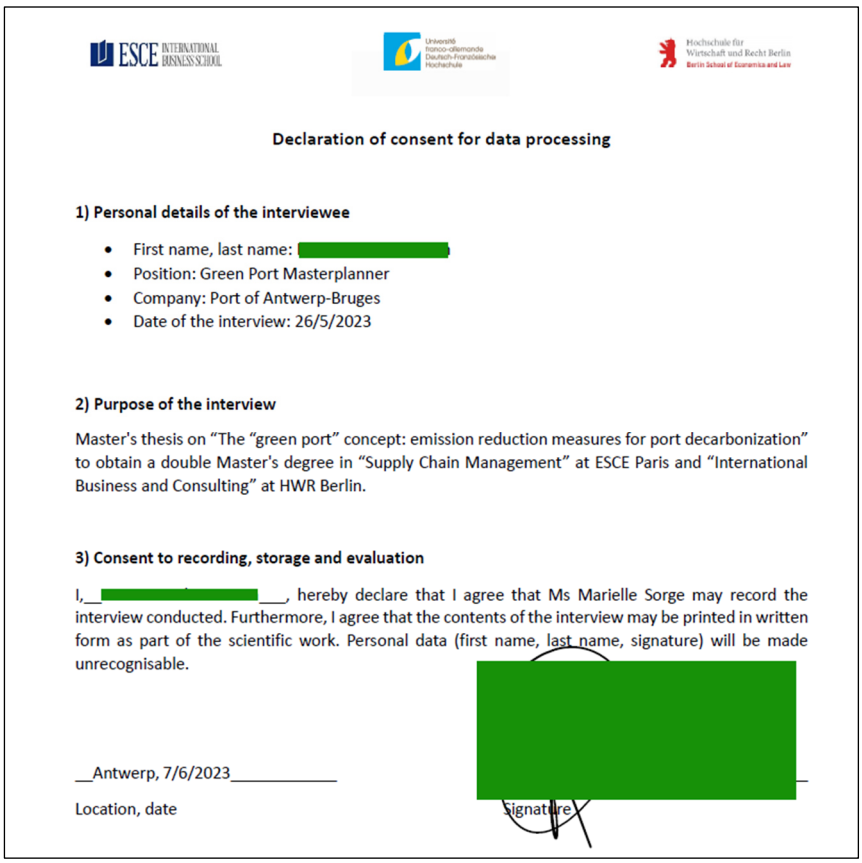
Interviewer

This interview focuses on emission reduction measures in the port and within the green port concept. But are there also other environmental issues that green ports need to address?

Interviewee 4

In fact, other topics are important like traditional environment criteria, meaning air quality, noise, the adequate management, the water surroundings. As for the social aspect, I believe it comes naturally because ports are usually next to a city. And since one of the objectives is having a low impact on the environment, you automatically have a positive impact on the surrounding society, who is the one directly complaining about the port activity.

Annex 6: Declarations of consent for data processing from the interviewees



Declaration of consent for data processing

1) Personal details of the interviewee

- First name, last name: [redacted]
- Position: Green Port Masterplanner
- Company: Port of Antwerp-Bruges
- Date of the interview: 26/5/2023

2) Purpose of the interview

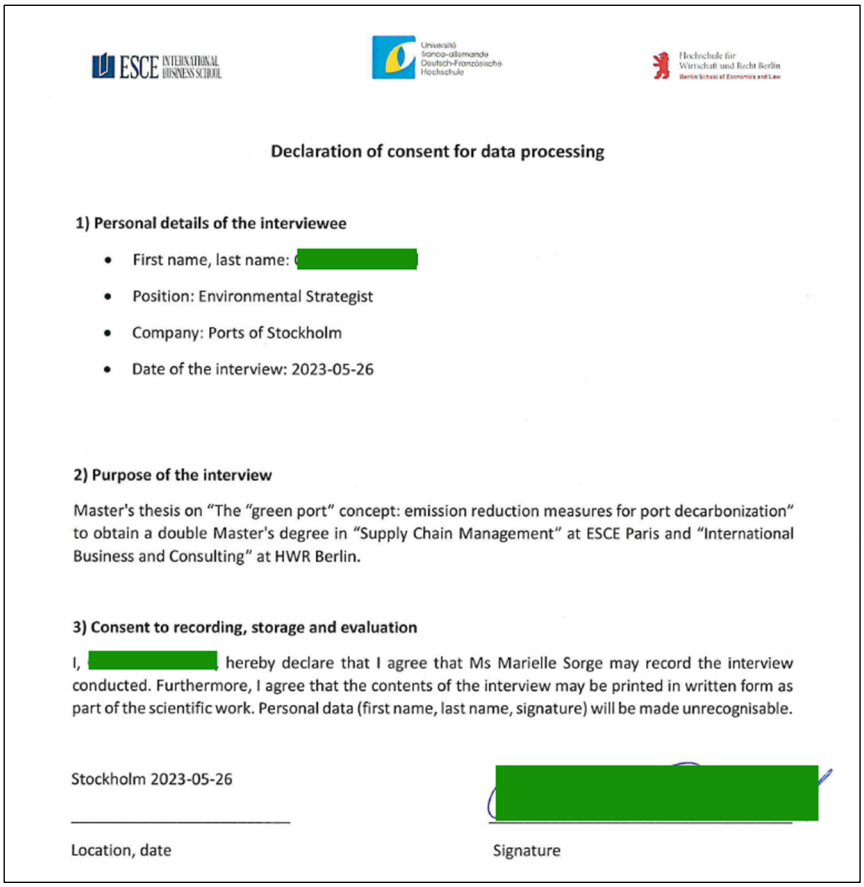
Master's thesis on "The "green port" concept: emission reduction measures for port decarbonization" to obtain a double Master's degree in "Supply Chain Management" at ESCE Paris and "International Business and Consulting" at HWR Berlin.

3) Consent to recording, storage and evaluation

I,__[redacted]___, hereby declare that I agree that Ms Marielle Sorge may record the interview conducted. Furthermore, I agree that the contents of the interview may be printed in written form as part of the scientific work. Personal data (first name, last name, signature) will be made unrecognisable.

__Antwerp, 7/6/2023_____ [redacted]

Location, date Signature



Declaration of consent for data processing

1) Personal details of the interviewee

- First name, last name: [redacted]
- Position: Environmental Strategist
- Company: Ports of Stockholm
- Date of the interview: 2023-05-26

2) Purpose of the interview

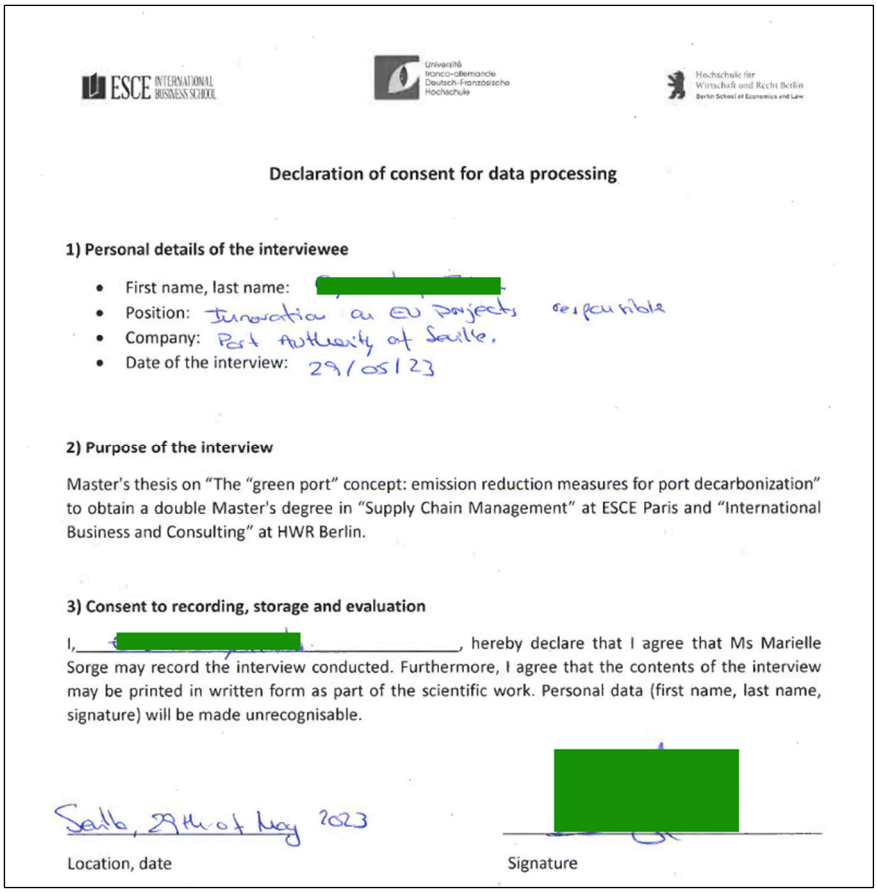
Master's thesis on "The "green port" concept: emission reduction measures for port decarbonization" to obtain a double Master's degree in "Supply Chain Management" at ESCE Paris and "International Business and Consulting" at HWR Berlin.

3) Consent to recording, storage and evaluation

I, [redacted] hereby declare that I agree that Ms Marielle Sorge may record the interview conducted. Furthermore, I agree that the contents of the interview may be printed in written form as part of the scientific work. Personal data (first name, last name, signature) will be made unrecognisable.

Stockholm 2023-05-26 [redacted]

Location, date Signature



ESCE INTERNATIONAL BUSINESS SCHOOL

Université franco-allemande Deutsch-Französische Hochschule

Hochschule für Wirtschaft und Recht Berlin Berlin School of Economics and Law

Declaration of consent for data processing

1) Personal details of the interviewee

- First name, last name: [redacted]
- Position: Innovation on EU projects responsible
- Company: Port Authority of Seville.
- Date of the interview: 29/05/23

2) Purpose of the interview

Master's thesis on "The "green port" concept: emission reduction measures for port decarbonization" to obtain a double Master's degree in "Supply Chain Management" at ESCE Paris and "International Business and Consulting" at HWR Berlin.

3) Consent to recording, storage and evaluation

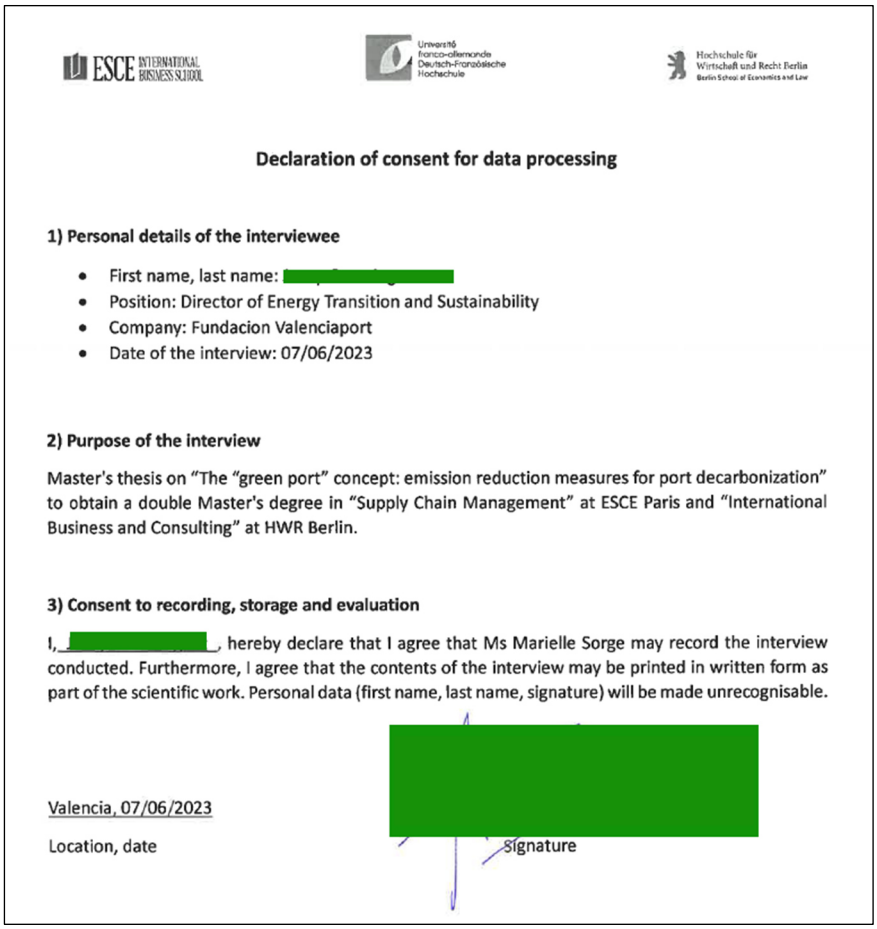
I, [redacted], hereby declare that I agree that Ms Marielle Sorge may record the interview conducted. Furthermore, I agree that the contents of the interview may be printed in written form as part of the scientific work. Personal data (first name, last name, signature) will be made unrecognisable.

Seville, 29th of May 2023

Location, date

[redacted]

Signature



ESCE INTERNATIONAL BUSINESS SCHOOL

Université franco-allemande Deutsch-Französische Hochschule

Hochschule für Wirtschaft und Recht Berlin Berlin School of Economics and Law

Declaration of consent for data processing

1) Personal details of the interviewee

- First name, last name: [redacted]
- Position: Director of Energy Transition and Sustainability
- Company: Fundacion Valenciaport
- Date of the interview: 07/06/2023

2) Purpose of the interview

Master's thesis on "The "green port" concept: emission reduction measures for port decarbonization" to obtain a double Master's degree in "Supply Chain Management" at ESCE Paris and "International Business and Consulting" at HWR Berlin.

3) Consent to recording, storage and evaluation

I, [redacted], hereby declare that I agree that Ms Marielle Sorge may record the interview conducted. Furthermore, I agree that the contents of the interview may be printed in written form as part of the scientific work. Personal data (first name, last name, signature) will be made unrecognisable.

Valencia, 07/06/2023

Location, date

[redacted]

Signature

Annex 7: Enthusiastic survey and interview feedback and result requests

Bonjour,

Je vous remercie de votre intérêt, et relaie votre message à [redacted] (en copie de ce message), en charge du suivi de ces sujets.

Bien cordialement,

Bonjour,

Je vous remercie de votre message et tenterai de répondre à votre question.
Pour éviter tout doublon d'envoi, l'avez-vous déjà diffusé auprès des ports français et de l'European Seaports Organization (ESPO)?

Cordialement

Dear Ms Sorge,

Thank you for your email, and for sharing the invitation to answer the survey. I will fill it in this afternoon.

Best regards,

Bonjour Madame Sorge,

Vous pouvez compter sur moi pour répondre au questionnaire.

Bien cordialement

Sehr geehrte Frau Sorge,

haben Sie vielen Dank für Ihre Anfrage zu der interessanten Thematik Ihrer Master-Arbeit.
Bitte entschuldigen Sie unsere späte Rückmeldung, leider sind wir derzeit krankheits- und Geschäftsreisen-bedingt personell stark eingeschränkt.

Wir bedauern es sehr, dass wir aus diesem Grund in dem angefragten Zeitraum leider keine personellen und zeitlichen Kapazitäten für die Beantwortung der Fragen oder für ein Gespräch haben.

Gerne hätten wir Ihnen inhaltlich weitergeholfen und wünschen Ihnen weiterhin viel Erfolg bei Ihrer Masterarbeit.

