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Implementing decarbonisation measures in Norwegian ports

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ABSTRACT

Despite the extensive literature on port sustainability, empirical research has so far paid limited attention to experiences with implementing measures that contribute to decarbonisation in small and medium-sized ports. This study contributes to the literature by investigating decarbonisation measures implemented by Norwegian ports, and drivers and barriers that ports associate with such efforts. We rely on a unique dataset of survey responses from 96 Norwegian port organisations, supplemented with insights from qualitative research. We find that most ports have implemented at least one measure that contributes to decarbonisation. Most prominent is shore power, followed by increased energy efficiency. We find that support from owners and surroundings is prominent in decarbonisation efforts and that political guidelines and steering from port owners are important drivers. Heterogeneity in port types and contexts implies that further empirical research is needed. This study calls for raising the role of ports in the energy transition on the political agenda.

1. Introduction

The pressure to improve environmental footprints of transport and logistics operations is mounting worldwide. There is a growing sense of urgency to reduce greenhouse gas (GHG) emissions, as reflected in the 2015 Paris Agreement and in the United Nation's Sustainable Development Goals (SDGs). The shipping industry represents 2,8 per cent of global GHG emissions (IMO, 2020), and the share of emissions from shipping is increasing. Norway is a case in point, aiming to reduce GHG emissions from domestic shipping and fisheries by 50 % in 2030 (MoCE, 2019). However, along with aviation and heavy-duty transport (Sharmina, 2020), shipping is considered a hard-to-abate sector (Energy Transitions Commission, 2020; Bergek, 2023). In Norway and elsewhere, environmental upgrading in shipping has to date mainly occurred through improved energy management and efficiency, as well as the introduction of end-of-pipe solutions[1] such as marine scrubbers. To significantly reduce emissions, alternatives to conventional fossil fuels are needed, and the greening of shipping is likely to require a mix of different low- and zero-carbon fuels and energy carriers (Lindstad, 2021).

The environmental sustainability agendas of ports are increasingly oriented towards tackling climate change (Lawer et al., 2019; Lozano et al., 2019; Acciaro et al., 2014; Acciaro et al., 2014; Poulsen et al., 2018; Sornn-Friese, 2021). According to the former Executive Secretary of the United Nations Framework Convention on Climate Change, Christina Figueres, 'There is no way that we can move this world towards sustainability without ports' (World Ports Sustainability Program, 2018). This quote reflects the critical role of ports as nodes in transport and energy systems, and as sites of interaction between different types of actors. Despite growing scholarly attention to the implementation of energy- and climate-related sustainability efforts in ports [see e.g., Acciaro et al., 2014, Sornn-Friese et al., 2021] research has mainly focused on large international ports such as Rotterdam and Los Angeles. Little is therefore known about decarbonisation measures in small- and medium-sized ports (GloMEEP and Toolkit, 2018; Bjerkan and Seter, 2019) that may serve both domestic and international users.

This paper addresses the following research questions: *which decarbonisation measures are implemented by small- and medium-sized ports, and how is implementation (or non-implementation) associated with various drivers and barriers?*

When investigating decarbonisation measures, we build on Bjerkan and Seter (Bjerkan and Seter, 2019) who identified a range of tools and technologies available to ports, spanning from the use of port fees to providing alternative energy solutions or automating port operations.

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[1] End-of-pipe solutions refer to pollution-control approaches or measures that clean up contaminated air or water where those enter the environment.

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When investigating drivers and barriers, we build on previous research on both ports and shipping [e.g. (Acciaro et al., 2014; Poulsen et al., 2018; Damman and Steen, 2021; Bjerkan et al., 2021; Mäkitie et al., 2022)] that has identified different factors influencing the (non)implementation of measures.

Given the limited attention in previous research to the decarbonisation efforts of small- and medium-sized ports (SMPs), our research design is both exploratory and explanatory. That is, we provide a mainly descriptive empirical account of decarbonisation measures among SMPs and the drivers and barriers associated with the (non-) implementation of measures. Note that it is beyond the scope of this paper to evaluate costs and efficiency of measures.

Throughout the article, we refer to ports as "port organisations". This is to emphasize how ports as *actors* can implement decarbonisation measures, and to contrast perceptions of ports as geographical sites, nodes in the transport system, or assemblages of actors (Damman and Steen, 2021). Further, by focusing on 'decarbonisation efforts' for climate- and energy-related measures we do not address the full width of sustainability issues (e.g. water, waste, dredging) that are relevant for ports.

Empirically we rely on a unique survey among 96 Norwegian ports. Our sample is heterogeneous in terms of port size, ownership (includes both public and private ports), and markets, and represents 26 % of ports nationally. Considering the lack of formal authority held by private ports we use the term "port organisation" rather than "port authorities". The analyses aim to understand patterns regarding implementation of decarbonisation measures in SMPs in Norway, and drivers and barriers associated with implementation in general and for the implementation of alternative fuels and onshore power supply (OPS). Further, understandings of implementation are substantiated and complemented by previous qualitative data generated in the same temporal and national context (Damman and Steen, 2021; Bjerkan et al., 2021; Damman, 2019; Bjerkan and Ryghaug, 2021; Bjerkan et al., 2021).

In Section 2 we present a review of the scientific literature on decarbonisation and sustainability efforts in ports. Our research setting, methods, and data are described in Section 3. We present our results in Section 4 before they are discussed in Section 5. Section 6 presents our conclusions.

2. Literature review

Historically, ports have grappled with a range of issues related to environmental sustainability, including dredging, noise, waste treatment, and emissions to air and sea. The European Sea Ports Organisation (ESPO) regularly surveys what key issues or priorities their members (i.e., port organisations) have on their agenda. ESPO (ESPO, 2019) compare environmental priorities in the port sector from 1996 to 2019, during which a remarkable shift in priorities occurred. The five top issues in 1996 were port development, water quality, dredging operations, dredging disposal and dust. In 2019 only two of these remain on the top ten list of issues. The five top issues in 2019 were air quality, energy consumption, climate change, noise and relationship with the local community. This shift in attention has also been confirmed by research on port sustainability [e.g. (Lawer et al., 2019)].

2.1. Port sustainability

The scientific literature on the environmental sustainability of ports has grown rapidly over the last decade [e.g. (Davarzani et al., 2016; Sislian et al., 2016; Lim et al., 2019)]. Several studies develop and suggest performance indicators that can guide sustainability efforts [e.g., (Puig et al., 2014; Di Vaio et al., 2018)]. These suggest, among other, what issues ports should focus on to increase their environmental performance.

Ports are increasingly faced with both local and global pressures to address environmental issues and demands [e.g. (Bosman et al., 2018)]. Global pressures emanate for instance through regulations and targets as set by MARPOL,[2] the Kyoto Protocol[3] (Lim, 2019), and IMO targets for GHG reductions in shipping.[4] Increasing local pressures reflect how many ports are becoming more integrated in their local community and are responding actively to issues such as local air pollution and noise (Poulsen et al., 2018; Di Vaio et al., 2018; Bjerkan and Seter, 2021). Tighter integration between port development and urban development also results in ports increasingly receiving attention in media and public debates (Ashrafi et al., 2019). To maintain or improve their public image (Ng et al., 2018), ports need to respond to calls for actions towards environmental issues (Poulsen et al., 2018). In other words, both global and local pressures can translate into drivers to implement decarbonization measures.

Ports address environmental issues via different types of measures, and their opportunities and challenges for doing so is conditioned by location, regulations, types of traffic and so on (Damman, 2019; Steen, 2022). Hence, understanding how ports can contribute to decarbonisation also requires knowledge about the drivers and barriers associated with measure implementation, and how those vary across different ports.

2.2. Decarbonisation measures in ports

The port sustainability literature describes many decarbonisation measures. Some studies also look into drivers and barriers associated with (non)implementation of measures. Ashrafi et al. (Ashrafi et al., 2020) reviewed the existing literature to identify drivers behind corporate sustainability, related to social, economic and market factors, as well as policy and governance. Further, Lozano et al. (Lozano et al., 2019) highlight governmental strategies, economic viability, and increasing societal awareness regarding environmental issues as the most important drivers for implementing decarbonisation measures in the Port of Gävle (Sweden). By contrast, they identified the most important barriers to be economic costs and the prioritization of economy over environment. Similarly, an online survey about corporate social sustainability in Canadian and US ports by Ashrafi et al. (Ashrafi et al., 2019) found economic constraints to be among the most significant barriers towards implementing decarbonisation measures. Hossain et al. (Hossain et al., 2019) also studied decarbonisation efforts in Canadian ports by surveying their implementation of administrative and managerial measures, albeit without considering the prerequisites for their implementation. Poulsen et al. (Poulsen et al., 2018) did so, however, when studying decarbonisation efforts in five major frontrunner ports (i.e. early movers addressing environmental issues) in North America and Europe. They found that a high degree of issue visibility (e.g., smog from local air pollution) was an important driver for measure implementation, along with low implementation complexity (e.g., energy management for port operations). Issue visibility may also explain why shore power has been introduced in many ports (Krämer and Czermański, 2020). Sornn-Friese et al. (Sornn-Friese, 2021) investigated what port characteristics can be considered drivers behind the adoption of air emission reduction measures in 93 of the world's largest ports. They identified three key drivers: population density, a specialization in servicing container shipping, and the landlord business model[5] of ports (Verhoeven, 2010).

[2] International Convention for the Prevention of Pollution from Ships: https://www.imo.org/en/KnowledgeCentre/ConferencesMeetings/pages/Marpol.aspx.

[3] The Kyoto Protocol: https://unfccc.int/kyoto_protocol.

[4] IMO targets to cut GHG emission from ships: https://www.imo.org/en/MediaCentre/HotTopics/Pages/Cutting-GHG-emissions.aspx.

[5] The landlord business model reflects one of the three traditional functions or roles of port authorities, alongside the roles as regulator and operator (Davarzani et al., 2016).

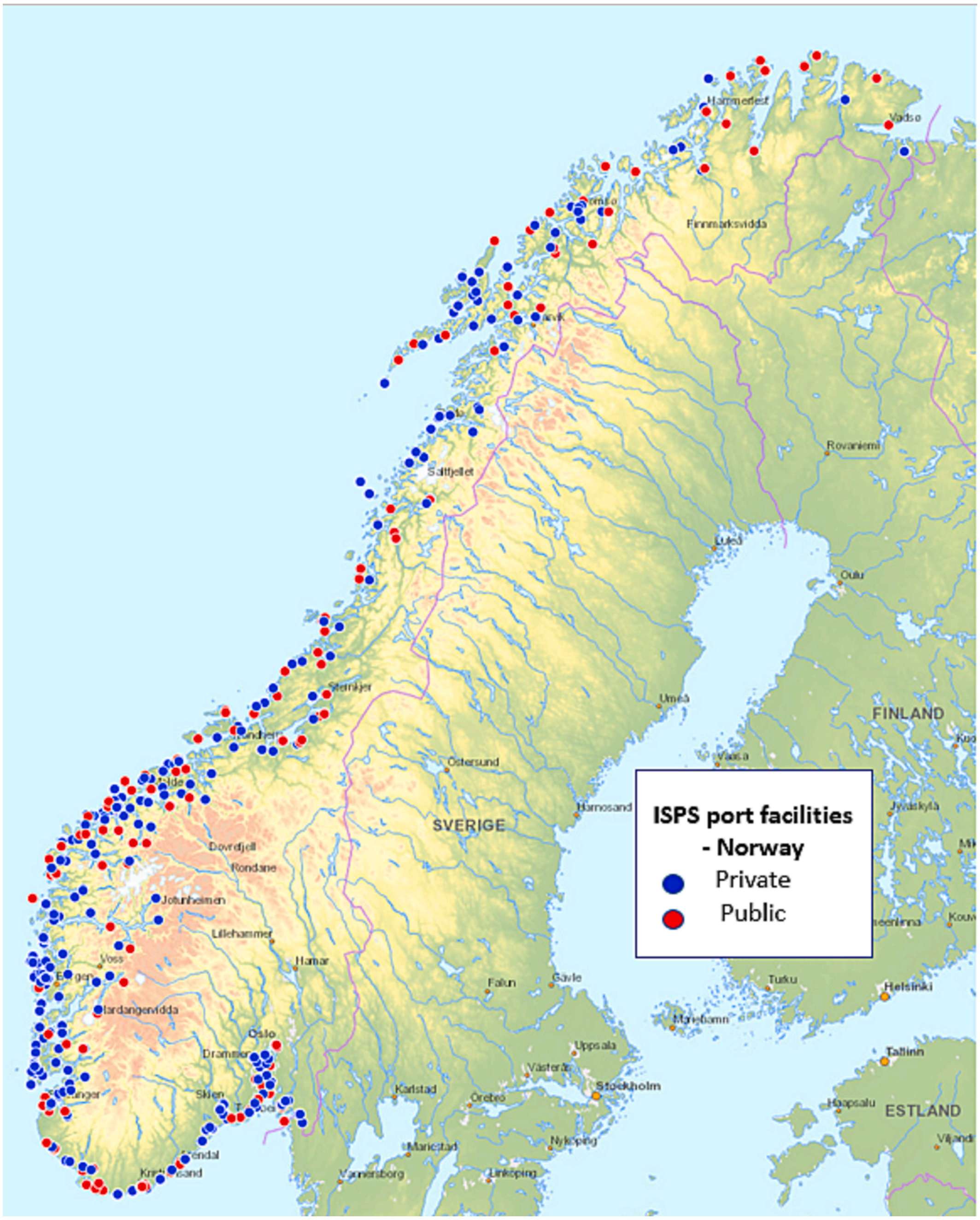

Fig. 1. Overview of ISPS port facilities in Norway. Source: Kystinfo (Kystinfo, n.d.).

Research on drivers and barriers associated with the implementation of decarbonisation measures in the shipping industry also provides useful inputs to our study. Serra and Fancello (Serra and Fancello, 2020) identified three main categories of implementation pressure: (1) regulatory and institutional pressures, (2) market factors and resource availability, and (3) social pressures and ecological awareness and responsiveness. Barriers relate to costs, technology, time and planning, regulatory frameworks, negative side effects, contractual issues, information, conservative attitudes and politics. Other studies on shipping (both coastal and deep sea) argue along similar lines and point out considerable differences between shipping segments regarding decarbonisation pressures and opportunities [e.g. (Mäkitie et al., 2022; Poulsen et al., 2016; Stalmokaitė and Hassler, 2020; Bergek et al., 2021)]. Thus, the shipping segments that ports serve are crucial for the selection and implementation of decarbonisation measures, for instance by determining demand for alternative fuels.

In a broader review of the scholarly literature on decarbonisation efforts in ports, Bjerkan and Seter (Bjerkan and Seter, 2019) identified 26 measures that ports have at their disposal. They comprised measures in port management and policies (e.g., energy management, concession agreements, port dues), power and fuels (e.g., energy production, fuel distribution), activities at sea (e.g., speed reduction) and on land (e.g., technology shifts in terminal operations and trucking, automation). This literature review (ibid.) concluded that research has focused on large international frontrunner ports, and that there is also a lack of empirical research on ports' experiences in measure implementation. This reduces the ability to provide research-based advice to the port sector, policy makers and other stakeholders on how to progress decarbonisation efforts.

Owing to aforementioned factors such as new regulations, increasing

Table 1
Ports targeted in the study (N).

	Public ports	Private ports	Unspecified	Total
Population (N)	60	339		399
Survey distribution	60	304		364
Survey sample (n)	41	52	3	96

local pressure to reduce air pollution, or demand from customers, ports are increasingly considering investments in infrastructures for various fuels, energy carriers, and energy services. The most progressive vision of future ports is perhaps as integrated energy hubs for both sea and onshore transport, that facilitate energy distribution (i.e., bunkering and charging) as well as production and conversion of fuels and energy carriers (Damman and Steen, 2021; Geidl, et al., 2007). Because they operate at the intersection between land and sea transport, and may host energy-intensive industry actors, ports have an advantageous position for becoming hubs for renewable energy generation, conversion and distribution (Gl, 2020).

For ports to transform in this direction, substantial change needs to occur both in ports and among port users. As discussed, ports can implement various measures to address climate- and energy-related issues, such as providing alternative fuels or improving energy efficiency in port operations. Measures differ considerably with regards to implementation complexity (i.e., how many stakeholders need to be involved for a measure to function) and to what degree they address issues that are visible to the public (Poulsen et al., 2018). In the absence of strong drivers (e.g., regulatory demands) it is for instance unlikely that many ports will provide alternative low- or zero-carbon fuels, given the high complexity of this measure. However, with increasing attention to both air pollution and climate change (i.e., issue visibility or awareness), change may nonetheless occur. Other measures, such as more efficient energy use in ports, may involve low implementation complexity. The drivers and barriers associated with specific measures are thus likely vary considerably, making it important to better understand patterns of measure implementation and reasons why certain measures are implemented and others are not. Given the limited knowledge about decarbonisation efforts of small- and medium-sized ports, we opted for research design that would help us map implementation of particular measures (i.e. exploratory), and the drivers and barriers associated with measure implementation (i.e. explanatory).