Kommen Sie zukünftig gerne wieder mit Anfragen auf uns zu.
Mit freundlichen Grüßen

Guten Tag Marielle Sorge,

wir haben Ihre Nachricht erhalten.

Wir werden uns mit Ihnen baldmöglichst in Verbindung setzen.

Wir bitten um Verständnis, dass die Bearbeitung ein paar Tage in Anspruch nehmen kann.

Mit freundlichen Grüßen,

Sehr geehrte Frau Sorge,

vielen Dank für Ihre Anfrage.

Ich werde schauen, dass ich Ihre Umfrage bis zum 25. Mai 2023 ausfülle.

Beste Grüße und weiterhin viel Erfolg bei Ihrer Masterarbeit

Mit freundlichen Grüßen

Bonjour,

Je transfert votre email à des collègues qui seront plus en position de vous répondre.

Sincères salutations

Hallo Marielle Sorge,

vielen Dank für Ihre Anfrage, die ich an die [redacted] Port Authority weitergeleitet habe [redacted] . Ich hoffe, dass sich jemand bei Ihnen meldet. Für Ihre Abschlussarbeit wünsche ich Ihnen Glück und Erfolg!

Freundliche Grüße

Sehr geehrte Frau Sorge,

gern werden wir sie im Rahmen ihrer Ausarbeitung unterstützen und an ihrer Umfrage teilnehmen. Ich leite diese hausintern an den richtigen Ansprechpartner für ihr Anliegen weiter.

Mit freundlichen Grüßen

Liebe Marielle,

ich schreibe gerade selbst meine Masterarbeit und fühle also mit dir 😉 Deinen Fragebogen fülle ich natürlich gerne aus. Da ich selbst noch nicht so lange beim [redacted] Hafen bin, bin ich noch nicht mit allen Themen zum „Green Port" vertraut, aber versuche es bestmöglich zu beantworten. Ich leite deinen Fragebogen auch intern an meine Kollegen weiter.

Hast du den Fragebogen auch an die [redacted] und die [redacted] verschickt? Falls nicht, würde ich dir auf jeden Fall dazu raten! Beide Unternehmen sind wesentliche Treiber was Energy Transition, Landstrom, Digitalisierung/Automatisierung, etc. im [redacted] Hafen angeht. Die [redacted] betreibt auch Terminals in anderen europäischen Häfen, da könntest du also auch internationale Insights bekommen.

Eine Frage in eigener Sache: Meine Masterarbeit geht um das Thema Employer Branding/Arbeitgeberattraktivität. Ich möchte dabei Studierende befragen, was für sie einen attraktiven Arbeitgeber ausmacht, um herauszufinden, was Betriebe im [redacted] Hafen kommunizieren sollten, um neue Arbeitnehmer für sich zu gewinnen. Die Umfrage richtet sich speziell an Studierende aus dem Bereich Logistik (im weitesten Sinne). Würdest du mir den Gefallen tun und meinen Fragebogen ausfüllen und an deine Kommilitonen weiterleiten?

Liebe Grüße und viel Erfolg mit deiner Thesis,

Bonjour Mme, j'ai répondu à l'enquête ce matin.
Bonne lecture.

Cordialement,

Lieber [redacted]

Könntest du diese Umfrage übernehmen bzw. an deine zuständigen Kollegen weiterleiten?

LG

hallo Frau Sorge, ich sehe mir den Fragebogen nachher mal im Detail an. Sollte sich einrichten lassen, das bis 17.05. fertig zu kriegen. Wenn mir jemand über den Weg läuft, den ich auch noch an quatschen könnte auf Mitwirkung hin, sage ich Bescheid. Nicht ganz unwahrscheinlich, ich bin in München auf der Transport Logistik Messe.

cheers / s

Dear Marielle
A's i AM retired, I forward this e-mail to environmental manager [redacted]

Dear Marielle,

Thank you for your message!

I'd be happy to help you with your research. How would next Friday, May 26th, work? I have 30 minutes available at 13h00.

Have a great day,

Dear Marielle,
plese e-mail [redacted] to do your survey, he has all the facts and figuers:)

Allt gott - Best Regards,

Sehr geehrte Frau Sorge,

meine Kollegin Frau [redacted] sollte Ihnen in meiner Abwesenheit geantwortet haben. Sollten Sie noch weitere Fragen haben, melden Sie sich gerne.

Mit freundlichen Grüßen

Sehr geehrte Frau Sorge ,

bitte entschuldigen Sie die verspätet Rückmeldung.

ich habe Ihre Mail an Herrn [redacted] Abteilung Marketing weiterleitet.

Herr [redacted] hat mir mitgeteilt, dass er mit Ihnen in Kontakt treten wird.

Liebe Grüße

Estimada Sra. Sorge:

Acusamos recibo de su email y damos traslado del mismo a nuestro Departamento Técnico, por si fuera posible atender la encuesta.

Atentamente,

Dear Marielle,

Thank you for your mail.

I would be happy to talk to you regarding the transition towards green ports.

I am for example available:
26th of May at 1500
29th of May at 1500
30th of May at 0900-1100 or 1400-1600

Kindest regards,

Dear Marielle,
Thanks for contacting, sure, I would love to help you.
Would you be available next Monday at 14.00?
Kind regards,

Dear Marielle,

So nice to talk to you!

Here is the signed declaration. Good luck with your work!

All the best,

Good afternoon Marielle,
Here you have the documents.
Kind regards and good luck!

Cher,

J'ai rempli votre questionnaire au mieux de mes capacités. Si vous avez d'autres questions concernant votre enquête, vous pouvez toujours poser des questions spécifiques.

Cordialement,

Cher,

Votre message ci-dessous a été bien reçu.
Je l'ai transmis à l'expert 'Green Ports' du Port of [redacted]. (lit en cc.)
Il remplira le questionnaire.

Salutation distinguée,

Dear Marielle,

Thanks for reminding me, please find the signed form in attachment!

How are you doing with your research? I hope you're finding interesting insights and lots of inspiration!

Good luck,

Hello, Marielle,

I've recieved an email from <marielle.sorge@edu.esce.fr> asking to answer questionair. The email is written in lithuanian language and it looks suspicious as you are studying in frech/german. The topic "Green port" is relevant for me and I'd be glad to answer it if you are really carrying such. I want to find out if it is not a decietful email before pressing on the link.

[redacted]

Bonjour, J'ai rempli l'enquête.
Cordialement.

Requests for survey results

Dear Marielle,

I just responded to your Master Thesis questionnaire on "Green Ports". I thought it was very thorough and well-constructed. If you would be so kind as to share the results when they are ready, I would be most obliged.

I wish you good luck in your work!

Yours sincerely,

Sehr geehrte Frau Sorge,

ich habe Ihren Fragebogen nach bestem Wissen ausgefüllt und werde ihn ebenfalls weiterleiten, damit sich noch weitere Unterstützer finden.
Über die Zusendung der Ergebnisse würde ich mich freuen.

Mit freundlichen Grüßen

Sehr geehrte Frau Sorge,
ich habe Ihre Umfrage beantwortet und an Akteure weitergeleitet, die Ihnen vielleicht noch andere Blickwinkel auf Ihr Thema ermöglichen. Natürlich würde ich mich freuen, wenn Sie mich nach Abschluss über die Ergebnisse Ihrer Umfrage und ggfs. das Ergebnis Ihrer Studienarbeit informieren.

Mit freundlichen Grüßen

Dear Marielle,
Please notice that I and also few of my colleagues from [redacted] port administration have already completed your questionnaire during the previous week. Please provide us with the feedback after the deadline.
Kind regards
[redacted]

Dear Mrs Sorge,

My name is [redacted] and i am Director of Sustainability & Environmenta Strategy at [redacted] I would like to thank you for choosing us to participate and contribute to your research, and to inform you that we have completed the questionnaire you sent us and wish you good luck in completing your postgraduate diploma. We look forward to receiving the results of your research.

Thank you & kind regards,

Hallo Frau Sorge,

vielen Dank für Ihre Anfrage. Wir unterstützen Sie gerne.

Wir sind sehr interessiert an den Studienergebnissen und würden uns freuen, wenn Sie uns diese nach Beending zukommen lassen würden.

Vielen lieben Dank & alles Gute

Dear Marielle,

Thank you for your mail. Your Master's thesis sounds really interesting and it will be interesting to see the results of your survey when they are available.

Our Head of Sustainable Development Mr. [redacted] is cc in this mail. His the right person to answer to your questions in your survey and he might also know the right person in other [redacted] ports that could participate in this survey.

Have a great weekend,

Best regards

Dear Ms. Sorge,

Thank you for your interest in our port.

My colleague [redacted] will get in contact with you to arrange an interview.

I wish you very fruitful discussions and look forward to receiving the final results of your study.

Kind regards,

Liebe Frau Sorge,

ich nehme mir gerne die Zeit. Ich bin allerdings noch nicht so lange am Hafen [redacted] tätig, daher würde ich die Fragen gerne gemeinsam mit meinem Team besprechen, um Ihnen hier auch eine zuverlässige Einschätzung zu Ihren Fragen zu gewährleisten - bitte Sie also um etwas Geduld aber bis zum 25.05.23 sollte machbar sein – passt dies so für Sie? Zudem werde ich Ihren Fragebogen gerne auch an wirklich tolle, versierte Kolleg:innen weiterleiten, wir sind jedoch alle bis Anfang Juni sehr eingespannt- ich hoffe sie bekommen dennoch Rückmeldungen.

Gerne übermitteln Sie mir im Nachgang die Ergebnisse der Umfrage.

Liebe Grüße und viel Erfolg bei Ihrem Masterabschluss.
[redacted]

PS Da ich selbst gerade dabei bin mich für meine Arbeit in das Thema der „Emissionsminderungsmaßnahmen in (Binnen)häfen " und „Klimaneutralität in (Binnen)häfen" einzulesen, würde ich mich über gute Literatur Tipps Ihrerseits freuen.

Hey Marielle,
Ich habe deine E-mail über deine Masterthesis bekommen und dich hier gefunden - wollte schnell nachschauen ob ich dem Link folgen kann, wir haben in letzter Zeit so viel Spam bekommen.
Dein Thema hört sich spannend an, wirst du die Ergebnisse deiner Thesis vielleicht sogar teilen können?

Could you pls. send the results of your study to me?
[redacted]
Thanks
:-)

+ the 4 interviewees

Annex 8: Three-dimensional data compilation for recommendations

Detailed qualitative data argument list for main measures and sub-measures

Environmental policy and regulatory framework

Global governance initiatives

Questionnaire comments	• 1 respondent: regulation • 1 respondent: funding options • 1 respondent: "regulation, regulation, regulation" • 1 respondent: "ports are organized in different ways but they need the necessary resources (human resources, regulation, finances) to develop the necessary changes" • 1 respondent: counts on an upcoming regulation obliging shipping lanes to use OPS when they are in ports • 1 respondent: environmental assessment schemes and certification to motivate the port management to take action • 1 respondent: "coherence vis-à-vis existing European and national legislation, and with the recently de-fined policy initiatives and objectives set out in the European Green Deal, the RepowerEU plan and the Net-Zero Industry Act"
Interview comments	• Interviewee 2: "the fit for 55 package and the FuelEU and Maritime legislations will now push OPS further, with the obligation to install OPS in all TEN-T ports until 2030" and that "the customers are much more aware now of higher environmental standards". • Interviewee 1: "It's actually a bit of a chicken and egg problem, a paradoxical situation in which the sector calls for clarity on roles and responsibilities. But I would think that once the policymakers in Europe take an initiative and make clear what the roles and responsibilities are, they will face a lot of resistance from the sector - (…) that's not how the democratic pro-cess in Europe works". • Interviewee 4: "In terms of business model, the ports need to talk to everyone possibly involved. But it also depends on the regulation, in which sense the Port Authority can also play a role in which to guide the regulators" • Interviewee 3: "we are looking for grants to be able to finance the OPEX because it's so expensive and not only for our infrastructure, but also the modifications in the ships that are needed" • Interviewee 2: incentive contribution of 1,000,000 Swedish crowns made to a vessel that has been retrofitted to OPS • Interviewee 3: pilot project for energy management system which the port has just terminated and which seems to be working well • Interviewee 1: investment in so-called lighthouse projects for demonstration of systemic change or innovation
Literature	• It has, for instance, been proven that port policy is strongly and directly influencing green port implementation (Munim et al., 2022) • In Europe as well as on a global scale, however, there are large observable differences from country to country and from port to port in regard to the adoption of environmental measures, which is directly related to the local geographical, economic, regulatory and political context. (Sornn-Friese and Poulsen, 2016; Lam and Notteboom, 2014) • The literature is broadly calling for more intervention from international organizations regarding international guidelines and regulations. (Tseng and Pilcher, 2019) • Report of the Intergovernmental Panel on Climate Change and resulting initiatives. (Howell et al., 2017) • Initiatives from United Nations Framework Convention on Climate Change. (Talberg et al., 2013; IPCC, 2011) • Signature of the Kyoto protocol. (Reynolds et al., 2017; Dutton, 2015) • Signature of the Paris Agreement. (Reynolds et al., 2017; Dutton, 2015) • Adoption of the UN 17 Sustainable Development Goals under the 2030 Agenda. (Argyriou et al., 2022) • Adoption of the International Convention for the Prevention of Pollution from Ships (MARPOL) by IMO. (Castellano et al. 2020)

	• Proposition of the Maritime Environmental Protection Committee (MEPC). (IMO, 2005) • Report of the International Association of Ports and Harbors (IAPH) and IMO. (Wang et al., 2023) • Publications of the World Ports Climate Initiative (WPCI). (WPCI, 2010) • Publication of the Organisation for Economic Cooperation and Development (OECD). (OECD, 2011) • Introduction of emission and pollution reduction measures by IMO. (IMO, 2011; IPCC, 2013) • Publication of IMO's 'Initial Strategy' and related "Port Emissions Toolbox". (IMO, 2018a; IMO, 2018b) • Adoption of resolution MEPC.323 by IMO. (IMO, 2019) • European Green Deal. (EC, 2021a; EC, 2021b; EC, 2019) • European Climate Law. (EC, 2021a; EC, 2021b; EC, 2019) • EU 'Fit for 55' Package. (EC, 2021a; EC, 2021b; EC, 2019) • Green practice programs by the European Sea Port Organisation (ESPO). (ESPO, 2016)

Voluntary vs. compulsory incentives

Questionnaire comments	• 8 respondents: funding, subsidies and eco-incentives are the most needed incentives for pro-environmental actions • 5 respondents: European research and funding programs
Interview comments	• Interviewee 4: funding, subsidies and eco-incentives are the most needed incentives for pro-environmental actions • Interviewee 2: "either we had the investment for the installation of OPS in the port but no customers or vice versa". For encouragement of the customers, an environmental discounted port fee has set up for a long time.
Literature	• In spite of the rewarding measures, the literature mentioned economic governmental subsidies and funding programs, tax rate reduction and port fee discount, and for the punishment measures, air pollution pricing, the imposition of fines and forced suspension of business have been suggested. (Xu et al., 2021; Wang et al., 2020; Tseng und Pilcher 2019; Radu and Grandidier, 2012; EU, 2003) • Punishment measures should be controlled within a reasonable scope to avoid fur-ther negative influences (Xu et al., 2021)