Research setting, methods and data

Research setting

Norway is a frontrunner in the development and implementation of low and zero-carbon energy alternatives to conventional fossil fuels for shipping (Bergek, 2023; Mäkitie, 2022), and the reduction of GHG emissions from domestic shipping has been high on the national policy agenda in recent years (Regjeringen, 2019). The Norwegian coastline is long and jagged with many ports of different sizes and types catering to the needs of shipping and maritime activities (offshore petroleum, shipping, fishing, aquaculture). There are 32 main ports located in cities and larger towns. These are governed by publicly owned enterprises (port authorities). Specialized ports include offshore supply bases, industry ports, cruise ports, and a large number (approx. 650) of mainly very small fishing ports. Whereas industry ports are privately owned, most other ports are owned by one or several municipalities, or by regional county municipalities (e.g. fishing ports). The ports targeted in our survey (see Section 3.2) all have ISPS facilities (see Fig. 1).

Research design, survey and sample

This study forms part of a research project (TRAZEPO, 2018–2022) on sustainability transitions in Norwegian ports, focusing on the ports in the Norwegian cities Oslo, Narvik, and Kristiansand. Prior to this project, little systematic research had been conducted on ports and their GHG emission reduction efforts – both internationally and nationally. We therefore developed an exploratory research design that involved comprehensive document analysis and literature reviews, 40 semi-structured interviews with actors in and around the three case ports as well as on the national level, (participatory) observation at various events, and workshops with representatives from the three case ports, the Norwegian Coastal Administration (public actor) and the interest organisation Norwegian Ports Association. We draw on this prior qualitative work (see e.g. (Damman and Steen, 2021; Bjerkan et al., 2021) when interpreting our survey results in this paper, for instance by including illustrative quotes from interviews[6] that were undertaken in the same context.

The insights gained through this highly contextualized qualitative work seeking thick description - surmounting to *intensive* research (Sayer, 1999) – illuminated drivers and barriers for introducing strategies, expectations, and experiences with implementing particular measures for decarbonisation in specific ports [e.g. (Damman and Steen, 2021)]. It was clear that decarbonisation opportunities and challenges (and efforts) varied significantly between ports. As stated by one project partner: *“If you've seen a port, you've seen one port!”*. This motivated a more *extensive* approach (Sayer, 1999) to survey decarbonisation efforts across many ports, for which the use of a questionnaire is a valuable method. Given our prior qualitative work and literature reviews, we included both exploratory and explanatory questions pertaining to ports' decarbonisation measures in the survey (Adams et al., 2007; Jain, 2021). In terms of exploration, the survey aimed to gain insights into implementation efforts (e.g., which ports are doing what, how do different measures compare). In terms of explanation, the survey aimed to probe causal factors explaining why particular measures are implemented (or not).

The questionnaire was thus developed on the basis of previous qualitative work, studies on port governance and decarbonisation [e.g. Acciaro et al., 2014, Damman and Steen, 2021, Bjerkan et al., 2021], various documents (e.g. reports, media) and online data resources, including those provided by Statistics Norway,[7] the ESPO Environmental Report 2019 (ESPO, Espo Environmental Report, 2019), the greenhouse gas protocol (Greenhouse Gas Protocol, 2014]), and also a similar survey targeting Norwegian shipowners (Mäkitie, 2022). The questionnaire[8] draft was reviewed by representatives from Ports of Norway. This quality check by a non-academic body, yet one with comprehensive experience and knowledge of the empirical domain (ports), helped to ensure internal data validity.

The questionnaire was distributed via Survey Design (online software) to representatives in public and private ports in the period March to June 2020. Participants from public ports were identified by a membership list provided by the industry association Ports of Norway, with contact information for port personnel considered to have knowledge about each port's sustainability efforts. Participants from private ports were identified from a list of Norwegian port facilities certified through the International Ship and Port Facilities Security Code (ISPS), provided by the Norwegian Coastal Administration. Online searches on publicly accessible web pages were used to obtain contact information for the facilities, although we failed to obtain such information for all private facilities. Although private ports often had a general e-mail address listed as their contact information (e.g., shared mailbox), we tried to find as much detailed contact information as possible.

[6] Readers should note that the sample set for interviews and the survey is non-identical. Because the survey was anonymous we also do not know anything about the extent of overlap.

[7] https://www.ssb.no/a/kortnavn/havn/arkiv/tab-2008–08-29–05.html.

[8] The full original questionnaire is in Norwegian and can be shared upon request.

Table 2
Main characteristics of the studied ports – port organisation and traffic.

	Categories	Frequency	%
Port organisation/ ownership	Municipal enterprise	29	30.21
	Intermunicipal enterprise	11	11.46
	State-owned enterprise	1	1.04
	Private company	52	54.17
	Other*	3	3.13
Port size (No. of employees)	1–5	40	41.67
	6–19	25	26.04
	20 or more	31	32.29
Port calls (per year)	0–100	23	24.47
	101–350	24	25.53
	351–2000	24	25.53
	2001–10,000	17	18.09
	10,001 or more	6	6.38
Types of traffic	Bulk/container carrier (dry)	69	71.88
	Liquid bulk	51	53.13
	Container ship	30	31.25
	General cargo ship	58	60.42
	RoRo	34	35.42
	Barge	29	30.21
	Offshore/supply	42	43.75
	Fishing and aquaculture vessels	46	47.92
	Ro/Pax	30	31.25
	Cruise ship/Coastal routes	39	40.63
	Other passenger boats	29	30.21
	Other	20	20.83
Traffic complexity**	1	19	19.79
	2	10	10.42
	3	15	15.63
	4	9	9.38
	5	2	2.08
	6	7	7.29
	7	5	5.21
	8	11	11.46
	9	6	6.25
	10	6	6.25
	11	4	4.17
	12	2	2.08

*Not included in the analyses **Additive index based on types of traffic. The number categories show ports with between 1 and 12 types of traffic.

Table 3
Operationalisation of main variables/items.

Measure: Measures of decarbonisation efforts	Scale in analyses
List of 17 measures (see overview in Fig. 1), in four main categories:	Yes, No
Port management and policies	
Power and fuels	
Sea activities	
Land activities	
Drivers and barriers in decarbonisation generally	
Survey question: To what degree does the port have a documented overview of the following?:	
Energy use in the port area	1 No degree
Emissions in the port area	2 Small degree
In the port's efforts with low- and zero-emission, to what degree do you experience the following?	3 Neither/nor 4 Some degree
Pressure from owner	5 Large degree
Pressure from users	
Pressure from surroundings (e.g., politicians, neighbours, interest organisations, the public, media)	
Support from owner	
Support from surroundings (e.g., politicians, neighbours, interest organisations, the public, media)	
Survey question: To what degree do you experience the following as barriers or drivers in your work with low- and zero emissions?	
Economic resources	1 Significant barrier
Own competence	
Time and personnel resources	2 Small barrier
Laws and regulations	3 Of no consequence
Technological maturity	
Political steering and guidelines	4 Small driver
Steering from owner	5 Significant driver
Attitudes and ambitions among port users	
Cooperation and coordination	
Other factors	
Drivers and barriers in implementing specific measures	
Survey question: To what degree has the following been important for the implementation or lack of implementation of the following?	
Demand (or low demand) from ports users	1 No degree
Desire (or lack of it) to create demand	2 Small degree
Sufficient (or insufficient) energy provision	3 Neither/nor
Sufficient (or insufficient) knowledge about the tool/ technology	4 Some degree 5 Large degree
Public economic support (or lack of it)	
Cooperation (or lack of it)	
Pressure from surroundings (or lack of it)	

The numbers of port organisations (public and private) included in the population, questionnaire distribution and the final sample are listed in Table 1. In total, 96 ports completed the online questionnaire. The response rates among public and private ports were 87 % and 13 % respectively, and the total response rate was 26 %, which is normal for online surveys of this kind (Sauermann and Roach, 2013). As the questionnaire was distributed as an open link, we could not identify which ports did or did not respond.

This approach, with anonymous respondents, for selecting the sample means that we do not know whom within the port organisation answered the survey, which could have implications for the conclusions we can draw from the sample. However, following Bosman et al. (Bosman et al., 2018) we assume that the port organisation represents an "incumbent organisation", and that the dominant narrative within the organisation is quite stable and by-and-large shared internally. This is discussed further under 5.1 Limitations.

Table 2 describes the sample of ports in the study, based on self-reported characteristics regarding organisation and/or ownership, port size (number of employees), and traffic characteristics (port calls per year and types of traffic). While the sample is heterogeneous, predominant characteristics include small port size, bulk and general cargo transport.

3.4. Operationalisation and statistical analyses

We relied on an adaptation of the 26 different measures identified by Bjerkan and Seter (Bjerkan and Seter, 2019), relating to i) port management and policies, ii) power and fuels, iii) sea activities, and iv) land activities. These reflect the breadth of decarbonisation activities that port organisations can engage in. As including all 26 measures would be overly comprehensive for a survey questionnaire, we chose 17 decarbonisation measures (listed in Fig. 2, see Appendix 1 Table A for overview) representing all measure categories. Measuring the effectiveness of these measures in terms of decarbonisation is beyond the scope of this paper. It should however be noted that all measures can contribute to decarbonisation, but that especially onshore power supply and the provision of alternative fuels are considered crucial options in this regard (Bjerkan and Seter, 2019; Alamoush et al., 2020; Bergqvist and Monios, 2019) We therefore pay particular attention to these measures in this paper.

Our selection of drivers and barriers for measure implementation are also drawn from existing research on decarbonisation in ports and shipping [e.g. (Poulsen et al., 2018; Ng et al., 2018; Acciaro et al., 2014; Steen et al., 2019)]. This research has demonstrated the influence of different types of resources (economic, time, competence, personel), technological maturity and collaboration on the implementation of decarbonisation measures.

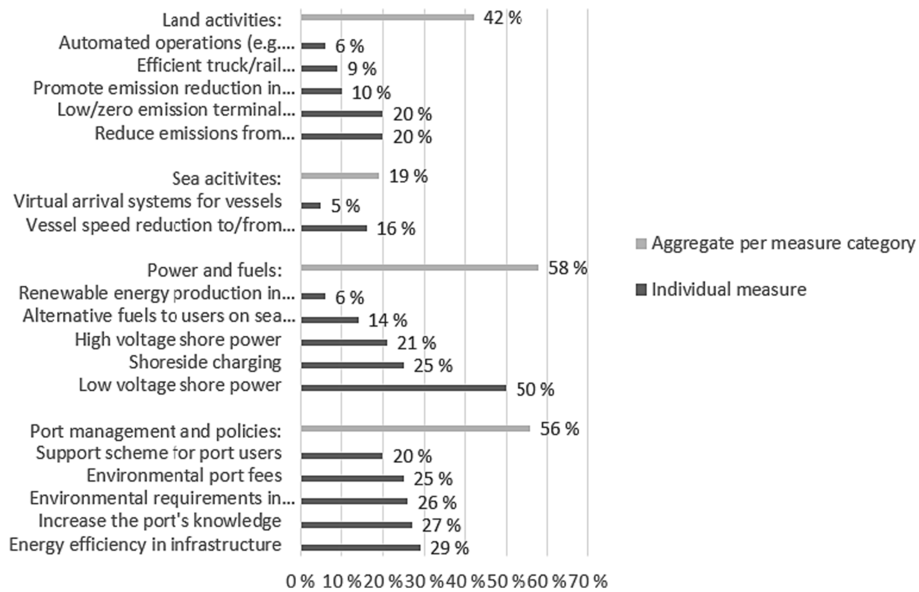

Fig. 2. Percentage of ports that had implemented decarbonisation measures (N = 96).

We also included implementation drivers and barriers related to governance. While 'governance' generally speaking refers to efforts that are dedicated to solve problems or create opportunities in society, governance is a multifaceted concept which encompasses activities conducted by private and private actors alike, spanning a range of sectors and to varying degrees rooted in law (Kooiman, 2003) or formal institutions (D.C. North Institutions, 1990). We have therefore included one measure of goverance specifying laws and regulations, i.e., formal institutions, as drivers or barriers to implementation of decarbonisation measures. We also included aspects of governance that are not explicit in regulation (e.g. measures that actors must comply with), in the form of policy objectives, strategies and expressed political sentiments, based on more informal institutions. These are collectively described as "political steering and guidelines".[9] Further, "steering from owners" refers to how implementation efforts are shaped by strategies and ambitions of port owners that may be more or less progressive compared with existing regulations or policies, and more or less aligned with prevailing political sentiments.

The survey furthermore distinguished between drivers and barriers related to decarbonisation in general, and drivers and barriers related to experiences with implementing specific decarbonisation measures. Drivers and barriers were measured by use of five-point Likert scales, where respondents stated whether they agreed with a set of statements about decarbonisation efforts in their ports. Further, one set of measures related to barriers and drivers in decarbonisation more generally ranges from 1 = Significant barrier to 5 = Significant driver.

To gain detailed knowledge about implementation experiences, we investigated drivers and barriers specifically associated with the implementation of onshore power supply (OPS) and alternative fuels. OPS (low or high voltage) was selected because of its prominence in the literature (Bjerkan and Seter, 2019) as well as its widespread implementation in Norwegian ports, driven by generous public funding schemes and a national electricity surplus. At current, more than 90 Norwegian ports have implemented OPS. Alternative fuels are crucial to maritime decarbonisation, and rely on mutual inter-dependence on the supply-side (i.e. bunkering in ports) and the demand side (i.e., adoption by shipowners) (Mäkitie, 2022; Bach, 2021).

The decarbonisation efforts of ports might also be shaped by ports' *documented overview of emissions and energy use* in the port. This has not been addressed in previous research. Therefore, we included 'documented overview' to indicate whether ports had a basis for making implementation decisions, assuming that knowledge of emissions and energy use (or lack thereof) impacts implementation.

To examine measures for decarbonisation that Norwegian ports have implemented, we conducted descriptive univariate analyses with calculation of percentages. For drivers and barriers related to decarbonisation more generally, we calculated the mean for all continuous variables. To investigate how such general drivers and barriers vary according to port characteristics we relied on different measures depending on the type of variables, including Wilcoxon Mann Whitney rank sum test and Spearman ran's rank correlation. Regarding drivers and barriers associated with the implementation of specific measures, we calculated and compared mean values for ports that had or had not implemented measures. We also tested significance levels. Details of the analyses, approaches and equations behind the different tests are listed in Appendix 2. The statistical analyses were run using STATA 16.

4. Results

4.1. Implemented measures for decarbonisation in Norwegian ports

Fig. 2 shows how many Norwegian ports have implemented the 17 decarbonisation measures included in the survey.[10] In total, 56 % of ports have implemented one or more measures relating to port management and policies. As these measures are typically carried out by the port organisation alone, they are associated with low implementation complexity. In particular, ports have implemented measures to increase energy efficiency in buildings and infrastructure (29 %) and to increase the port's knowledge (27 %).

In the category of power and fuel measures, 58 % of ports in the sample have implemented one or more measures. Overall, the most prominent measure is low voltage OPS, which is implemented by 50 % of the ports. High voltage OPS has only been implemented in 21 % of the ports in this survey, reflecting that it has a smaller base of potential users

[9] The English translation of the Norwegian phrase "*politisk styring og føringer*" could alternatively be "political governance and leadership". This refers to an admittedly broad set of factors that are not expressed in law or regulation, such as locally (politically) set ambitions to reduce greenhouse gas emissions (or other measures) that may go beyond national or international regulation.

[10] Frequencies for all measures are listed in Appendix 1, Table A.

Table 4
Explanatory variables for decarbonisation efforts. Means. Statistically significant findings $p < 0.1$.

Documented overview of *	All ports (N = 96)	Public ports (N = 41)	Private ports N = 52
Total emissions	3.42	3.13	3.78
Total energy use	3.73	–	–
Experience the following:*			
Pressure from owner	3.52	4	3.13
Pressure from users	3.10	–	–
Pressure from surroundings	3.71	4.07	3.43
Support from owner	4.27	–	–
Support from surroundings	4.00	4.26	3.75
Experienced barriers or drivers**			
Economic resources	2.41	–	–
Competence	2.76	–	–
Time and personnel resources	2.44	–	–
Laws and regulations	2.95	–	–
Technological maturity	2.76	2.56	2.96
Political steering and guidelines	3.45	3.78	3.21
Steering by owner	3.54	3.87	3.29
Attitudes and ambitions among users of the port	3.17	3.44	2.92
Cooperation and coordination with others	3.14	3.46	2.87
Other factors	3.0	–	–

Table 5
Prominent aspects in implementation experiences related to specific measures. Based on tables in Appendices 4–8.