Renewable electricity sources

General

Questionnaire comments	• 1 respondent: "the use of locally produced renewable energy is very dependent on the actual port layout. In some cases, own production can be very feasible, but for example in our case, the reliance on the massive development of the national renewable energy production is a better option" • 1 respondent: need for resilience • 1 respondent: role of ports becoming energy hubs • 1 respondent: review of the 2013 TEN-T guidelines, through which the Transport Council tries to motivate ports to join the comprehensive network if they "contribute to diversification of energy supplies and acceleration of renewable energy as main activity of the port" • 1 respondent: the different technological options depend on the exact geographic and meteorologic conditions in a port • 1 respondent: need for sufficient energy capacity • 2 respondents: collaboration with the energy sector, implying both energy companies and local transmission systems operators • 1 respondent: expressions of interest for an overview of capacity need • 1 respondent: repowering of both wind turbines and PV panels after a certain time of operation, usually between 20 and 30 years, because "in that way, more output electricity can be produced within the same available space" • 2 respondents: collaboration with the energy sector, implying both energy companies and local transmission systems operators

	• 1 respondent: feasibility analysis and a study on the conditions of construction for renewable energy sources, also including a proposal for implementation, follow-up actions and recommendations
Interview comments	• Interviewee 2: "we will need quite a lot of power reinforcement to our ports. We need to go up to 200 meg-awatts in 2030 and we now have, I think 70 or 80 megawatts. (…) In the process, we are mainly talking to the grid owner. (…) Since they need five or six years to be able to come up to that power, it takes a lot of time, and it costs us very much. That's the problem, really" • Interviewee 3: "the only way is by finding the funds and by overcoming the technical constraints. Meetings for the exchange are important as well. We have recently signed an agreement with the energy supply company that is working in Spain because it is in their hand (…), they just give us the connection to the grid" • Interviewee 4: "by upgrading and increasing the green production of electricity, with wind or solar energy. Exploring new options is important, for example offshore potential, but that will depend on the geographical area of each port. Energy storage will be needed, which is a great challenge but also required for integrating the electrification and reduce the peaks of the supply. Also, intelligent grid management is very crucial. These three are main topics to be dealt with in the coming years" • Interviewee 4: "it will not just be a need for being competitive but also for being positive because we are moving from a pretty straightforward energy management, in which the producer produces and there are a lot of consumers. But the energy value chain will be a more complex one in which you will produce yourself electricity at the terminal, you will buy from your neighbour, and you will have surplus all at once. We have to be prepared and foresee the energy demand required" • Interviewee 1: "would say we need more focus also on different ways of thinking and different ways of organizing" when it comes to addressing the future electricity bottlenecks of ports
Literature	• Since the source of emission is transferred to the source of power generation, the indirect life-cycle emissions need to be considered, too, including emissions from energy extraction, transportation, consumption and generating stations, (Peng et al., 2021) • "The percentage of energy from renewable resource" is considered a typical KPI for green and sustainable port evaluation. (Buiza et al., 2015; STP, 2015; Acciaro et al., 2014) • Renewable power-purchase agreements can be signed (Li et al., 2019; PIANC, 2019; Christo-foraki and Tsoutsos, 2017; Blazauskas et al., 2015)

Solar energy

Questionnaire comments	• 2 respondents: installation of PV panels on rooftops of port buildings to solve the space availability, which requires cooperation with the building owners • 1 respondent: installing solar panels on the sea water surface inside the port area
Interview comments	• Interviewee 3: "we do have problems when the energy companies come and say they want to have a lot of space for PV, for green energy production. That's something that we cannot feed them with because we have to reserve our spaces for industry or for logistic"
Literature	• Solar = In several assessments for renewable energy opportunity in ports, photovoltaics ended up having the highest applicability rate. (PLB, 2016) • Solar water heating (SWH) accounts more for high-temperature industrial processes, whereas photovoltaic (PV) converts the directly radiated light into electricity, with monocrystalline solar cells being the most efficient panel type. (Hess et al., 2011; Labouret and Villoz, 2010; Hagopian et al., 2007) • Unexploited areas like empty pieces of land or the rooftops of ship or container docks, buildings, warehouses, cruise terminals are ideal installation surfaces for PV. (Sifakis and Tsoutsos, 2021; Song and Poh, 2017; Boile et al., 2016; Vincent, 2014; E-Harbours Electric, 2012)

Wind energy

Questionnaire comments	• 1 respondent: seaports to be great locations for the installation of offshore wind parcs
Literature	• Since port areas are often exposed to high-speed wind, their location is ideal for using wind as energy source. (Li et al., 2018; Weiss et al., 2018; Kotrikla et al., 2017; Yarova et al., 2017; Spiropoulou et al., 2015; Solari et al., 2012) • The turbines can be installed at onshore and offshore sites, but offshore sites are more effective and stable. (Cavvazi and Dutton, 2016)

	• In order to determine the ideal location for wind turbine installation, parameters such as wind speed, geological structure of the site, transmission networks and the required material and mineral sources need to be evaluated. (Blazauskas et al., 2015)

Tidal energy

Literature	• Marine energy: feasibility studies before implementation are inevitable. (Cascajo et al., 2019; Li et al., 2018)

Geothermal energy

Literature	• Geothermal energy = due to very scarce research, the efficiency and applicability of geothermal energy in ports remains unclear. (Sifakis and Tsoutsos, 2021)

Fuel cells

Questionnaire comments	• Q26: 67,31% of respondents believe that fuel cells will play a mayor role in balancing intermittencies for (partly) self-reliant ports in the near future.
Literature	• When being used as a back-up or emergency installation, critical loads can be provided con-tinuously, based on green electricity sources, replacing polluting technologies such as diesel generators, meanwhile also serving as a reliable and resilient solution in comparison to the national power grid or intermittent renewable sources only. (Kinnon et al., 2021)

Green port management

General

Questionnaire comments	• 1 respondent: “the management of every port needs to make the first steps. "Not having the time and resources" is a reason for insufficient environmental action but being aware of this gives the opportunity to change it”
Interview comments	• Interviewee 1: “having port authorities being more of managing stakeholders, I think we need to move more towards a participation approach where we really co-create, cooperate” for a common strategy of a desired green port, as well as by setting up all kinds of corporations on the operational level • Interviewee 3: philosophy of working with nature • Interviewee 1: investment in so-called lighthouse projects for demonstration of systemic change or innovation
Literature	• Port management which drives the development of green ports the most, meanwhile still considered as being the least competitive attractiveness factor of ports today. (Munim et al., 2022) • Port authorities are increasingly pressured to greening their ports, not only in view of growing their environmental and economic competitiveness, but also for safeguarding their ‘license to operate’. (Roh et al., 2016; Lam and Van der Voorde, 2012) • Setting environmental parameters enables green port evaluation and in result, better govern-ance practices. (Hua et al., 2020) • Integrating the human factor into the transition to green ports is fundamental for port operators to really understand the potential environmental risks, pollution reduction measures and corporate social responsibility (CSR) actions planned to fully support the green port project. (Campisi et al., 2022; Heij and Knapp, 2012; Mellin and Rydhed, 2011; Petrosillo et al., 2009)

Stakeholder participation

Questionnaire comments	• 2 respondents: strategic agreements or Memorandums of Understanding • 7 respondents: Cooperation and collaboration between stakeholders • 1 respondent: “setting up logistic chains, share expertise, share costs, use synergies, strengthen competitiveness” • 1 respondent: general sharing of information • 1 respondent: building of port community networks • 1 respondent: collaborative planning platform

	• 1 respondent: engagement of consultants
Interview comments	• Interviewee 3: "everything is related and needs to be put together. That's more complicated" • Interviewee 1: "The shipping industry is what I call a self-organized ecosystem, so it's got many, many parties that play a small role in a very large chain of events or a very large supply chain without having really one single responsible for the entire chain, right? So, the actor field in the port is very complex, very diverse" • Interviewee 1: "I wouldn't say there's a lot of trust in between all parties in the sector • Interviewee 2: collaboration between stakeholders: "When it comes to the shipping customers, the direct dialogue is mostly done through our market department and those responsible for different shipping segments within our organisation. So they have the dialogue with the customers, but I think that we need to perhaps change that for the future. We need to have a more active dialogue around environmental issues" • Interviewee 1: "having port authorities being more of managing stakeholders, I think we need to move more towards a participation approach where we really co-create, cooperate" for a common strategy of a desired green port, as well as by setting up all kinds of corporations on the operational level • Interviewee 4: "to create spaces. How you create the space will be different from port to port, based on dialogue and agreement. So, you have to find places of dialogue to convince and to collabo-rate" • Interviewee 4: regular meeting and also through a dedicated website • Interviewee 2: "need to be more systematic and more structured in our dialogue with the shipping customers".
Literature	• Cooperation between all these named stakeholders is a complex task, especially in regard to finding common goals. But at the same time, coordination is essential for green port implementation to succeed. (Cheon, 2017; Le et al., 2014) • The term stakeholders refers to "an individual, a group, or an organization affected by the proposed changes, such as shipping companies, store owners, local industry, local organizations, and social and academic institutions such as schools and universities". (Kahane et al., 2013)

Integration of environmental managers

Questionnaire comments	• 1 respondent: "ports are organized in different ways but they need the necessary resources (human resources, regulation, finances) to develop the necessary changes" • Q9: 87,5% of questionnaire respondents agreed on importance of hiring environmental managers or agents • 1 respondent: besides the management, the staff was described to be needed to be engaged, too.
Interview comments	• Interviewee 1: "having port authorities being more of managing stakeholders, I think we need to move more towards a participation approach where we really co-create, cooperate" for a common strategy of a desired green port, as well as by setting up all kinds of corporations on the operational level
Literature	• One way to integrate the human factor is through the integration of sense-agents into the change process, who will take the key role of giving the port employees a meaning to the environmental reform, materialize the reform plan into action and create a 'going green' identity. (van der Heijden et al., 2012; Dunphy et al., 2007) • The implementation of environmental multi-disciplinary teams as appropriate and integrated approach of port management is suggested in the literature, to encourage participation and motivation towards port greenification. (Pavlic et al., 2014) • Another fundamental component within the environmental governance system of ports is the engagement of so-called climate change managers, environmental managers, and energy managers. (Pavlic et al., 2014; Ng et al., 2013) • Implementation of national umbrella organizations to fulfil the need for coordination and uniformity in the promotion of the green port concept. (Homsombat et al., 2013)

Green port strategies

Questionnaire comments	• 3 respondents: need for clear green port strategies including fixed priorities and key objectives • 1 respondent: "reports on emissions and measures are very important for transparency" • Q10: 94,64% of questionnaire respondents agreed on need for green marketing strategy
Interview comments	• Interviewee 1: "what we tried to do is to make that visible, to inspire the community to make that also part of the mainstream, like to create a sense of urgency also with all of the others. Having them become

	aware of their peers will make people more tempted to move themselves as well or act, that's a psychological thing" • Interviewee 4: "the promotion of green practices via marketing campaigns are nice to have and will become increasingly important, but they are not critical. Operational and logistical issues are today more important in this balance" • Interviewee 2: A long-term environment and climate action plan: "for each environmental goal, we have identified a few strategies to work on, to be able to fulfil these environmental targets. Then, each year, every department within the Port of Stockholm implements their budget, including their respective action plan activities for the next year. In that way, the activities and budget can be united" • Interviewee 1: "having port authorities being more of managing stakeholders, I think we need to move more towards a participation approach where we real-ly co-create, cooperate" for a common strategy of a desired green port, as well as by setting up all kinds of corporations on the operational level • Interviewee 4: strategy being "related to something called environmental task. Environmental task means purification" • Interviewee 2: A long-term environment and climate action plan: "for each environmental goal, we have identified a few strategies to work on, to be able to fulfil these environmental targets. Then, each year, every department within the Port of Stockholm implements their budget, including their respective action plan activities for the next year. In that way, the activities and budget can be united" • Interviewee 1: "what we tried to do is to make that visible, to inspire the community to make that also part of the mainstream, like to create a sense of urgency also with all of the others. Having them become aware of their peers will make people more tempted to move themselves as well or act, that's a psychological thing"
Literature	• Firstly, to reflect the environmental commitment of the port management, it is recommended to specify the latter in the mission statement, vision, or organizational goals, which leads to differentiation from competitors. Secondly, the responsible bodies for environmental measures need to be integrated into the port's structure, for example into the organization-al chart. Thirdly, the environmental functions need to be clear, such as sections dedicated to climate and sustainability, separate annual and environmental reports, or plans or development initiatives, published for example in reports, news releases, publications, or the port's websites. In general, it is necessary for environmental measures to be in line with the overall port strategy. In this regard, it is essential for the green marketing efforts to be representative and transparent, to avoid greenwashing and thus credibility in the customers and authorities' eyes. (Lam and Li, 2019) • Let go of today's mainly used private governance model, which stand for monopolistic be-haviour, port speculation and missing interest in the long-term perspective of port development. Instead, the landlord model is recommended to be introduced, opening the opportunity to push private operators to implement green practices. (Munim et al., 2020)

Alternative fuels

General

Questionnaire comments	• 1 respondent: immediate solutions to replace currently used diesel is needed • 1 respondent: need of exploring all possible energy production options • 1 respondent: necessity in the feasibility of new fuels which need to be analysed and tested, both in terms of operation and cost-effectiveness • 1 respondent: need for sufficient energy capacity • 2 respondents: closer collaboration between ports, energy companies and local industry for assuring availability, operating the infrastructure, and financing the projects • 1 respondent: Furthermore, procedures for letters of intent or expressions of interest are said to be needed to be set up for assuring sufficient fuel capacity, and to have a robust supply process by the operators
Interview comments	• Interviewee 4: "Port Authorities' personnel (…) to be properly trained and informed about the risks of these alternative fuels in the port environment" • Interviewee 2: "We look at the port as a hub to be able to provide fuels and energy both for the shipping sector but also for road transport, for example from the port and inlands. This topic of ports becoming energy hubs is very interesting and a growing issue in the future" • Interviewee 4: "there is currently a huge uncertainty and difficulty to decide which of the alternative fuels that are currently on the table will prosper" • Interviewee 1: "ports should include options for all these fuels. LNG, hydrogen, ammonia. Methanol. I'm not too big of a fan of biofuels"

	• Interviewee 1: European Port Services Regulation • Interviewee 4: "If we focus on the Port Authority, I think they should be facilitators. Because in the end, the Port Authority will not be the one providing the fuel. There will be others. There will be third companies that apply for the use of some space on the port land to be able to store and sup-ply the alternative fuel" • Interviewee 3: "we have no people available to develop the use of alternative fuels and it's not our role as I said, but we really think that we should promote it, be in contact with the concerned industry, by mounting common projects and facilitating the installations in the port" • Interviewee 1: "first and foremost providing a framework, because a port is responsible for safeguarding safety in the port", falling under the European Port Services Regulation. He adds that "the port could also provide land where intermediate storage of these compounds can happen. (…) There is plenty of storage capacity today for conventional, fossil fuels in the port, and since these fuels in a way chemically and physically very comparable, there is no need to have specific infrastructure for that". • Interviewee 2: "In order to decide which fuels will be used, we need again the dialogue with the customers and the surrounding society. But I see that we would have actors who can perhaps have a fuelling station close to the port for heavy vehicles and decide with them what kind of fuels we will be able to offer. Will it be electricity? Biodiesel, LNG?" • Interviewee 4: "It's the same as for the alternative fuels. Ports have to be facilitators, but they are not the regulators, they're not the International Maritime Organisation. So, ports can support ship owners to transform their fleet to carbon neutral use as far as they can, for example through environmental taxes benefits. Authorities have to be technology neutral, meaning open of any alternative that ship owners have in mind"
Literature	• Since ship fuels like marine diesel oil (MDO) or heavy fuel oil (HFO) are poor in quality with high viscosity, high density as well as high ash and sulphur content, their resulting emissions are tremendous. (Zhan et al., 2019; Zetterdahl et al., 2016) • Ports need to build the corresponding infrastructure, including charging piles, storage facili-ties and pipelines. (Wang et al., 2023)

LNG

Literature	• Liquified natural gas (LNG) plays a superordinated role for the decarbonization of shipping and is also the current most mature option of all alternative fuels. (Daniel et al., 2022; DNV, 2019; IMO, 2016) • LNG = counts several advantages over other alternative fuels, which are mainly technological advances, cost effectiveness, higher energy density and higher thermal efficiency. (Hoang et al., 2022; Ni et al., 2020; Ammar, 2019b; Thomson et al., 2015; Banawan et al., 2009) • LNG = The disadvantages of LNG are flammability, methane leakage, spacious infrastructures for storage and bunkering, imperfect technical specifications, insufficient price competitive-ness, reduced market and supply issues, uncertainty of operational risk and regulation. (Peng et al., 2022; Alamoush et al., 2020; Iannaccone et al., 2020; Ni et al., 2020; Xu and Yang, 2020; Hwang et al., 2019; Ushakov et al., 2019; Fernández et al., 2017; Schinas and Butler, 2016; Burel et al., 2013; Bengtsson et al., 2011) • LNG can be used as a fuel for ship propulsion, especially for large ships, or for inland operations. (Sifakis and Tsoutsos, 2021; Ni et al., 2020; Xu and Yang, 2020)

Biofuels

Literature	• Biofuels are another climate-friendly option in comparison to fossil fuels. (Gaurav et al., 2017) • Biofuels = The main advantages are renewability, compatibility of existing engines, low toxicity, availability and diversity of raw materials for production, high energy density, simplicity in handling and storing and reduced total cost of ownership once scaled up. (Olçer et al., 2021; Pitpoint clean fuels, 2021; Dharma et al., 2016; Johari et al., 2015; Lapuerta et al., 2005) • Biofuels = The disadvantages of biofuels include complex use characteristics, low technological maturity (instability, corrosiveness), current limited availability, high processing and maintenance costs (fuel tank and filter cleaning), lack of adequate safety instructions, operational experience and incapable infrastructure. (Wang et al., 2023; Ni et al., 2020; Svanberg et al., 2018; Eide et al., 2013; Mander et al., 2012) • Biofuels are mainly suitable for small and medium-sized ships, as well as certain port operation equipment. (Ni et al., 2020)

Methanol

Literature	• When considering the entire life-cycle perspective of methanol, its GHG reduction potential is higher than the one of conventional fuels. (Gilbert et al., 2018; Brynolf et al., 2014) • Methanol = Focusing on methanol's advantages, the technical feasibility, supply chain availability and low-load methane leakage can be named, whereas methanol's immiscibility with diesel and safety of storage, high costs are considered the main application barriers (Ni et al., 2020; Ammar, 2019a; Balcombe et al., 2019; Svanberg et al., 2018; APEC, 2014; Brynolf et al., 2014).

Hydrogen

Literature	• Hydrogen is also considered an alternative fuel capable of replacing today's fossil fuel of ships and port application (Wang et al., 2023). • Hydrogen = research is focusing on establishing this energy carrier further, especially because of green hydrogen's characteristic of emitting near-zero GHG and air pollutants at combustion (CO2, SO2, PMs, etc.). (Daniel et al., 2022; Hoang et al., 2022; Chang et al., 2019; Bicer and Dincer, 2018; Castellani et al., 2018; Chang et al., 2016; Pereira et al., 2014; Wang et al., 2013; Arteconi et al., 2010)

Ammonia

Literature	• Ammonia = there is an existing ammonia infrastructure in place due to its established use for fertilizer production. (Daniel et al., 2022; Lan et al., 2012; Klerke et al., 2008) • Ammonia can be blended with diesel, hydrogen and methanol. (Rehmatulla et al., 2017; Valera-Medina et al., 2017; Westlye et al., 2013; Boretti, 2012; Reiter and Kong, 2011; Reiter and Kong, 2008)

Onshore power supply

Questionnaire comments	• 1 respondent: counts on an upcoming regulation obliging shipping lanes to use OPS when they are in ports • 1 respondent: there is a need for incoming vessels supporting the OPS technology • 1 respondent: "Our port tends to go for electric supply of ships and vehicles. The amount of energy is huge (over 2 GWh/day). The energy needs to be there. Who can assure that?" • 1 respondent: the ports of Stockholm, Helsinki, and Tallinn in the Baltic Sea, having decided to set same standards for cold ironing for the ships operating in all three ports • 1 respondent: existence of a port service company that can undertake the sale of electricity and thus financial guarantees to develop OPS • 1 respondent: the setup of procedures for letters of intent or expressions of interest are important to get a clear vision of the needed capacity for integrating the volumes into the infrastructure planning • 1 respondent: "OPS in liner traffic is by far the easiest to start with. That, in turn, builds in-house know how to help in tackling the more difficult OPS cases, for example the container and cruise segments" • 1 respondent: the elaboration of studies related to port equipment, infrastructure, performance and safety for OPS implementation are key • 1 respondent: participation in EU projects like the EALING project • 1 respondent: need of strengthening the grid around the port • 1 respondent: combination of OPS and auto mooring systems to reduce the emissions and time from ships at berth, which directly results in decreased power need for OPS
Interview comments	• Interviewee 2: "the fit for 55 package and the FuelEU Maritime legislations will now push OPS further, with the obligation to install OPS in all TEN-T ports until 2030" and that "the customers are much more aware now of higher environmental standards". • Interviewee 1: "It's actually a bit of a chicken and egg problem, a paradoxical situation in which the sector calls for clarity on roles and responsibilities. But I would think that once the policymakers in Europe take an initiative and make clear what the roles and responsibilities are, they will face a lot of resistance from the sector - (…) that's not how the democratic pro-cess in Europe works".

	• Interviewee 4, "the aspect which is not clear yet is the business of how the operators will operate in the future", a probable reason for the insecurities. • Interviewee 2: "either we had the investment for the installation of OPS in the port but no customers or vice versa". For encouragement of the customers, an environmental discounted port fee has set up for a long time. • Interviewee 4: "a constant dialogue with technological providers is necessary and to involve innovation actions" • Interviewee 1: One of the major barriers is the clarity of roles and responsibilities when it comes to OPS. So you have the terminal operator, the shipping line or ship owner, the labour, the Port Authority, and there are all kinds of agencies of federal or regional governments. There's the distribution system operator. There's the energy provider. So, all kinds of parties involved and none of them is really taking the leadership. • Interviewee 4: "electric grid expansion is something needed in every port before going into providing OPS, and it is more difficult when the Port Authority is not the grid owner. These ports need to start conversations, convincing the transmission or distribution system operators to build the upgrade" • Interviewee 4: "In terms of business model, the ports need to talk to everyone possibly involved. But it also depends on the regulation, in which sense the Port Authority can also play a role in which to guide the regulators" • Interviewee 3: "There are also other struggles like the energy capacity" • Interviewee 3: "we are looking for grants to be able to finance the OPEX because it's so expensive and not only for our infrastructure, but also the modifications in the ships that are needed" • Interviewee 2: incentive contribution of 1,000,000 Swedish crowns made to a vessel that has been retrofit-ted to OPS
Literature	• Since the source of emission is transferred to the source of power generation, the indirect life-cycle emissions need to be considered, too, including emissions from energy extraction, transportation, consumption and generating stations. (Peng et al., 2021) • Examples of grid levelling technologies are fuel cells, turbines or LNG on barge. Coppola and Quaranta, 2014; Battistelli et al., 2012)

Energy efficiency for port equipment and fleet transformation

General

Interview comments	• Interviewee 4: "The Port Authority is not the owner of any equipment. There is not much the Port Authority can do rather than, for example, support innovation actions."
Literature	• The operational equipment in and between terminals also widely contributes to emissions in ports, with quay cranes being the second highest emission source in ports after ships, yard cranes on the third position and trucks on the fourth. (Yun et al., 2018)

Working efficiency improvement

Questionnaire comments	• 1 respondent: there is no need to build a solution to cover all possible exceptions, but that focusing on energy efficiency can be an adequate option
Literature	• Energy saving is considered as one of the green port indicators and has been rated by ESPO as second highest priority after air pollutants in the EU priorities, leading to a steep increase of energy efficiency programs in European ports. (ESPO, 2018; Chen and Pak, 2017) • Since a large proportion of emissions is related to ships at berth as described above, the improvement of operation around the berthed ships can contribute to reducing emissions, even though the increase in working efficiency of the equipment itself only has a small direct impact considering its proportion within total port emissions. Yun et al. (2018) • Reasonability is the key component for an optimal trade-off between timesaving and energy saving. Yun et al. (2018) • Since most cranes operate with an alternative current drive, a conversion to direct current technology using a proper current factor is very likely to reduce emissions from port operation, too, as well as using the hoist-down movement, cranes can recover large parts of energy. (Zhao et al., 2014; Tran, 2012)

Purchase, replacement and retrofit

Questionnaire comments	• 1 respondent: need for sufficient energy capacity • 1 respondent: "swapping batteries is the most relevant way to reduce costs and to improve the life cycle of the batteries" • 1 respondent: "Do not consider it as a classic business case - consider the environmental return as the most important one, and the economical ROI in the longer run" • 1 respondent: emission-free workboat, running on a battery pack and carrying out harbour operation like maintenance or towing
Interview comments	• Interviewee 1: certain risk of shifting the environmental action in time, which underlines once more the urgent need for acceleration of retrofitting expertise for port equipment • Interviewee 2: The risk of deferral of environmentally friendly port operation has hereby been approved and the mentioned sale of the older port equipment when opting for replaced or new equipment reveals the threat of carbon leakage associated with this precise issue • Interviewee 3: "If vehicles or machines could be easily retrofitted, we would beat on that, but the technology is not yet completely tested. Sometimes, it's not economically worthy because the machine is very old, or the size isn't viable. (…) I think that once the technology is fully tested and the current equipment is fully depreciated (amortized), that will be the moment where we should replace the old machines for the new ones". • Interviewee 2: "Heavy vehicles, for example, can go from diesel fuel to hydrogen, and we are partly con-verting terminal tractor to dual fuel technique hopefully. Otherwise, I know for when it comes to cranes and so on, we sell it on the market to another port or other business that is interested. (…) When it comes to retrofitting, I think it's most important to put in effort and money to retrofit the existing vessels because we cannot wait just for the new vessels to be environmentally friendly since they have such a long lifetime" • Interviewee 4: "The Port Authority is not the owner of any equipment. There is not much the Port Authority can do rather than, for example, support innovation actions. I think, it will highly depend on the specific local conditions. For an RTG crane in which the energy part is not very important, but the global investment cost of the RTG is very high, retrofitting may make a lot of sense. In terminals however, trucks which have a smaller life span and where the weight of the total cost of the energetic use is much higher than the equipment investment, it might make more sense to opt for a newly purchased truck. This, however, will also depend on the technology" • Interviewee 1: "the way you could approach the issue is by using the merit order, which helps making decisions"
Literature	• Especially the soaring diesel prices in recent times, increasing terminal operation costs and stricter air pollution regulations force ports to replacing their operation equipment. (Yang, 2017) • The ranking between the four discussed types of cranes regarding emission reduction is as follows: E-RTG < ARMG < RMG < RTG. (Hoang et al., 2022) • Besides, equipment such as forklifts, rail movers, yard trucks, stacking cranes and automated guided vehicles also use swappable and portable "battery electric" systems, a widely used technology. (Hoang et al., 2022; Dhupia et al., 2011) • Hydrogen-powered fuel cells are considered an emerging technology for port operation equipment. While benefitting from easier and more rapid re-charge as well as lower space requirements than batteries, this technology is not commercially viable today. (Kinnon et al., 2021; Curtin and Gangi, 2014) • Furthermore, hybridization is another way of introducing electrification into port operation, divided into fuel-electric hybrids (engine and battery), rechargeable plug-in electric hybrids and diesel-hydraulic hybrid. (CARB/EPA, 2015) • In order to store potential energy for the use of electric port operation equipment, batteries, flywheels supercapacitors have proven to be energy efficient solutions. (Antonelli et al., 2017; Niu et al., 2017; Tan and Yap, 2017; Greencranes, 2012; Flynn et al., 2008; Kim and Sul, 2006)

Further equipment improvement measures

Questionnaire comments	• 1 respondent: "traditional energy reducing measures in ports (buildings, lighting, etc.) are still underutilized options"
Literature	• Among port activities, lightning consumes about 3-5% of total energy use. (Acciaro et al., 2014a) • The use of LED lamps saved 70–90% of energy in the Port of Venice, saved 300,000 euros of electricity cost in the ECT Delta terminal in the Netherlands and could save 1000 tons of CO2 per year in the Port of Rotterdam (Van Duin et al., 2017; Hippinen and Federley, 2014)

	• Therefore, it is recommended to modernize the lightning equipment by replacing todays mainly used high-pressure sodium lamps with energy-efficient light-emitting diode lamps (LED). (Sifakis and Tsoutsos, 2021) • Furthermore, to minimize cooling demand and heat loss in port buildings, greening the roofs, painting walls in white, cleaning lamps, cold storage insulation and curtains are recommended measures. (Alamoush et al., 2020) • To reduce port's dust pollution coming from mainly cargo (un)loading and transportation processes, sprinkler systems, dust-proof nets and thatch covers are proposed and applied measures. (Wang et al., 2023)

Energy management systems

General

Questionnaire comments	• Q27: 89,09% of questionnaire respondents agreed on need to control and optimize future energy demand and supply • 2 respondents: create energy communities based on renewable sources inside the port, complemented with an intelligent energy management system
Interview comments	• Interviewee 1: "we have a lot of wind turbines and solar PV in the port, so a lot of intermittent energy sup-ply. Then, there's very limited amount of demand side management in the port. In that regard, energy management systems could really help to align these two" • Interviewee 2: "What kind of energy we are using? Which emissions are resulting of this energy use? That's the major environmental aspects of our business and that's why it's crucial for us" • Interviewee 3: energy management systems as important assets for both ecologic and economic reasons "because nowadays, we don't have any numbers. We just receive the invoices and that's all. But we have to check whether the demand of the invoice matches the availability of the electricity in the port or if there is something that is not working correctly" • Interviewee 4: "it will not just be a need for being competitive but also for being positive because we are moving from a pretty straightforward energy management, in which the producer produces and there are a lot of consumers. But the energy value chain will be a more complex one in which you will produce yourself electricity at the terminal, you will buy from your neighbour, and you will have surplus all at once. We have to be prepared and foresee the energy demand required" • Interviewee 1: "something that terminal operators among themselves could set up. Then, regulating the mentioned intermittencies is really up to the distribution system operator or even the trans-mission system operator, they have the corresponding responsibility. I think ports can play a role in building the community or something, but that's not our expertise" • Interviewee 3: pilot project for energy management system which the port has just terminated and which seems to be working well
Literature	• With energy efficiency being a key lever to become greener, the energy consumption of ports has become the focus of attention in recent years. (Di Vaio et al., 2018) • The aim of EMS in ports is to control, optimize and match energy demand, energy supply, energy flow and energy storage by connecting real-time operation monitoring via smart devices. (Iris and Lam, 2019; Ngai et al., 2011) • In order to establish and comply with such systems, ports can refer to ISO 50001 energy management system standards. (Iris and Lam, 2019)