Onshore power supply (N = 49)	Alternative fuels (N = 13)
Political steering and guidelines	Overview of emissions
Steering by owner	Attitudes and ambitions of port users
Pressure from surroundings	Collaboration with others
Pressure from users	Access to measure
Public economic support	Knowledge about measure
Desire to create demand	Pressure from owner
Overview of energy use	
Pressure from owner	
Access to measure	
Knowledge about measure	

(e.g. cruise vessels) than low voltage OPS. High voltage OPS also implies greater economic costs and strains on the energy grid due to greater power effects and thereby complementary investments in energy (grid) infrastructure (Mäkitie et al., 2022). Interestingly, only 14 % of the ports have implemented alternative fuels, indicating lack of drivers and/or substantial barriers associated with this measure. Measures for reducing emissions from land activities (e.g. via low-emission terminal equipment) have been implemented by 42 % of the ports.

Although 16 % of respondents report that they have implemented speed reduction measures for vessels to and from the port, decarbonisation efforts related to on-sea activities are not prominent in our sample. In total, 19 % of respondents have implemented one or more measures in this category.

Overall, the findings in Fig. 2 demonstrate the many different measures that ports take to foster decarbonisation, corresponding with assumptions that various measures are needed for shipping and other port-related sectors. It is also likely that implementation of different decarbonisation measures varies between ports operating in different contexts. These contexts, expressed in implementation drivers and barriers, are investigated further in the following.

4.2. Drivers and barriers in decarbonisation

This section presents drivers and barriers that ports associated with decarbonisation in general. Table 4 shows how respondents perceive

Table A
Implemented sustainable tools and technologies – frequencies and percent.

Implemented sustainable tools and technologies	Frequency	Per cent
Establish a support scheme for users in the port that want to reduce their own emissions	19	19.79
Include environmental and/or emission requirements in contracts with the port's users and tenants	25	26.04
Discounted or increased port fees based on the ship's environmental or emission characteristics (e.g. EPSI, ESI)	24	25.00
Increased energy efficiency in buildings and infrastructure	28	29.17
Targeted work to increase the port's knowledge of emissions and sustainability work	26	27.08
Establish own facilities for power from geothermal energy or solar, wind or wave power	6	6.25
Offer low voltage shore power	48	50.00
Offer high voltage shore power	20	20.83
Shoreside charging	24	25.00
Offer alternative fuels (e.g. LNG, biofuels, hydrogen, methanol, ammonia) to users at sea and on land	13	13.54
Measures to reduce the speed of ships to/from the port	15	15.63
Virtual arrival systems for ships	5	5.21
Use cranes, lifting equipment, port tractors, and other terminal equipment with zero/low emission technology	19	19.79
Automated operations (e.g. mooring, reloading)	6	6.25
Increase efficiency in loading/unloading of trucks/goods wagons (e.g. truck appointment system)	9	9.38
Measures to reduce emissions from industrial and production activities in the port	19	19.79
Measures to promote emission reduction in land transport to/from the port (e.g. freight transfer, promote the use of railways)	10	10.42

decarbonisation to be shaped by *pressure and support from different actors and the surroundings*, among other politicians, neighbours, interest organisations, the public, and the media. All values are above the mean, indicating that ports are encouraged by their surroundings to implement decarbonisation measures. This is in line with previous research suggesting that issue visibility (Poulsen et al., 2018) and societal awareness regarding environmental issues (Lozano et al., 2019) are important aspects of decarbonisation. Hence, as environmental issues gain attention among different actors in the port and its surroundings, ports are likely to increasingly perceive this attention as pressure and/or support for them to progress decarbonisation efforts.

Table 4 (section "Experienced barriers", column "All ports") shows that Norwegian ports on average consider *economic resources, time and personnel resources* to be barriers towards decarbonisation, echoing previous research (Lozano et al., 2019; Ashrafi et al., 2019). One informant (Interview 2019) argued that the cost of implementing decarbonisation measures is essential: *"It is important [for the port] to make wise investments and not invest in facilities that are not used and that may become expensive."*

Table 4 further shows that *technical maturity and competence* are also rated low, indicating that these variables are considered barriers against decarbonisation, which supports previous research from the shipping sector (Serra and Fancello, 2020). A representative of one of the larger Norwegian ports (Interview 2019) described the importance of external competence in establishing OPS: *"We use a lot of consultants. I do not have the expertise myself."* This is particularly challenging for smaller ports. One port representative (Interview 2018) comments: *"The smaller ports do not have the administrative capacity or competence to work with this (…)."*

A range of other factors investigated in the survey were not prominent, neither as barriers nor drivers. These include *regulation*, *attitudes* and *ambitions among port users*, and *cooperation and coordination with others*. The apparently small role of regulation was surprising and could derive from respondents finding it difficult to evaluate regulations in general rather than regulations connected to particular measures.

Table B
Barriers and drivers ports experience in the decarbonisation efforts in general.

		Mean, all ports (N = 96)	Mean, public ports* (N = 41)	Mean, private*** N = 52	Correlation, port calls (N = 96)***	Correlation, traffic complexity (N = 96)***
Documented overview in *	Total emissions	3.42	3.13	3.78		
	Total energy use	3.73				
Experience the following in decarbonisation efforts: *	Pressure from owner	3.52	4	3.13		
	Pressure from users	3.10				
	Pressure from surroundings	3.71	4.07	3.43		
	Support from owner	4.27				
	Support from surroundings	4.00	4.26	3.75	0.33	
Experienced barriers or drivers**	Economic resources	2.41				
	Competence	2.76				
	Time and personnel resources	2.44				
	Regulation	2.95				
	Technological maturity	2.76	2.56	2.96		
	Political steering and guidelines	3.45	3.78	3.21		0.32
	Steering by owner	3.54	3.87	3.29		0.38
	Attitudes and ambitions among users of the port	3.17	3.44	2.92		
	Cooperation and coordination with others	3.14	3.46	2.87	0.34	0.36
	Other factors	3.0				

*Categories ranged from 1 (no degree), 2 (little degree), 3, (neither/nor), 4 (some degree), to 5 (large degree).**Categories ranged from 1 (considerable barrier), 2 (small barrier), 3 (no barrier/driver/of no consequence), 4 (small driver), to 5 (considerable driver)
.
***Only statistically significant findings $p < 0.1$

Another explanation could be that current regulation simply is not very strong: some measures (such as the Environmental Port Index) are for instance voluntary and not formally binding, whereas others might depend on both national and international coordination and alignment.

Table 4 also shows how public and private ports differ in their decarbonisation efforts. The small role of laws and regulation is for example contrasted with the importance of non-legislative governance. In public ports these efforts are to a larger extent driven by their relations with other actors, such as owners, users, and surroundings (i.e. neighbouring residents, industry, stakeholders). Political steering and steering from owners is more prominent in decarbonisation efforts in public ports, reflecting how locally set ambitions with regards to environmental issues may be more progressive than national regulation (Damman and Steen, 2021), with a knock-on effect on ports. For example, in our qualitative data, a representative of a large Norwegian port stated (Interview 2018) that they have experienced a very active owner regarding reducing emissions in the port, and that they expected further political pressure on this issue. In private ports, relations to other actors and steering are not equally prominent drivers.

Our data further shows that decarbonisation efforts relate to port characteristics, such as traffic volumes and traffic complexity in each port (see Appendix 1, Table C). More specifically, the prominence of collaboration and support from other stakeholders (i.e. ‘surroundings’) increases with increasing traffic volumes. Also, drivers related to political steering, guidelines and collaboration increase with increasing traffic complexity. These findings could indicate that ports with high traffic volumes and complexity experience greater need and opportunity for aligning with their surroundings and their many users from different segments. These findings all support the argument that the decarbonisation efforts of ports are strongly connected to port characteristics (e.g. size, ownership) and operational context.

4.3. Drivers and barriers related to specific measures

In this section we present findings related to experiences with implementing OPS and alternative fuels. Whereas 53 % of ports have implemented OPS (low or high voltage), 14 % have implemented alternative fuels. Implementation of OPS is relatively evenly distributed regardless of port size, whereas implementation of alternatively fuels is more prominent in the large ports compared with those that are medium and small (see Appendix 1, Table G).

Drivers and barriers in the implementation of specific decarbonisation measures are presented in two ways. First, we examined how ports that have implemented these measures perceive of decarbonisation more generally. Specifically, we compared the prominence of decarbonisation drivers and barriers in ports that have and have not implemented OPS or alternative fuels. Second, we examined drivers and barriers that ports experienced in the actual implementation of these measures (Fig. 2). The survey results confirm that different drivers and barriers apply to different measure implementation. The main findings from statistical analyses (see Appendix 1, Tables B–F) are summarised in Table 5.

Our data provides most insight into implementation experiences related to OPS. Above all, the data demonstrates the broad support and commitment to OPS policies, expressed in how implementation is driven by informal institutions and non-legislative political steering and guidelines, steering by owner and pressure from surroundings. A generous public support scheme that has funded more than 90 shore power facilities in Norway has clearly also been important. One port representative (Interview 2019) stated that *“If we did not get the funding, we would not have been given the permission [by the port board] to build the shore power facility.”*

The substantial focus on OPS likely points to the ability of this measure to address issue visibility, as it reduces exhaust gas and local air pollution from ships at berth. One port representative (Interview 2019) described how local air pollution represents a large problem: *“There has been a strong push for implementing solutions. This relates particularly to the cruise ships. One can discuss how large the effect [of shore power] is, but due to the high visibility, this is a strong driver locally.”*

Overall, the ambition to create demand has been another strong driver for the implementation of OPS (Table 5). This is also reflected in our qualitative interviews. One port representative (Interview 2019) stated that: *“When we just start building shore power facilities, we see that we succeed in engaging the actors.”* This reflects how some decarbonisation measures constitute proactive steps to overcome chicken-and-egg challenges.

Also important to the implementation of OPS is having knowledge of and access to the measure. In our qualitative data, one port representative stated that *“[OPS] is the solution we have most knowledge about, and therefore the solution we are most comfortable with.”* The importance of

Table C
Comparison of port characteristics and drivers/barriers in ports that have or have not implemented shore power (OPS).

	Not implemented Percent (Freq)	Implemented Percent (Freq)	Test	P-value
Ownership			Chi2	0.002***
Private	72.73 (32)	40.82 (20)		
Public	27.27 (12)	59.18 (29)		
	100	100		
Size			Fisher's exact	0.943
Small	42.22 (19)	41.18 (21)		
Medium	24.44 (11)	27.45 (14)		
Large	33.33 (15)	31.37 (16)		
	100	100		
	Mean	Mean	Wilcoxon-Mann-Whitney rank sum test	
Port calls	2.136364	2.94		0.0011***
Traffic Complexity	3.444444	6.313725		0.0000***
Documented overview of emissions	3.428571	3.411765		0.8110
Overview of energy use	3.428571	3.980392		0.0876
Pressure from owner	3.177778	3.823529		0.0139**
Pressure from users	2.866667	3.313725		0.0569*
Pressure from surroundings	3.318182	4.039216		0.0036***
Support from owner	4.159091	4.372549		0.4273
Support from surroundings	3.818182	4.156863		0.1995
Economic resources	2.311111	2.490196		0.7546
Competence	2.733333	2.784314		0.8239
Time and personnel resources	2.355556	2.509804		0.5627
Regulation	2.933333	2.960784		0.9043
Technological maturity	2.755556	2.764706		0.9957
Political steering and guidelines	3.133333	3.72549		0.0038***
Steering from owner	3.333333	3.72549		0.0215**
Attitudes and ambitions among users	3.088889	3.235294		0.3528
Collaboration/ coordination from others	3.044444	3.215686		0.2952
Other factors	3.066667	2.941176		0.4758

*, **, *** indicates significance at the 90%, 95%, and 99% level, respectively.

Table D
Comparison of port characteristics and drivers/barriers in ports that have or have not implemented alternative fuels.

	Not implemented Percent (Freq)	Implemented Percent (Freq)	Test	P-value
Ownership			Chi2	0.172
Private	58.75(47)	38.46(5)		
Public	41.25 (33)	61.54(8)		
	100	100		
Size			Fisher exact	0.333
Small	44.58 (37)	23.08 (3)		
Medium	25.30 (21)	30.77 (4)		
Large	30.12 (25)	46.15 (6)		
	100	100		
	Mean	Mean	Wilcoxon-Mann-Whitney rank sum test	
Port calls	2.493827	3		0.1406
Traffic complexity	4.686747	6.769231		0.0286**
Documented overview of emissions	3.3125	4.076923		0.0641*
Documented overview of energy use	3.625	4.384615		0.0440**
Pressure from owner	3.409639	4.230769		0.0188**
Pressure from users	3.060241	3.384615		0.3032
Pressure from surroundings	3.646341	4.076923		0.2205
Support from owner	4.256098	4.384615		0.8896
Support from surroundings	3.97561	4.153846		0.9580
Economic resources	2.457831	2.076923		0.2242
Competence	2.783133	2.615385		0.5733
Time and personnel resources	2.461538	2.461538		0.7503
Regulation	3.012048	2.538462		0.1467
Technological maturity	2.722892	3		0.4433
Political steering and guidelines	3.385542	3.846154		0.1180
Steering from owner	3.445783	4.153846		0.0118**
Attitudes and ambitions among users	3.096386	3.615385		0.0679*
Collaboration/ coordination from others	3.108434	3.307692		0.3761
Other factors	3	3		0.8584

*, **, *** indicates significance at the 90%, 95%, and 99% level, respectively.

access likely reflects how sufficient power supply and the ability of the power grid to handle effect peaks have been decisive for implementation. One informant (Interview 2019) stated that *"the city has a well-developed power supply system that is built all the way down to the port area. Hence, it was relatively easy to establish shore power here."*

Table 5 further displays drivers associated with the implementation of alternative fuels. Ports that have implemented alternative fuels typically have a better overview of emissions in the port area and refer to the attitudes and ambitions of port users as important drivers behind implementation. However, the sampled ports do not experience push from potential users, which could be exacerbating the chicken- and egg problem (Mäkitie et al., 2022). Unlike OPS, public authorities are less specific on the scale and type of alternative fuel implementation. Thus, implementation is more likely to occur via bilateral collaboration among ambitious actors. This also reflects how alternative fuels represent a type of measure with high implementation complexity, in that it requires collaboration between producers, distributors, and users of alternative fuels, as well as the port itself and several public authorities.

Although access to measures is important to the implementation of any measure, it is particularly relevant to implementation of alternative fuels. This likely reflects the importance of market penetration of alternative fuels and predictability in supply and value chain functioning. For instance, one port representative (Interview, 2022) described how they worked to ensure such access: *"We want to position ourselves, combine production of hydrogen with a bunkering station. […] We see that this is coming."*

Table E
Ports that had implemented/ not implemented shore power (OPS) – importance of factors for the ports. Answers ranged from 1 (no degree), 2 (little degree), 3, (neither/or), 4 (some degree), to 5 (large degree).

Introduced shore power	Mean (Yes)	SD.	Obs.	Mean (No.)	SD.	Obs.
Importance of:						
Demand/low demand from port users	3.7	1.38873	50	2.913043	1.755848	23
Wanted to/did not want to create demand	4.591837	0.9556492	49	2.454545	1.405	22
Good/insufficient access to power	4.183673	1.148794	49	2.952381	1.596126	21
Good/insufficient knowledge about shore power	4.416667	0.8208282	48	2.636364	1.364358	22
Economic/lack of economic support from the public sector	4.020833	1.436449	48	3.2	1.576138	20
Cooperation/insufficient cooperation with other actors	3.897959	1.31093	49	2.809524	1.327368	21
Pressure/lack of pressure from the surroundings	3.714286	1.118034	49	2.954545	1.495303	22

Table F
Ports that had implemented/ not implemented alternative fuels – importance of factors for the ports. Answers ranged from 1 (no degree), 2 (little degree), 3, (neither/or), 4 (some degree), to 5 (large degree).