Energy management plans

Questionnaire comments	• 1 respondent: a validate database firstly needs to be set up, with all other measures depending on it
Literature	• Energy Management plans: Establishing an energy management plan (EMP) is fundamental to meet energy consumption reduction and thus improve the efficiency of a port's operating system. (Parise et al., 2016a; Hippinen and Federley, 2014; Pavlic et al., 2014) • To establish an energy profile, ports must acquire a detailed, long-term and reliable database, which will evaluate and analyse the energy consumption and performance in order to make realistic projections, as well as enable appropriate correction measures and technologies. (Cammin et al., 2020; Boile et al., 2016; Lam and Notteboom, 2014; Pavlic et al., 2014)

Energy storage systems

Literature	• Energy storage systems (ESS) are fundamental to integrate and balance the fluctuations of renewable energies by helping the power grid to collect and transit excess energy, as well as meet the local power demand to ensure a port's unhampered functionality. Without ESS, the reliance on 100% RES for ports would be impossible. The main used technologies of ESS are batteries, supercapacitors, flywheels and more recently hydrogen fuel-cell systems. (Sifakis and Tsoutsos, 2021; Ahamad et al., 2019; PIANC, 2019; Yigit et al., 2016)

Smart microgrid

Literature	• Smart (micro) grids are very likely to replace traditional power grids in ports of the next generation. (Sifakis and Tsoutsos, 2021; Siemens, 2017) • Smart grids include information technologies like sensors, smart meters, real-time monitoring systems and control tools. (Iris and Lam, 2019; Lam et al., 2017; Siemens, 2017; Spbp, 2017; Bayindir et al., 2016; Ihle et al., 2016; Parise et al., 2016b; Yigit et al., 2016; Mondragon et al., 2015; Sharma and Saini, 2015) • Micro grids are often integrated in a smart grid and are also indispensable to support and manage the energy needs of future ports and represent a stand-alone energy network com-prising different electricity sources and controllable loads that can operate synchronously with the traditional centralized grid ("grid") or disconnect and function autonomously ("island" or "islanding mode"). (Roy et al., 2020; Parise, 2016; Katiraei et al., 2015; Sudhoff, 2015) • Ports should firstly undergo a load analysis of equipment (energy fluctuation based on RES generation), then to prepare a smart grid scenario analysis (peak shaving and demand response planning), before focusing on energy balancing (energy storage planning) and finally con-duct a benefit analysis (tariffs and costs). (Liang et al., 2014) • Secure critical smart grid infrastructure in ports is fundamental to avoid disruptions (Niglia, 2017)

Smart load management

Literature	• Smart Load Management (SLM) is another technique part of EMS, especially necessary considering the increasing electrification of ports. (Gennitsaris and Kanellos, 2019; Tao et al., 2014) • On the one hand, SLM focusses on load shifting by moving certain operations with high electricity demand to times with lower electricity demand, which minimizes costs since peak loads are the most expensive electricity prices. (Alamoush et al., 2020) • On the other hand, peak shaving is another SLM technique applied to reduce the energy demand by the use of intelligent sensors, for example for reefers, yard lights, heating or office fridges. (Alamoush et al., 2020)

Hinterland integration

Questionnaire comments	• 2 respondents: river and railway transport • 1 respondent: mobility modelling and studies of alternatives • 1 respondent: automated traffic management for trucks
Interview comments	• Interviewee 2: river and railway transport • Interviewee 4: "For using the train, you need railways outside the port. And road transport is probably the most difficult sector to decarbonize in the port activities (…). There needs to be a willingness of ports to deliver low carbon fuels in the close port environment. Since the alternatives are not yet in a very mature state, participation in innovation projects is useful to validate some of the alternatives that are on the table right now. To date, there are pure electric trucks, hydrogen trucks, etc. but they are not yet in a very commercial state" • Interviewee 1: "As a Port Authority, we don't really operate the hinterland part. But I do think it's partly within the port's responsibility since we are providing employment for many people that also live around the areas of the port. Also, in the port there's quite some emissions of nitrogen oxide, a particular matter, and also Sox. These also put pressure on the communities sur-rounding the port, so we definitely should take some responsibility there as well" • Interviewee 3: "it's not only about the internal but about the whole city. (…) It is in fact very necessary that trucks are involved, that trains are involved, that ships are involved, that the port terminals are involved with their cranes and their vehicles" • Interviewee 2: "we need to connect and have partners that are more experts in that kind of issues, able to provide the fuelling station, for example"

Literature	• Using green hinterland technologies significantly contributes to green port development, too since CO2 emissions from port hinterland transportation exceed the emissions of port opera-tion itself, excluding ships (Alamoush et al., 2020; Du et al., 2019; Gonzalez-Aregall et al., 2018; Kavakeb et al., 2015; Lirn et al., 2013; Bergqvist and Egels-Zanden, 2012) • The literature has claimed ports to have in fact a part of responsibility of reducing such negative externalities linked to their indirect operation, in this specific case for the hinterland. (Gonzalez-Aregall et al., 2018; Marta et al., 2018) • Modal shift or modal split improvement is a further emission reduction measure of port's hinterland, translated by the move of cargo to rail, barges or short sea shipping (IMO, 2018b; IAPH, 2007). • All measures are drastically reducing CO2 emissions, and rail cargo reduces them even more than truck cargo improvement (Mamatok and Jin, 2016; You et al., 2010). • Therefore, authors claim that ports have a part of responsibility of reducing the negative externalities linked to their operation. (Gonzalez-Aregall et al., 2018; Marta et al., 2018) • Truck emission reduction, including truck replacement or retirement, repowering or retrofit of engines. (Alamoush et al., 2020) • Polluting trucks can also be banned from terminals, or simply excluded on a voluntary basis. (Clott and Hartman, 2013; Norsworthy and Craft, 2013) • Second, truck congestion reduction outside gates and terminals can be achieved by implementing truck appointment systems, a measure which has proven significant emission reductions. (Schulte et al., 2017; Chen et al., 2013; Guan and Liu, 2009; Giuliano and O'Brien, 2007) • Automated gate processing systems or extended off peak terminal and gate hours are other congestion reduction measures, as well as trucks empty return coupled with loaded pickups. (IMO, 2018b; Accenture and SIPG, 2016; APEC, 2014) • Encouraged employees to use public transportation or bicycles to reduce local air pollution. (I2S2, 2013)

Renewable electricity for ship propulsion

General

Questionnaire comments	• 1 respondent: swapping of batteries • 1 respondent: Environmental Ship Index (ESI) and "Green Ports Awards" for green ships and shipping companies • 1 respondent: offering eco-incentives for environmentally friendly actions of customers
Interview comments	• Interviewee 2: ports are not responsible for it, but they are a support • Interviewee 3: "we as ports need to foster the development of these technologies and even need to produce green electricity in the port as well. But on ships, it's up to the shipping companies to invest in their own technologies for the propulsion of their ships. We can help with that and we will for sure do it and facilitate the change, make our contribution. (…) Because it is something that we want to happen" • Interviewee 1: "ports gain money by quoting ships visiting the port. What we do is give reductions on the port dues for green ships. This could be a reason. But apart from that, I don't really see how a Port Authority has the responsibility this on, it's up to the ships" • Interviewee 4: "It's the same as for the alternative fuels. Ports have to be facilitators, but they are not the regulators, they're not the International Maritime Organisation. So, ports can support ship owners to transform their fleet to carbon neutral use as far as they can, for example through environmental taxes benefits. Authorities have to be technology neutral, meaning open of any alternative that ship owners have in mind"

Solar propulsion

Literature	• Solar = fuel saving between 1,5% and 10%, highest single value 40%. (Karatug and Durmusoglu, 2020; Yuan et al., 2018; FathomShipping, 2012) • Solar = solar energy generation on marine vessels will lie between 0.2% and 12%. To intensify the percentage, the integration of energy systems including storage is considered a viable option, as well as increasing the efficiency of the panels (Bouman et al., 2017) • Solar energy = is mainly used through the installation of photovoltaic systems on a ship's upper deck to provide additional electricity for the electric equipment on board. (Hoang et al., 2022)

Wind propulsion

Literature	• Wind = fuel saving calculated between 1% and 50%, but mostly around 25% (Lu and Ringsberg, 2019; SkySails, 2019; IWSA, 2018, Traut et al., 2014) • Replaced engine power can amount between 15% and 25%. (Qiu et al., 2015) • Wind energy = The used sails can be of conventional or modern style, like Flettner rotors, kites or spinnakers, soft sails, wing sails, and wind turbines. (Mofor et al., 2015; Carlton et al., 2013) • Wind energy = The most effective values are usually obtained under slow-speed conditions (>16 knots) and on smaller sized vessels (3000–10, 000 tons). (Smith et al., 2016; Smith et al., 2013)

Fuel cell propulsion

Literature	• Fuel cells can either be used for direct marine vessel propulsion (especially smaller ships) or for port equipment, however, their application, remains scarce to date. (Hoang et al., 2022; Kinnon et al., 2021; Pagliaro, 2020; Bicer and Dincer, 2018; Sharaf and Orhan, 2014)

Nuclear propulsion

Literature	• Nuclear = Nuclear power for marine propulsion is only used for applications of certain warships, sub-marines, aircraft carriers and icebreakers. (Khlopkin and Zotov, 1997)

Smart resources and automation

General

Literature	• A smart port is "emphasising especially operational and energy efficiency, productivity, and the environmental impact aspect". (Buiza et al., 2015) • A smart port is "a system of port transportation and activity based on modern knowledge platform that enables multiple and diverse information services for port stakeholders based on the collection, processing, release, exchange, review, and use of relevant information". (Siror et al., 2011)

Information measures

Questionnaire comments	• 1 respondent: 5G as a further digitalization tool • 1 respondent: digitalization can "highly contribute to optimize capacity and traffic/congestion, with resulting extra benefits for the environment" • 3 respondents: the need for digital platforms for tracking real-time emission data in the port, captured by sensor networks, and enabling to tackle the main emission sources first
Interview comments	• Interviewee 1: digital tools are used to optimize the vessel traffic to increase efficiency
Literature	• The use of advanced technologies in ports began around the year 2000 and is evolving ever since. (Jiang et al., 2013) • The information measures can be divided into three categories: emission and energy inventory, monitoring and reporting. Data collection is a necessary first step to identify pollution sources. Monitoring, especially air pollution, then helps improving port environment grasping activities with external effects on the port calculating the cost of GHG emissions and raising the green image of the port. (Kang and Kim, 2017; Tichavska and Tovar, 2015a; Tichavska and Tovar, 2015b; Lam and Notteboom, 2014; Darbra et al., 2009; Peris-Mora et al., 2005)

Automation

Questionnaire comments	• Q16: 89,29% of respondents agreed that implementing automation processes into ports daily operation is necessary for staying environmentally and economically competitive in the middle and long term • 1 respondent: auto mooring systems are proposed for optimizing ship speed and time spent waiting • 1 respondent: automated traffic management systems
Interview comments	• Interviewee 4: "I think initially, the focus lies on economic reasons because you can increase productivity." • Interviewee 1: more for economic reasons

	• Interviewee 2: more for economic reasons • Interviewee 3: more for economic reasons • Interviewee 4: "But it is true that with automation, the electrification is much easier, and you can explore other concepts and other technologies that it will be much more difficult with non-automated terminals. I would say that right now, the economy is first, but there is also an increasing interest for ecological energy transition reasons for this type of measure".
Literature	• With increasing electrification of equipment, conversion to automated systems is enabled, which also significantly contributes to energy and emission savings. (Sifakis and Tsoutsos, 2021) • A state-of-the-art report by PEMA (2016) concluded that gate automation, scheduling yard trucks and container tracking are today's uses of port automation. • Examples of used technologies in the context of port automation are automatic shut-down and start-up systems automated mooring systems, double loading cycles of quay cranes, twin-lift or tandem-lift operations in gantry cranes, variable speed generator for RTGs, eco-driving, route optimisation, acceleration techniques for port vehicles, intelligent and auton-omous vehicles (IAVs), waterborne autonomous guided vessels and drones and robots for warehouses (Sifakis and Tsoutsos, 2021; Tan et al., 2018; Zheng et al., 2017; Accenture and SIPG, 2016; Lee et al., 2015; Yang, 2015; Hippinen and Federley, 2014; Gelareh et al., 2013; IAPH, 2007).

Energy efficiency for ships in ports

Vessel speed reduction

Questionnaire comments	• Q18: 57,41% of questionnaire respondents do not think that ports should impose an immediate reduction of vessel speed as short-term applicable measures to reduce emissions
Interview comments	• Interviewee 4: "there is a trend to reduce speed because the impact of the speed is quite high on energy consumption" • Interviewee 3: "the entrance into our port is very constrained by the tidal conditions. It usually takes like 5 hours to go from the sea mouth to the port" • Interviewee 1: constraint by tidal conditions and long way to port • Interviewee 2: constraint by tidal conditions and long way to port • Interviewee 3: "a speed beneath 10 knots is not recommended for safety reasons" • Interviewee 3: "In general, we will have to do a trade-off between being earlier in ports for whatever rea-sons and ecologic reasons like fuel saving" • Interviewee 1: "it's not the ports that reduce the speed, right? It's the vessels. Since it's open water, the ports are not responsible for the speed that the ship is taking. (…) That should be part of the strategy of the shipping line" • Interviewee 2: shipping companies are responsible • Interviewee 3: shipping companies are responsible • Interviewee 2: ports are in the hands of the customers
Literature	• Carbon emission reduction from ships in waterway channels: - 7% (Bergqvist and Monios, 2019), - 48.4% (Yun et al., 2018), - 41% (Chang and Jhang, 2016), - 8–20% (Zis et al., 2014) • However, a drawback of the application of vessel speed reduction is the associated implica-tion of increased number of ships in service to cover the same demand (Daniel et al., 2022). • Virtual arrival time can manage vessel's speed regarding the current and upcoming situation of port's berth schedule. This technique is already well-established and has proven reliable and safe expertise. (Du et al., 2015) • When vessel speed exceeds the 10 knots, the reduction of speed in waterways can cut down carbon emissions, whereas when the vessel speed is lower than 10 knots, the reduction of speed in waterways will instead increase carbon emissions by a small quantity Yun et al. (2018). In fact, al-ready in 2011, Cariou (2011) called the 10 knots line "the most energy efficient speed".