Introduced alternative fuels for the port's users	Mean (Yes)	SD.	Obs.	Mean (No)	SD.	Obs.
Importance of:						
Demand/low demand from port users	3.538462	1.391365	13	3.431034	1.612583	58
Wanted to/did not want to create demand	4	1.290994	13	2.689655	1.187758	58
Good/insufficient access to alternative fuels	4.461538	0.6602253	13	3.345455	1.363793	55
Good/insufficient knowledge about alternative fuels	4.384615	0.9607689	13	3.068966	1.105998	58
Economic/lack of economic support from the public sector	3	1.414214	13	3.615385	1.105314	52
Cooperation/insufficient cooperation with other actors	4	0.7071068	13	3.163636	1.134699	55
Pressure/lack of pressure from the surroundings	3.230769	1.235168	13	3.178571	1.063564	56

Table G
Distribution of OPS and alternative implementation and non-implementation among small, medium and large ports.

		Total Freq	N = 96 %	Small Freq	*n* = 40 %	Medium Freq	*n* = 25 %	Large Freq	*n* = 31 %
OPS	Implemented	51	53,1	21	52,5	14	56,0	16	51,6
	Not implemented	45	46,9	19	47,5	11	44,0	15	48,4
Alternative fuels	Implemented	13	13,5	3	7,5	4	16,0	6	19,4
	Not implemented	80	83,3	37	92,5	21	84,0	25	80,6

5. Discussion

The purpose of this study has been to explore decarbonisation efforts in small- and medium sized ports and to offer explanations to identified patterns by analysing the drivers and barriers associated with such efforts. Our analysis was based on data from a survey distributed to both public and private ports in Norway, most of which are small, and supported by complementary qualitative data from interviews, document studies and workshops. Our results show that 82 % of ports in the sample had implemented at least one measure for decarbonisation, suggesting considerable effort among Norwegian ports to address energy and climate issues. Overall, measures related to power and fuels were most prominent in the sample, followed by measures in port management and policy.

Collectively, the results of this study point to four broader 'influence themes' that shape the decarbonisation efforts of ports: *steering and guidelines*, *relations with surroundings*, *economy* and *non-economic resources*. These influences correspond with findings in previous research on decarbonisation efforts in ports and in shipping and are discussed in the following.

First, we found that non-legislative *steering and guidelines* drive implementation, for example expressed in the exertion of pressure by port owners. Our results show that such pressure is less prominent in private ports, indicating that active port governance is a more prominent feature of public ports in this sample. Private ports are often specialised and adapted to particular user and customer needs, specifically located to minimise logistics costs and reduce distribution with trucks (Prop. 86 L). This might reduce the need for steering by port owners. More limited, specialised operations could also explain why private ports have a better overview of emissions and energy use in the port area. Further, as private ports are often located in vicinity to industrial activities and more remotely from dense residential areas, operations in private ports are less likely to generate 'issue visibility' (Poulsen et al., 2018). With lower issue visibility, private ports most likely experience less pressure from owners or surroundings to implement decarbonisation measures. Conversely, public ports, and especially those located in urban areas, are more likely confronted with 'issue visibility' and subjected to restrictions that ensure amenity and recreational values for shoreside urban areas.

This relates to differences between private and public ports as subjects of political steering, which we identify as a prominent driver in this study. Being highly public and political concerns, decarbonisation efforts in public ports – whose owners rely on political recognition – more likely bear political connotations. Our survey findings demonstrate differences between public and private ports in terms of how prominent steering from owners and politics are in driving sustainability efforts. This supports previous qualitative research on decarbonisation efforts in Norwegian ports, which suggests that the ambitions of public port owners to reduce local climate gas and particle emissions are highly influential for the environmental strategies of ports (Damman and Steen, 2021; Bjerkan and Seter, 2021). Also, investments in OPS and alternative fuels in public ports might indicate that the decarbonisation efforts in public ports go beyond their commercial interest. This corresponds with the increasingly prominent port function described in the literature as "community management" (Verhoeven, 2010; De Langen et al., 2007). As community managers, ports attend to their societal functions and their social licence to operate, and it is reasonable to assume that public ports are more likely to take on such functions than private ones (Bjerkan et al., 2021).

Second, and relatedly, we found decarbonisation efforts to be influenced by the relation between the ports and their *surroundings*, e.g. port users, politicians, port neighbours, interest organisations, and the media. This corresponds with previous studies (Lozano et al., 2019; Serra and Fancello, 2020) pointing to the importance of stakeholder support and pressure to raise awareness in ports' pursuit of decarbonisation. In our study, the implementation of OPS, alternative fuels and measures for land transport all related to pressure and attitudes in users and/or surroundings. Implementation was especially driven by the wish to create demand for specific technologies, while it was halted by the lack of user demand. This speaks to the importance of stakeholder management (Freeman, 1984), which is addressed by substantial research on port governance [see e.g. 60, 61–63]. Our findings comply with understandings that stakeholder management is crucial to avoid challenges that arise from diverse and ambivalent political interests (Lam et al., 2013) and that port decarbonisation requires substantial and dedicated resources to stakeholder management (Dooms et al., 2019).

This brings us to a third prominent influence in this study; namely how important *economic resources* are for the implementation of decarbonisation measures. As seen in section 2.2, economic aspects are fundamental to port sustainability (Lozano et al., 2019; Ashrafi et al., 2019; Serra and Fancello, 2020). In our study, economy was considered a small barrier in decarbonisation efforts in general, but a prominent driver in shore power implementation. This most likely captures the effect of a generous support scheme from Norwegian government enterprise Enova that in 2020 alone granted economic support to more than 50 OPS projects, with a combined value of more than EUR 10 million.

Finally, we found *non-economic resources* to be a prominent influence in the implementation of decarbonisation measures. This refers to potential drivers and barriers in Table 3 associated with overview of energy use and emissions, competence, time and personnel resources, and collaboration. Previous research suggests that knowledge allows ports to make qualified decisions and increases the likelihood of implementing measures (Ashrafi et al., 2019). In our study, implementation drivers were related to the ports' knowledge about energy use and emissions in the port area, as well as knowledge about specific measures and technologies (e.g., OPS, alternative fuels). Another critical resource was the availability of energy. This is clearly demonstrated in the differences between implementation of OPS and of alternative fuels. OPS is the most prominent decarbonisation measure in Norwegian ports. In contrast, the marginal position of alternative fuels in Norwegian ports mirrors limited user demand from ship-owners to date (Mäkitie, 2022), as well as supply-side constraints (Mäkitie et al., 2022). In turn, the reluctance of ports to provide alternative fuels probably has a negative influence on demand. As such, indecisiveness and insecurity associated with various (novel) alternative fuels and energy carriers represent a major barrier towards decarbonizing sea (and also hinterland) transport.

The above paragraphs demonstrate the prominence of both national and local contexts in the implementation of decarbonisation measures, relating to for instance energy resources and public funding schemes. This suggests a 'domestication' of global trends in port sustainability [for a similar argument with respect to adaptation to climate change, see 66] that accentuates the need to move beyond international frontrunner ports when investigating the decarbonisation efforts of ports (Bjerkan and Seter, 2019). One relevant example in this regard is the widespread implementation of OPS in Norway, which is not likely to have occurred without generous public support. Implementation was promoted by political steering and guidelines that aligned with local steering and pressure from (especially public) owners.

That current (national or international level) laws and regulations were found to not constitute an important driver for implementation of decarbonisation measures is indicative of those formal institutions being too lax, considering the need for a sustainability transition also in ports and shipping. This study therefore also reflects the importance of local contexts and policy in port decarbonisation (Poulsen et al., 2018; Damman and Steen, 2021; Bjerkan and Seter, 2021). Ambitious local policy has proven vital to install ambition and motivation. As such, the development of national policies that not only spur but also align local efforts is required to transition the port sector in a sustainable direction. Such transitions are tied to the inherently global character of ports, especially as represented by their close connection to shipping. Although the International Maritime Organisation (IMO), international port organisations (European SeaPort Organisation, International Association of Ports and Harbours) and the EU have increasingly recognised the need and potential for the port sector to contribute to reducing GHG emissions, more efforts of a supra-governmental nature are still needed to align and raise international policy for port sustainability on the agenda.

A limitation with this study is that the ports in the sample may be more engaged in decarbonisation than ports that did not respond (see also (Becker et al., 2012) for a discussion of this issue). Hence, results can be skewed towards ports with high awareness of climate and energy related issues, for instance expressed in a higher response rate among public ports. This could impact the prominence of different drivers and barriers, exemplified by above discussions on political steering. Although the predominance of public ports is partly controlled for by the comparative analyses of private and public ports (details in Appendix 1), it could nonetheless produce an overly progressive image of the Norwegian port sector.