Reduction of time for ships at berth

Questionnaire comments	• 1 respondent: increase productivity

	• Q18: 63,64% of questionnaire respondents do not think that ports should impose an immediate reduction of auxiliary time at berth as short-term applicable measures to reduce emissions • 1 respondent: auto mooring systems are proposed for optimizing ship speed and time spent waiting • 1 respondent: automated traffic management systems
Interview comments	• Interviewee 2: ports are in the hands of the customers • Interviewee 4: "the shorter the ships are at berth, the better. But it also depends on other aspects such as the number of cranes available, the number of containers that you have to move, etc. In a global sense, you have to be as productive as possible in order to stay as less time as possible at port" • Interviewee 1: agrees on the needs but criticizes that "it's however part of an entire operational chain, so I don't really see how reducing the berthing time in itself could be a measure. The only way would be if you could increase efficiency of the container terminal, for instance. But then, reducing berthing time is rather some kind of a consequence of another measure, being im-proving efficiency of the terminal" • Interviewee 3: tidal constraints • Interviewee 3: "I don't think it would have a very significant impact in our port" • Interviewee 4: vessels using their own batteries, "which might need to stay longer at berthing time to charge their batteries" • Interviewee 1: digital tools are used to optimize the vessel traffic to increase efficiency
Literature	• Carbon emission reduction from the whole container terminal: - 6.0% (Yun et al., 2018) • Fuel consumption reduction: - 2%–8% (Johnson and Styhre, 2015) • Carbon emission reduction from ships at berth: - 37% (Moon and Woo, 2014) • In theory, reducing ships berthing time appears to be an easily applicable measure. In prac-tice, however, numerous factors need to be calculated and integrated by port authorities, such as terminal opening hours, stevedore operations, berth availability, efficiency of container handling equipment, production efficiency and cost reduction, berth layout, allocation, quay crane assignment, tidal constraints, customer satisfaction, emission tax rates and vessel waiting time. (Jos et al., 2019; Ma et al., 2019; Styhre and Winnes, 2019; Wang et al., 2019; Ko-vac et al., 2018; Lin et al., 2018; Wang et al., 2018; Ernst et al., 2017; Umang et al., 2017; Xiang et al., 2017; Han et al., 2015; Winnes et al., 2015) • Replace the currently widely used first-come-first-serve model by an arrival booking scheme like guaranteed berth on arrival and booking by rendezvous, which have revealed to contribute to emission saving due to reduced ship waiting times. (Kontovas and Psaraftis, 2011) • Implementation of information measures such as information communication technologies, electronic data interchange, single window, port community system, and vessel traffic management, as well as streamlined ship clearance and standardized documents. (Styhre and Winnes, 2019; Poulsen et al., 2018; IMO, 2015; ESPO, 2012) • Information communication systems, electronic data interchange, single windows, port community systems, vessel traffic management, streamlined ship clearance and standardized documents are very well suited for support (Styhre and Winnes, 2019; Poulsen et al., 2018; IMO, 2015; ESPO, 2012).

Compilations - Priorities

Priorities by main measures - compilation

Quantitative results

Scale Q4
+ = 3,22-4,54
0 = 4,54-5,86
- = 5,86-7,18

Q4: Decarbonization urgency	Rank	Score	Score category
Environmental policy and regulatory framework	1	3,22	+
Renewable electricity sources	2	3,45	+
Alternative fuels	3	3,78	+
Energy efficiency for port equipment and fleet transformation	4	5	0
Onshore power supply	5	5,15	0
Green port management	6	5,24	0
Energy management systems	7	5,6	0
Smart resources and automation	8	6,38	-
Energy efficiency for ships in ports	9	7,18	-

Scale Q21
+ = 66,6-100
0 = 33,3-66,6
- = 0-33,3

Q21: Renewable electricity for ship propulsion	Rank	Score	Score category
Rather positively important	/	80,36%	+

Scale Q22
+ = 66,6-100
0 = 33,3-66,6
- = 0-33,3

Q22: Hinterland integration	Rank	Score	Score category
Rather positively crucial	/	98,18%	+

Qualitative results

Topic	Rank	Score category
Environmental policy and regulatory framework	2	+
Green port management	1	+
Renewable electricity sources	3	+
Alternative fuels	4	+
Energy management systems	5	+
Onshore power supply	6	0
Energy efficiency for port equipment and fleet transformation	7	0
Hinterland integration	8	0
Renewable electricity for ship propulsion	9	0
Smart resources and automation	10	-
Energy efficiency for ships in ports	11	-

Compilation of quantitative and qualitative findings

Topic	Quantitative rank	Quantitative category	Qualitative rank	Qualitative category	Final rank	Final category
Environmental policy and regulatory framework	1	+	2	+	1,5	+
Renewable electricity sources	2	+	3	+	2,5	+
Green port management	6	0	1	+	3,5	+
Alternative fuels	3	+	4	+	3,5	+
Onshore power supply	5	0	6	0	5,5	0
Energy efficiency for port equipment and fleet transformation	4	0	7	0	5,5	0
Energy management systems	7	0	5	+	6	0
Hinterland integration	/	+	8	0	/	0
Renewable electricity for ship propulsion	/	+	9	0	/	0
Smart resources and automation	8	-	10	-	9	-
Energy efficiency for ships in ports	9	-	11	-	10	-

Priorities by sub-measures – compilation

Environmental policy and regulatory framework

Quantitative results

Scale Q6
+ = 66,6% to 100%
0 = 33,3% to 66,6%
- = 0% to 33,3%

Q6: Policy framework	Rank	Score	Score category
Both, with stronger focus on compulsory regulations and policies	1	51,79%	0
Both, equally	2	21,43%	-
Both, with stronger focus on voluntary initiatives by port authorities and related stakeholders	3	17,86%	-
Compulsory regulations and policies	4	7,14%	-
Voluntary initiatives by port authorities and related stakeholders	5	1,79%	-

Scale Q8
+ = 66,6% to 100%
0 = 33,3% to 66,6%
- = 0% to 33,3%

Q8: Incentive type	Rank	Score	Score category
Both, with stronger focus on reward measures	1	44,46%	0
Reward measures	2	26,79%	-
Both, equally	3	14,29%	-
Both, with stronger focus on punishment measures	4	10,71%	-
Punishment measures	5	3,57%	-

Compilation of quantitative and qualitative findings

Global governance initiatives	Quantitative category	Qualitative category	Final category
Global governance initiatives	+	+	+

Policy framework	Quantitative category	Qualitative category*	Final category
Both, with stronger focus on compulsory regulations and policies	0	/	0
Both, equally	-	/	-
Both, with stronger focus on voluntary initiatives by port authorities and re	-	/	-
Compulsory regulations and policies	-	/	-
Voluntary initiatives by port authorities and related stakeholders	-	/	-

*importance of measure approved with a '+' by qualitative data

Incentive type	Quantitative category	Qualitative category*	Final category
Both, with stronger focus on reward measures	0	/	0
Reward measures	-	/	-
Both, equally	-	/	-
Both, with stronger focus on punishment measures	-	/	-
Punishment measures	-	/	-

*importance of measure approved with a '+' by qualitative data

Renewable electricity sources

Quantitative results

Scale Q24
+ = 30,06 to 40,74
0 = 19,66 to 30,06
,26 to 19,66

Q24: Power supply path	Rank	Score	Score category
Both, with stronger focus on reliance on the national electricity grid	1	40,74%	+
Both, with stronger focus on self-supply electricity system	2	20,37%	0
Both, equally	2	20,37%	0
Self-supply electricity system	3	9,26%	-
Reliance on the national electricity grid	3	9,26%	-

Scale Q25
+ = 1,75 to 2,29
0 = 2,29 to 2,83
,83 to 3,37

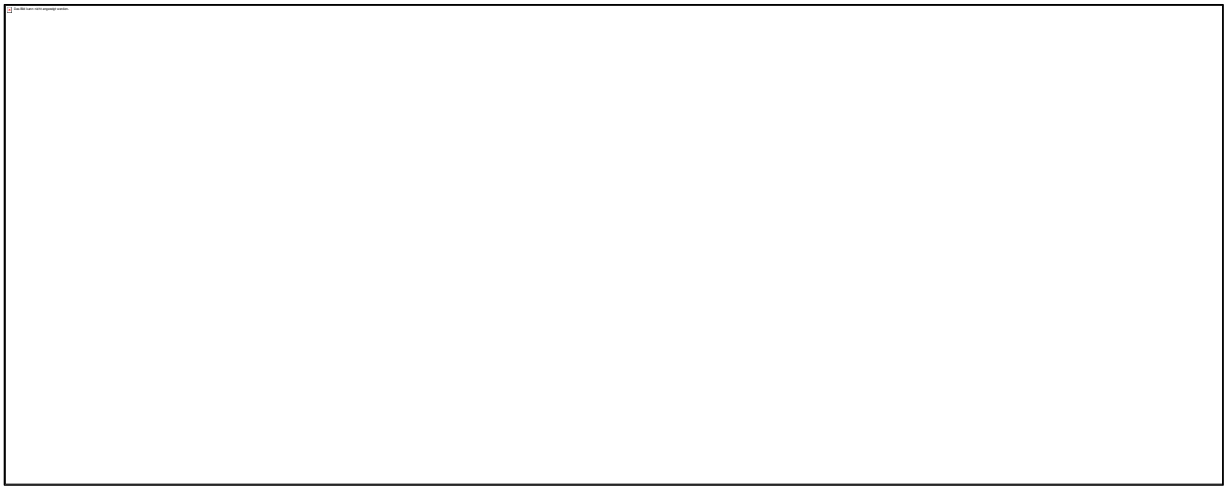
Q25: Renewable electricity sources	Rank	Score	Score category
Solar energy	1	1,75	+
Wind energy	2	1,77	+
Marine energy	3	3,12	-
Geothermal energy	4	3,37	-

Scale Q26
+ = 66,6% to 100%
0 = 33,3% to 66,6%
% to 33,3%

Q26: Fuel cell for intermittencies	Rank	Score	Score category
Yes	1	67,31%	+

Qualitative results

Topic	Score category
Solar energy	+
Wind energy	+
Tidal energy	0
Geothermal energy	-
Fuel cells	+



Green port management

Quantitative results

Scale Q9 and Q10
+ = 66,6% to 100%
0 = 33,3% to 66,6%
- = 0% to 33,3%

Q9: Dedicated managers or agents	Rank	Score	Score category
Yes	1	87,50%	+

Q10: Green marketing strategy	Rank	Score	Score category
Yes	1	94,64%	+

Qualitative results

Topic	Score category
Stakeholder participation	+
Integration of environmental managers	+
Green port strategies	+

Compilation of quantitative and qualitative findings

Stakeholder participation	Quantitative category	Qualitative category	Final category
Stakeholder participation	+	+	+

Integration of environmental managers	Quantitative category	Qualitative category	Final category
Integration of environmental managers	+	+	+

Green port strategies	Quantitative category	Qualitative category	Final category
Green port strategies	+	+	+

Alternative fuels

Quantitative results

Scale Q20
+ = 2,33 to 2,73
0 = 2,73 to 3,13
- = 3,13 to 3,53

Q20: Alternative fuel suitability	Rank	Score	Score category
Hydrogen	1	2,33	+
Methanol	2	2,69	+
Biofuels	3	3,14	-
Ammonia	4	3,31	-
LNG	5	3,53	-

Qualitative results

Topic	Score category
Hydrogen	+
Ammonia	+
LNG	+
Biofuels	0
Methanol	0

Compilation of quantitative and qualitative findings

Alternative fuels	Quantitative category	Qualitative category	Final category
Hydrogen	+	+	+
Methanol	+	0	0
Biofuels	-	0	0
Ammonia	-	+	0
LNG	-	+	0

Onshore power supply

Quantitative results

Scale Q12
+ = 66,6% to 100%
0 = 33,3% to 66,6%
- = 0% to 33,3%

Q12: Power supply options for OPS	Rank	Score	Score category
Direct connection to the national grid	1	96,55%	+
Direct connection to local micro grid	2	84,48%	+
Fuel cell on barge	3	50%	0
LNG on barge	4	24,56%	-
Turbine on barge	5	14,55%	-

Compilation of quantitative and qualitative findings

Power supply options for OPS	Quantitative category	Qualitative category*	Final category
Direct connection to the national grid	+	/	+
Direct connection to local micro grid	+	/	+
Fuel cell on barge	0	/	0
LNG on barge	-	/	-
Turbine on barge	-	/	-

*importance of measure approved with a '0' by qualitative data

Energy efficiency for port equipment and fleet transformation

Quantitative results

Scale Q13
+ = 66,6% to 100%
0 = 33,3% to 66,6%
- = 0% to 33,3%

Q13: Operation equipment transformation	Rank	Score	Score category
Both, equally	1	35,71%	0
Equipment transformation/replacement/retrofit	2	23,21%	-
Both, with stronger focus on equipment transf/repl/retro	3	21,43%	-
Both, with stronger focus on working efficiency improvement	4	17,86%	-
Working efficiency improvement	5	1,79%	-

Scale Q14
+ = 1,57 to 2,42
0 = 2,42 to 3,27
- = 3,27 to 4,11

Q14: Port operation equipment	Rank	Score	Score category
Trucks	1	1,57	+
Cranes	2	2,38	+
Cooling and heating of port buildings	3	3,32	-
Dust pollution	4	3,63	-
Lightning	5	4,11	-

Qualitative results

Topic	Score category
Working efficiency improvement	0
Purchase, replacement and retrofit	+
Further equipment improvement measures	-

Compilation of quantitative and qualitative findings

Operation equipment transformation	Quantitative category	Qualitative category	Final category
Both, equally	0	+ / 0	+
Equipment transformation/replacement/retrofit	-	+	0
Both, with stronger focus on equipment transf/repl/retro	-	+	0
Both, with stronger focus on working efficiency improvement	-	0	0
Working efficiency improvement	-	0	-

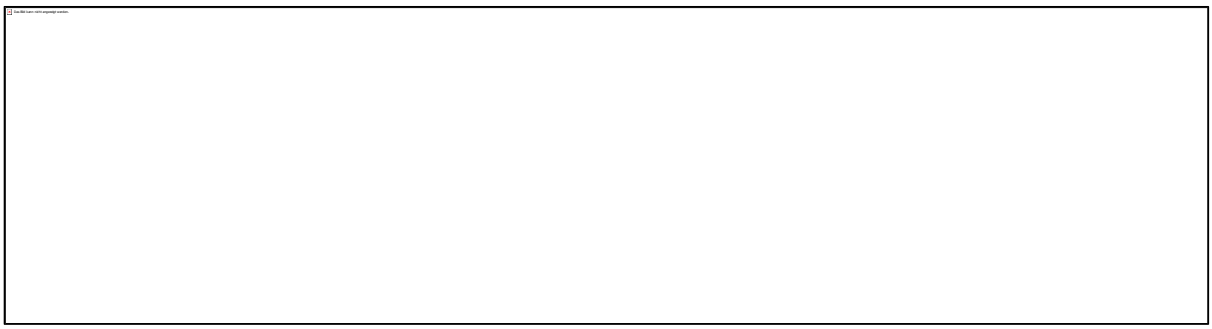
Port operation technologies	Quantitative category	Qualitative category	Final category
Cranes	+	+	+
Trucks	+	+	+
Lightning	-	0	0
Cooling and heating of port buildings	-	-	-
Dust pollution	-	-	-

Energy management systems

Quantitative results

Scale Q27
+ = 66,6% to 100%
0 = 33,3% to 66,6%

Q27: Energy management systems	Rank	Score	Score category
Yes	1	89,09%	+



Compilation of quantitative and qualitative findings

Topic	Quantitative category*	Qualitative category	Final category
Energy management plans	/	+	+
Energy storage systems	/	+	+
Smart microgrid	/	+	+
Smart load management	/	0	0

*importance of measure approved with a '+' by quantitative data

Hinterland integration

Quantitative results

Scale Q22
+ = 66,6 to 100
0 = 33,3 to 66,6
- = 0 to 33,3

Q22: Integration of the hinterland	Rank	Score	Score category
Very crucial	1	56,36%	0
Crucial	2	41,82%	0
Less crucial	3	1,82%	-
Not crucial	4	0%	-

Qualitative results

Topic	Score category
Hinterland integration	0

Topic	Score category
Rail transport	+
River transport	+
Truck transport	0

Compilation of quantitative and qualitative findings

Integration of the hinterland	Quantitative category	Qualitative category*	Final category
Very crucial	0	/	0
Crucial	0	/	0
Less crucial	-	/	-
Not crucial	-	/	-

*importance of measure approved with a '0' by qualitative data

Renewable electricity for ship propulsion

Quantitative results

None

Qualitative results

Topic	Score category
Renewable electricity for ship propulsion	+
Solar propulsion	0
Wind propulsion	0
Fuel cell propulsion	0
Nuclear propulsion	-

Compilation of quantitative and qualitative findings

Technologies for renewable electricity for ship propulsion	Quantitative category	Qualitative category	Final category
Solar propulsion	/	0	0
Wind propulsion	/	0	0
Fuel cell propulsion	/	0	0
Nuclear propulsion	/	-	-

Smart resources and automation

Quantitative results

Scale Q15
+ = 1,89 to 2,5
0 = 2,5 to 3,11

Q15: Digitalization tools	Rank	Score	Score category
Big Data	1	1,89	+
Internet of Things	2	2,04	+
ificial Intelligence	3	2,36	+
3D printing	4	3,71	-

Scale Q16
+ = 66,6% to 100%
0 = 33,3% to 66,6%

Q16: Automation processes	Rank	Score	Score category
No	1	89,29%	+

Qualitative results

Topic	Score category
Information measures	0
Automation	-

Compilation of quantitative and qualitative findings

Digitalization tools	Quantitative category	Qualitative category*	Final category
Big Data	+	/	+
Internet of Things	+	/	+
Artificial Intelligence	+	/	+
3D printing	-	/	-

*importance of measure approved with a '0' by qualitative data

Digitalization tools	Quantitative category	Qualitative category	Final category
Automation processes	+	-	0

Energy efficiency for ships in ports

Quantitative results

Scale Q18
+ = 66,6% to 100%
0 = 33,3% to 66,6%
3,3%

Q18: Reduction of vessel speed	Rank	Score	Score category
No	1	57,41%	0

Q18: Reduction of berthing time	Rank	Score	Score category
No	1	63,64%	0

Compilation of quantitative and qualitative findings

Energy efficiency for ships	Quantitative category	Qualitative category	Final category
Reduction of vessel speed	0	0	0
Reduction of time for ships at berth	0	-	-

Compilations - Responsibilities

Responsibilities by main measure - compilation

Quantitative results

Scale Q7
+ = 66,6-100
0 = 33,3-66,6
- = 0-33,3

Q7: Stakeholder responsibility	Rank	Score	Score category
Port Authorities	1	98,31%	+
EU	2	96,61%	+
National Governments	3	94,92%	+
Shipping companies	4	86,44%	+
Local industry	5	77,97%	+
Institutions	6	66,10%	0
Local organizations	7	33,90%	-
Citizen	8	27,12%	-

Responsibilities by main measures - compilation

Environmental policy and regulatory framework

Qualitative results

Environmental policy and regulatory framework	Questionnaire comments	Interview comments	Literature
International organizations	0	0	17
Policymakers (EU & governments)	5	4	3
Port Authorities	0	1	1

Questionnaire comments	Interview comments	Literature
5	5	21

Renewable electricity sources

Qualitative results

Renewable electricity sources	Questionnaire comments	Interview comments	Literature
Port Authorities	3	3	0
Energy companies	3	2	0
Transmission/distribution system operators	2	3	0
Policymakers	1	1	0
Independent energy producers	0	1	0
Customers	1	1	0

Green port management

Qualitative results

Green port management	Questionnaire comments	Interview comments	Literature
Port Authority	3	2	3
Third parties	2	1	0

Alternative fuels

Qualitative results			
Alternative fuels	**Questionnaire comments**	**Interview comments**	**Literature**
Port Authorities (facilitators)	3	4	1
Shipping companies	1	3	0
Local industry	3	1	0
Energy companies	3	0	0
Shipping fuel provision companies	1	2	0
Trucking fuel provision companies	0	2	0
Policymakers	0	2	0
Organizations	0	1	0

Onshore power supply

Qualitative results			
Onshore power supply	**Questionnaire comments**	**Interview comments**	**Literature**
Port Authorities	1	6	0
Shipping companies	1	3	0
Policymakers	0	4	0
Technological provider	0	1	0
Transmission/distribution system operators	0	2	0
Service company selling electricity	1	0	0
Agencies	0	1	0
Labour	0	1	0

Questionnaire comments	Interview comments	Literature
3	18	0

Energy efficiency for port equipment and fleet transformation

Qualitative results			
Energy efficiency for port equipment and fleet transformation	**Questionnaire comments**	**Interview comments**	**Literature**
Port Authority	0	5	3
Port equipment providers	0	1	0

Questionnaire comments	Interview comments	Literature
0	6	3

Energy management systems

Qualitative results

Energy management systems	Questionnaire comments	Interview comments	Literature
Port Authority (support)	0	5	3
Energy companies	0	2	0
Consumers	0	2	0
Transmission/distribution system operator	0	1	0

Hinterland integration

Qualitative results

Hinterland integration	Questionnaire comments	Interview comments	Literature
Port Authorities (partly)	0	4	12
Railway companies	2	3	4
Inland shipping companies	2	2	2
Trucking companies	0	1	1
Cities	0	2	0
Trucking fuel provision companies	0	2	0
Employees	0	0	1

Questionnaire comments	Interview comments	Literature
4	14	20

Renewable electricity for ship propulsion

Qualitative results

Renewable electricity for ship propulsion	Questionnaire comments	Interview comments	Literature
Port Authority (support)	1	4	0
Shipping companies	1	3	0
Policymakers	0	1	0
Organization	0	1	0

Smart resources and automation

Qualitative results

Smart resources and automation	Questionnaire comments	Interview comments	Literature
Port Authorities	0	0	1
Port equipment providers	0	0	1

Energy efficiency for ships in ports

Qualitative results			
Energy efficiency for ships in ports	**Questionnaire comments**	**Interview comments**	**Literature**
Port Authortity	0	2	6
Shipping companies	0	4	0

Questionnaire comments	Interview comments	Literature
0	6	6

Compilations - Best practices

Best practices by main measures and sub measures

Environmental policy and regulatory framework

Qualitative results			
Environmental policy and regulatory framework			
Global governance initiatives	**Questionnaire comments**	**Interview comments**	**Literature**
Regulation for environmental standards are necessary to develop the changes	2	1	0
Environmental assessment schemes and certification are needed to motivate the port management to take action	1	0	0
Establish further European research and funding programs, pilot and lighthouse projects	5	1	0
Set clarity on roles and responsibilities with the sector, in a democratic process	0	1	0
Let the Port Authorities guide policymakers for setting up the regulation	0	1	0
Cooherence vis-à-vis existing European and national legislation is needed	1	1	0
Voluntary vs. compulsory incentives	**Questionnaire comments**	**Interview comments**	**Literature**
Funding, subsidies and eco-incentives (tax rate reduction and port fee discount) are the most needed incentives for pro-environmental actions	8	4	5
Control punishment measures within a reasonable scope to avoid further negative influences	0	0	1

Questionnaire comments	Interview comments	Literature
17	9	6

Renewable electricity sources

Qualitative results			
Renewable electricity sources	**Questionnaire comments**	**Interview comments**	**Literature**
As a Port Authority, collaborate with the energy sector, implying both energy companies and local transmission/distribution systems operators	2	2	0
Set up procedures for expressions of interest for an overview of capacity need	1	0	0
Asses the suitability of the different technological options through feasibility studies, depending on the exact geographic and meteorologic conditions of the port	3	0	0
Consider repowering of both wind turbines and PV panels after a certain time of operation (20 to 30 years) to produce more output electricity within the same available space	1	0	0
Focus on different ways of thinking and different ways of organizing to avoid electricity supply bottlenecks	0	1	0
Actively look for funds	0	1	0
If none of the above technologies can be installed at a port site, renewable power-purchase agreements can be signed			4
Solar energy	**Questionnaire comments**	**Interview comments**	**Literature**
Consider the installation of PV panels on rooftops of ships, container docks, port buildings (warehouses, cruise terminals) to solve the space availability, while cooperating with the building owners	2	0	5
Consider the installation of solar panels on the sea water surface inside the port area	1	0	0
Solar water heating accounts more for high-temperature industrial processes, whereas photovoltaic converts the directly radiated light into electricity, with monocrystalline solar cells being the most efficient panel type	0	0	3
Wind energy	**Questionnaire comments**	**Interview comments**	**Literature**
Consider seaports as great locations for the installation of offshore wind parcs	1	0	1
Determine the ideal locations for wind turbine installation, evaluate parameters such as wind speed, geological structure of the site, transmission networks and the required material and mineral sources	0	0	1
Tidal energy	**Questionnaire comments**	**Interview comments**	**Literature**
Conduct feasibility studies before implementation	0	0	2
Geothermal energy	**Questionnaire comments**	**Interview comments**	**Literature**
Fuel cells	**Questionnaire comments**	**Interview comments**	**Literature**

Questionnaire comments	Interview comments	Literature
11	4	16

Green port management

Qualitative results

Green port management	Questionnaire comments	Interview comments	Literature
Create a philosophy of working with nature	0	1	0
Investment in lighthouse projects for demonstration of systemic change or innovation are useful	0	1	0
Consider the development towards green ports as an attractiveness factor and drive the change	0	0	1
Set environmental parameters for green port evaluation	0	0	1

Stakeholder participation	Questionnaire comments	Interview comments	Literature
Assure constant cooperation and collaboration between stakeholders for co-creation	7	2	2
Sign strategic agreements or Memorandums of Understanding with partners	2	0	0
Set up logistic chains, share information, share expertise, share costs, use synergies, strengthen competitiveness	2	0	0
Build a port community network, for example via a collaborative planning platform, a website or regular meetings	2	2	0
Increase the trust in the other parties of the sector	0	1	0
Set up a more active, systematic and strcutured dialogue around environmental issues	0	2	0
Engage consultants for support	1	0	0
Set up all kinds of corporations on the operational level	0	1	0
Integration of environmental agents	**Questionnaire comments**	**Interview comments**	**Literature**
Become managing stakeholders for a common green port strategy	0	1	0
Set up the necessary human resources to develop the necessary changes	1	0	0
One way to integrate the human factor is through the integration of sense-agents into the change process, who will take the key role of giving the port employees a meaning to the environmental reform, materialize the reform plan into action and create a 'going green' identity.			2
The implementation of environmental multi-disciplinary teams as appropriate and integrated approach of port management is suggested in the literature, to encourage participation and motivation towards port greenification.			1
Make sure the port staff is engaged in the transition	1	0	0
Integrate the responsible bodies for environmental measures into the ports structure (organizational chart)	0	0	1
Implement national umbrella organizations to fulfil the need for coordination and uniformity between ports and governments			1
Green port strategies	**Questionnaire comments**	**Interview comments**	**Literature**
Set up a clear long term green port strategy including fixed priorities, key objectives and a solid action plan	3	3	0
Implement the budget of each environmental goal in each department for the year to come to assure activities and budget will be united	0	1	0
Elaborate reports on emissions and measures for transparency	1	0	0
Make your green efforts visible and part of the mainstream to create a sense of urgency and inspire the community	0	1	0
Specify environmental goals in the mission statement, vision, or organizational goals	0	0	1
Clarify the environmental functions via sections dedicated to climate and sustainability, separate annual and environmental reports or plans or development initiatives, published for example in reports, news releases, publications, or the port's websites	0	0	1
The environmental measures need to be in line with the overall port strategy	0	0	1
The green marketing efforts need to be representative and transparent, to avoid greenwashing and thus credibility in the customers and authorities' eyes.	0	0	1
Let go of today's mainly used private governance model by opting for the landlord model, which opens the opportunity to push private operators to implement green practices	0	0	1

Questionnaire comments	Interview comments	Literature
20	16	14

Alternative fuels

Qualitative results			
Alternative fuels	**Questionnaire comments**	**Interview comments**	**Literature**
Collaborate closer between ports, energy companies and local industry for assuring availability, operating the infrastructure, and financing the projects	2	0	0
Explore the feasability all possible energy production options in terms of operation and cost-effectiveness	2	1	0
Set up procedures for letters of intent or expressions of interest to assure sufficient fuel capacity and to have robust supply processes by the operators	1	0	0
Train Port Authorities' personnel properly and inform personnel about the risks of these alternative fuels in the port environment	0	1	0
Be in constant dialogue with the customers (shipping and trucking) and surrounding society to decide which fuels will be needed	0	1	0
LNG	**Questionnaire comments**	**Interview comments**	**Literature**
LNG can be used as a fuel for ship propulsion, especially for large ships, or for inland operations	0	0	3
Biofuels	**Questionnaire comments**	**Interview comments**	**Literature**
Biofuels are mainly suitable for small and medium-sized ships, as well as certain port operation equipment	0	0	1
Methanol	**Questionnaire comments**	**Interview comments**	**Literature**
methanol can be blended with diesel, ammonia and hydrogen	0	0	0
Hydrogen	**Questionnaire comments**	**Interview comments**	**Literature**
Hydrogen can be blended with diesel, ammonia and methanol	0	0	0
Ammonia	**Questionnaire comments**	**Interview comments**	**Literature**
Ammonia can be blended with diesel, hydrogen and methanol	0	0	6

Questionnaire comments	Interview comments	Literature
5	3	10

Onshore power supply

Qualitative results			
Onshore power supply	**Questionnaire comments**	**Interview comments**	**Literature**
Follow the regulatory development of OPS obligation to prepare the port infrastructure	1	1	0
Set the same OPS standards between (newly) cooperating ports	1	0	0
Begin with OPS for liner traffic to build in house know how, before tackling the more difficult OPS cases, like the container and cruise segments	1	0	0
Elaborate studies related to port equipment, infrastructure, performance and safety for OPS implementation	1	0	0
Participate in EU projects, like the EALING project	1	0	0
Start collaborating with the energy sector now to assure sufficient energy capacity and to strengthen the grid around the port on time	2	2	0
Set up procedures for letters of intent or expressions of interest to get a clear vision of the needed energy capacity	1	0	0
Create or hire a port service company selling the electricity for OPS of electricity and financial guarantees to develop OPS further	1	0	0
Combine OPS with auto mooring systems to reduce the emissions and time from ships at berth to decrease the power need for OPS	1	0	0
Actively seek for grants to be able to finance both CAPEX and OPEX costs of OPS infrastructure and vessel retrofit	0	2	0
As a Port Authority, guide the policymakers with your expertise for a clear and visible regulatory framework for OPS	0	2	0
Set up a constant dialogue with technological providers and involve innovation actions	0	1	0
To avoid grid overload, additional peak levelling technologies are recommended for OPS installation to ensure system reliability during peak hours, with fuels cells on barge being the most suited option to date	0	1	0

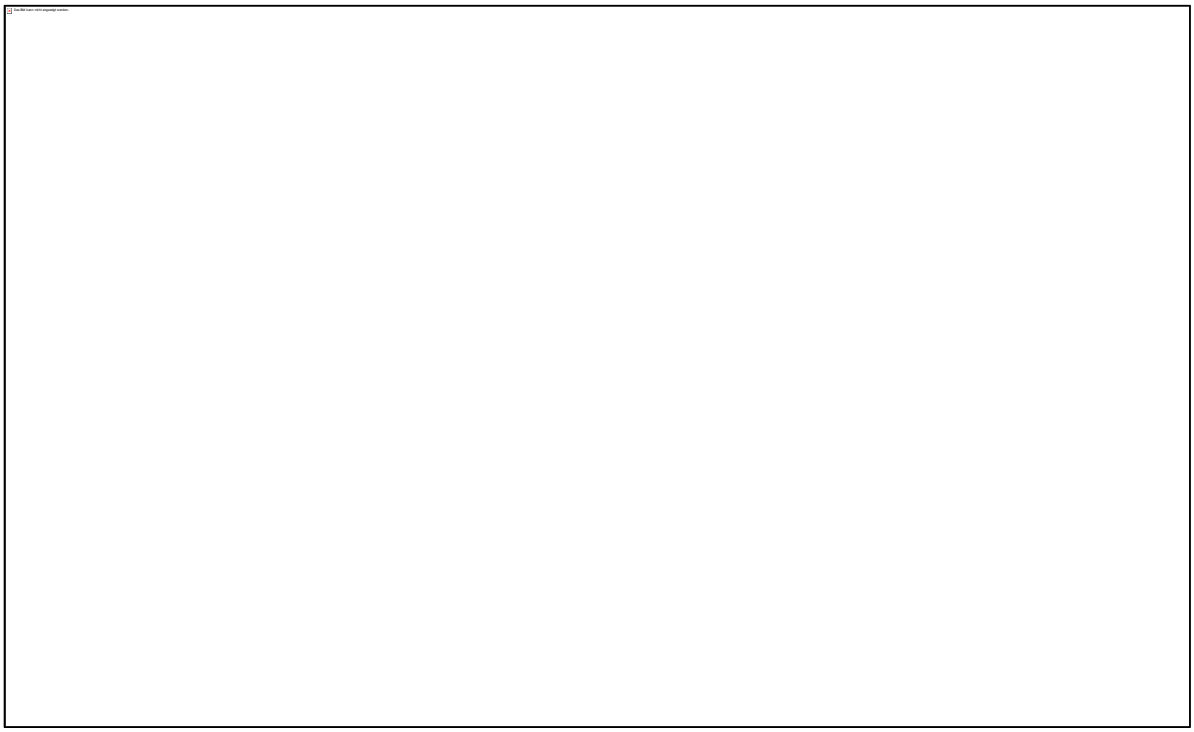
Energy efficiency for port equipment and fleet transformation

Qualitative results

Energy efficiency for port equipment and fleet transformation			
Working efficiency improvement	**Questionnaire comments**	**Interview comments**	**Literature**
Focusing on energy efficiency can be an adequate option to build a solution to cover all possible exceptions	1	0	0
Reasonability is the key component for an optimal trade-off between timesaving and energy saving	0	0	1
Speeding up the handling efficiency of quay and yard cranes and internal trucks	0	0	1
Convert the operation of cranes from today's alternative current drive to direct current technology using a proper current factor	0	0	1
Use the hoist-down movement for cranes, which permits to recover large parts of energy	0	0	1
Purchase, replacement and retrofit	**Questionnaire comments**	**Interview comments**	**Literature**
Do not consider purchase/replacement/retrofit as a classic business case - consider the environmental return as the most important one, and the economical ROI in the longer run	1	0	0
Use the technique of swapping batteries to reduce costs and to improve the life cycle of the batteries	1	0	0
Assure sufficient energy capacity	1	0	0
Asses the economical worthyness in regard to the age and size of the equipment	0	1	0
Be aware of carbon leakage when selling old equipment to other ports or markets	0	1	0
The following ranking between cranes regarding emission reduction applies: E-RTG < ARMG < RMG < RTG	0	0	1
For other equipment such as forklifts, rail movers, yard trucks, stacking cranes and automated guided vehicles, use swappable and portable “battery electric” systems, a widely used technology	0	0	2
If the port uses a workboat for harbour operation like maintenance or towing, retrofit it for electrification (running on a battery pack)	1	0	0
Options to fully electric are hybrid electric equipments or dual fuel engines	0	1	0
Consider hydrogen-powered fuel cells as an emerging technology for port operation equipment for benefitting from easier and more rapid re-charge as well as lower space requirements than batteries	0	0	2
In order to store potential energy for the use of electric port operation equipment, batteries, flywheels and supercapacitors have proven to be energy efficient solutions	0	0	6
If the Port Authority is not the owner of the equipment, support innovation actions	0	1	0
Opt for retrofitting when an equipment has rather low energy consumption but high global investment costs	0	1	0
Opt for newly purchased port equipment when the equipment has a smaller life span, with high energetic use and lower global investment costs	0	2	0
Use the merit order for making the right decision between purchase/replacement/retrofit	0	1	0
Further equipment improvement measures	**Questionnaire comments**	**Interview comments**	**Literature**
For energy management plans, establish an energy profile, wherefore A138:F153a detailed, long-term and reliable database must be aquired, which will evaluate and analyze the energy consumption and performance in order to make realistic projections, as well as enable appropriate correction measures and technologies	1	0	0
Modernize the lightning equipment by replacing todays mainly used high-pressure sodium lamps with energy-efficient light-emitting diode lamps (LED)	0	0	1
Green roofs, paint walls in white, clean lamps, use cold storage insulation and use curtains to minimize cooling demand and heat loss in port buildings	0	0	1
Install sprinkler systems, dust-proof nets and thatch covers to reduce port’s dust pollution	0	0	1

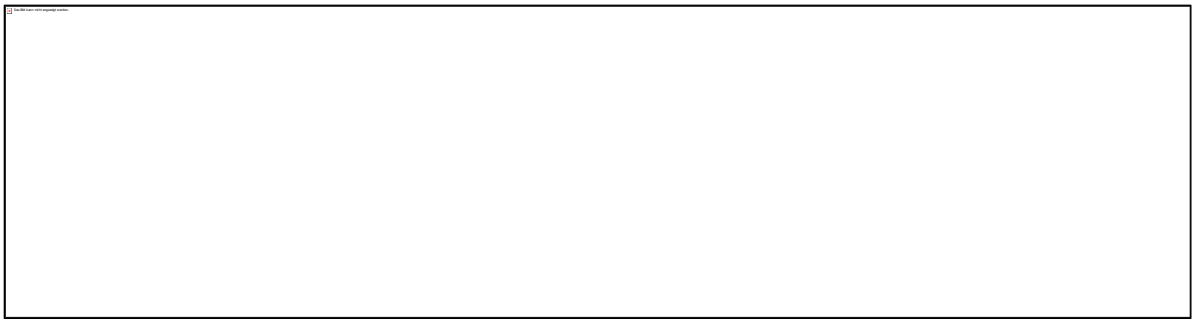
Questionnaire comments	Interview comments	Literature
6	8	18

Energy management systems



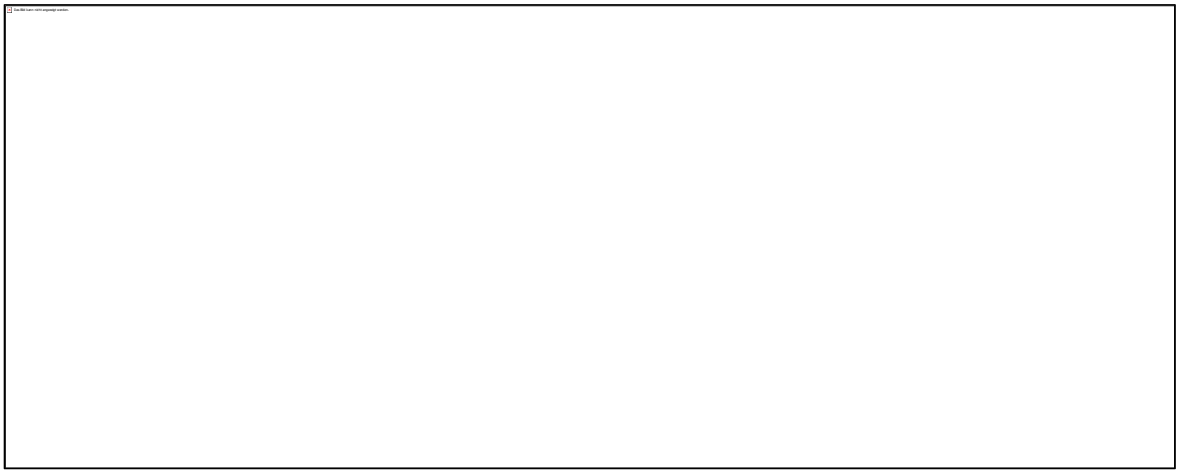
Questionnaire comments	Interview comments	Literature
3	0	28

Hinterland integration



Questionnaire comments	Interview comments	Literature
4	6	11

Renewable electricity for ship propulsion



Questionnaire comments	Interview comments	Literature
1	5	11

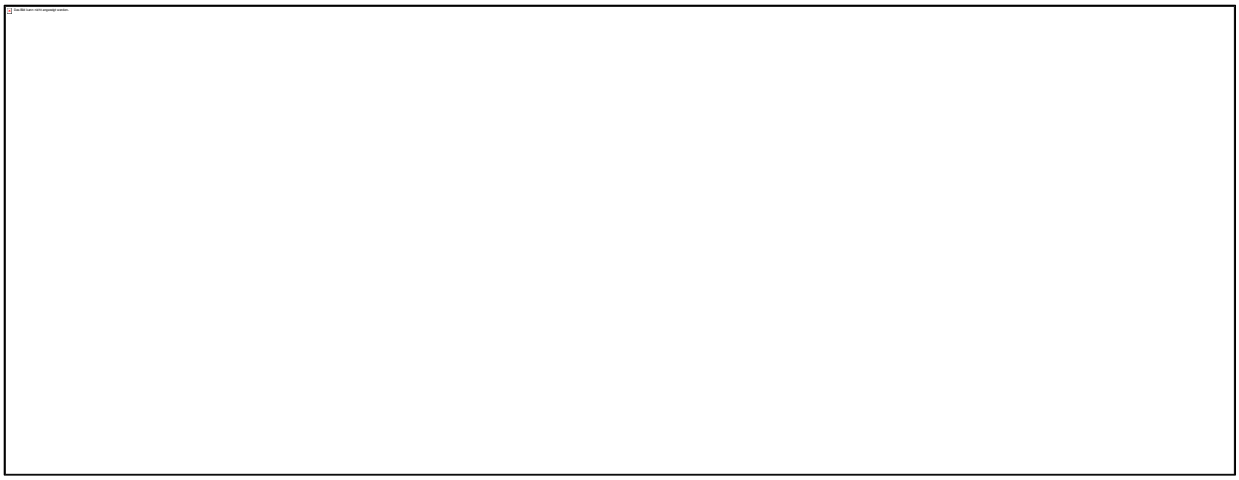
Smart resources and automation

Qualitative results

Smart resources and automation			
Information measures	**Questionnaire comments**	**Interview comments**	**Literature**
Install digital platforms for tracking real-time emission data in the port, captured by sensor networks, which enables the tackling of the main emission sources first	3	0	0
Use industry 4.0 technologies like Big Data, Artificial Intelligence, Internet of Things, 5G and 3D printing to increase efficiency	2	1	0
First, proceed data collection to identify pollution sources; second, set up monitoring to improve port environment by grasping activities with external effects on the port; third, report the results	0	0	6
Automation	**Questionnaire comments**	**Interview comments**	**Literature**
Install automated traffic management systems, for example with auto mooring systems, to optimize ship speed and time spent waiting	2	0	0
Explore new automation concepts and new technologies to facilitate electrification of the port	0	1	0
Primarily focus on gate automation, scheduling yard trucks and container tracking, which are today's main uses of port automation	0	0	1
Examples for automation for inspuration are: automatic shut-down and start-up systems automated mooring systems, double loading cycles of quay cranes, twin-lift or tandem-lift operations in gantry cranes, variable speed generator for RTGs, eco-driving, route optimisation, acceleration techniques for port vehicles, intelligent and autonomous vehicles (IAVs), waterborne autonomous guided vessels and drones and robots for warehouses	0	0	9

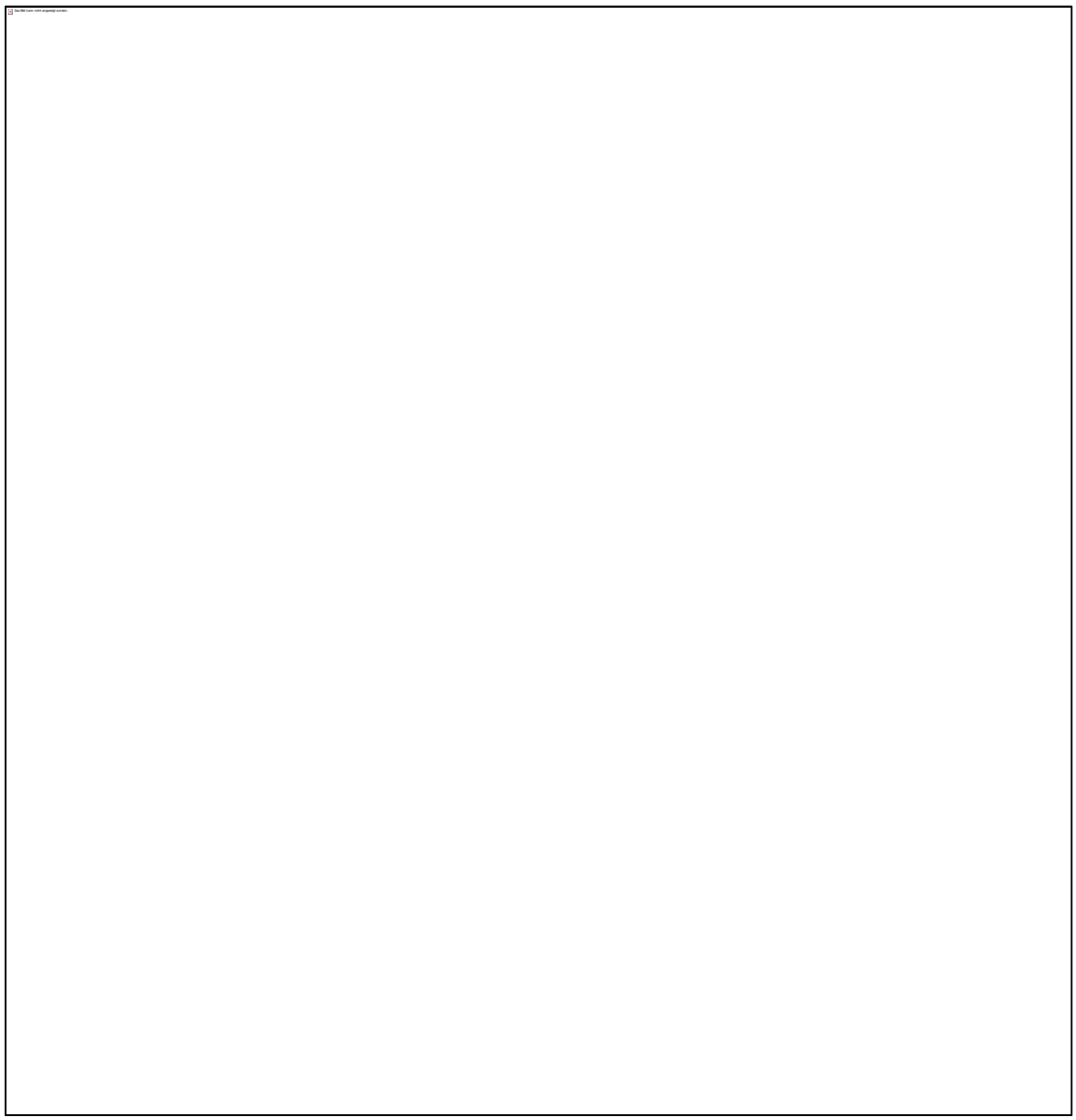
Questionnaire comments	Interview comments	Literature
7	2	16

Energy efficiency for ships in ports



Questionnaire comments	Interview comments	Literature
3	6	8

Annex 9: Self-assessment form



Annex 10: Evaluation sheet of individualized tutoring at the final thesis