Although we recognise that a broader sample consisting also of other port actors than port organisations would be of great interest, we argue that the particularly important role of port organisations as nodes in transport and energy system (Bjerkan and Seter, 2019) render them useful research subjects on their own. A broader survey consisting of several types of actors could be an interesting avenue for future research. For instance, perceived drivers and barriers may differ across stakeholder groups, especially when including stakeholders that are not a part of the incumbent regime. Transition processes include changes in social networks and the replacement of key actors (Bosman et al., 2018), and it is therefore likely that 'regime stakeholders' have different perceptions than 'niche actors', such as suppliers of hydrogen, ammonia or other alternative fuels operating in the port area or distributing on behalf of the port. To explores such discrepancies, it could be interesting to qualitatively investigate the lifeworld of non-incumbent stakeholders.

6. Conclusions

In this study, we have aimed to improve the understanding of decarbonisation efforts in Norwegian ports and the drivers and barriers associated with these efforts. We found that shore power (OPS) was the most prominent decarbonisation measure, followed by energy efficiency in infrastructure, and increasing the port's knowledge. We further discussed four sets of influences that were prominent in driving or obstructing decarbonisation efforts in ports: steering and guidelines, relations with surroundings, economic resources, and non-economic resources. Interestingly, we also found that drivers and barriers are specific to individual decarbonisation measures, indicating that there is no shared recipe for progressing implementation processes. Our study also demonstrated differences between private and public ports. In particular we found that public ports experience more pressure from owners and surroundings to implement measures. An implication of this is that one-size-fits- all policy instruments to support decarbonisation efforts are likely less effective in some ports than in others. The prominence of steering and political guidance in this study suggests that both academics and practitioners should pay more attention to different roles in port governance, for instance the emergent community manager function (Bjerkan et al., 2021; Verhoeven, 2010). Such a role not only (potentially) enables more active port governance in decarbonisation efforts, but also facilitates deliberate and targeted involvement of users and surroundings. Hence this study indicates that community management could be essential to succeed with measure implementation.

Considering broader implications emanating from our analysis, we are cautious to generalize due to the particularities of the Norwegian context where there is strong attention to emission reductions from both sea- and land-based transport, and where many ports are owned and operated by public authorities. However, the findings might be of special relevance for ports or similar node-organisations doing transition work (Bjerkan et al., 2021). We nonetheless conclude that there is yet a substantial untapped potential for emission reductions in ports. This is evident from our empirical findings, showing that widely implemented measures, such as low voltage OPS and improving the energy efficiency in infrastructure, are characterised by low implementation complexity. While they may be important in terms of reducing emissions from ports and port users, they nonetheless signal mainly incremental improvements. The measures needed for considerable reductions in GHG emissions from ports and the transport sectors that they serve, such as high voltage OPS and alternative fuels, have so far only been implemented in a limited number of ports in Norway. This implies that continued policy support, and more stringent regulations and requirements for transport sectors, are likely to be needed if such high-complexity measures with more substantial emission reduction potential can be implemented (Bergek, 2023). This in particular concerns smaller ports, which face capability, capital and capacity constraints in dealing with complex decarbonisation measures. Overall, this study points to the need for the port community to raise port sustainability on the political agenda and compel policy makers to recognise the crucial node position of ports also in transitioning the entire transport sector.

A key limitation of the study is that we have not evaluated the environmental sustainability associated with different measures, for example the degree to which LNG can be considered a sustainable technology. Furthermore, some sustainability measures have more radical implications than others in terms of changes in technologies, institutions and practices. Understanding how the ongoing sustainability transition affects ports and transport system requires attention from various research fields. Another issue is that as the perspective and experience of the port managements' themselves haven been a key source of data to this paper, we cannot guarantee it is without bias. The sample itself is balanced in terms of public and private ownership, however private ports are underrepresented compared with the total population. Further, non-response bias could have affected the results (Gail et al., 2005) as it is likely that the ports that responded to the survey are somewhat more progressive when it comes to sustainability, taking the topic into account. However, as the main point of the departure of the paper has been ports that implement decarbonisation measures, we do not see this as a limit to the actual findings.

This study identifies several avenues for future research on port decarbonisation and sustainability. First, this study was limited to Norway and there is clearly a need for more research in other national contexts. Comparative studies (including studies of ports of different types and sizes) using mixed-methods research design and also accounting for the efficiency and costs of different measures would be highly valuable. Second, there is clearly a need to increase our understanding of how ports' sustainability efforts are influenced and conditioned by local or regional characteristics such as existing infrastructure and physical assets, space limitations, institutions, capabilities, and market conditions. Third, we see a clear need for better understanding how ports use their different roles (Verhoeven, 2010) in their sustainability efforts, and how this may vary between countries and different types of ports. A final area of future research is enhancing our understanding of key port stakeholders, notably shipping and heavy-duty onshore transport actors, and how their sustainability endeavours align with those of ports given that new low- and zero-carbon energy value chains are needed (Mäkitie et al., 2022).

CRediT authorship contribution statement

Markus Steen: . **Kristin Ystmark Bjerkan:** Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Writing – original draft, Writing – review & editing. **Lillian Hansen:** Conceptualization, Formal analysis, Investigation, Methodology, Writing – original draft, Writing – review & editing. **Hanne Seter:** Conceptualization, Funding acquisition, Investigation, Methodology, Writing – original draft.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Markus Steen reports financial support was provided by Association of Norwegian Ports. Nothing else to declare.

Data availability

Data will be made available on request.

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Appendix 1

See Tables A–G

Appendix 2. Statistical analyses approaches and mathematical formulas for. Run by STATA 16

To compare the distribution of barriers and drivers among public and private ports, Wilcoxon-Mann-Whitney rank sum test was applied. Wilcoxon-Mann-Whitney is a nonparametric test and appropriate when the dependent variable is not normally distributed. Thus, it is the equivalent of the *t*-test, but has the advantage of not being dependent on normal distribution. It tests for differences between two groups on a single, ordinal variable with no specific distribution (McKnight et al., 2010).[11] However, we calculated the mean to show the direction more clearly. To measure associations with

[11] See also 9. Acciaro, M., et al., *Environmental sustainability in seaports: a framework for successful innovation.* Maritime Policy & Management, 2014. **41**(5): p. 480–500. for the use of this test for comparison of specific objectives related to degree of success of innovation for environmental seaports; and 70. Kim, S. and G. Chiang Bong, *The role of sustainability practices in international port operations: An analysis of moderation effect.* Journal of Korea Trade, 2017. **21**(2): p. 125–144. for application of the *t*-test for comparing level of implementation of sustainability practices in port operations.

traffic volumes and complexity Spearman's rank correlation was used, both to measure the strength and significance of correlations (Akoglu, 2018). To investigate drivers and barriers ports experience when implementing specific technologies, we used the Chi square test, which measures the difference between observed and expected outcome frequencies for a set of events or variables. It is used to test whether two variables are related or independent from one another. However, in certain cases, the Fisher test was applied, depending on the frequency in the cells of the tables [see 72 for advantages with Chi square test and Fischer's exact]. For ordinal variables, we applied the Wilcoxon-Mann-Whitney rank sum test.

Chi-Square:

The chi-squared test performs an independency test following the null hypothesis of independence, no association between groups, and the alternative hypotheses of non-independence with association between the groups.

$$x_c^2 = \sum \frac{(O_i - E_i)^2}{E_i}$$

where:
c = Degrees of freedom.
O = Observed value(s).
E = Expected value(s).

Fisher's Exact test:

While the chi-squared test relies on an approximation, Fisher's exact test calculates directly:

$$p = \frac{\binom{a+b}{a}\binom{c+d}{c}}{\binom{n}{a+c}} = \frac{\binom{a+b}{b}\binom{c+d}{d}}{\binom{n}{b+d}} = \frac{(a+b)!(c+d)!(a+c)!(b+d)!}{a!b!c!d!n}$$

Especially used when sample sizes are small, with cells having expected frequencies < 5.

The Wilcoxon Test

The Wilcoxon Rank Sum test can be used to test the null hypothesis that two populations have the same continuous distribution.

We used a normal approximation for Mann-Whitney u test Statistics, since $N > 20$.

$$z = \frac{U - n_x n_y}{\sqrt{\frac{n_x n_y (N+1)}{12}}}$$

Spearman's Rank Correlation

The Spearman rank correlation coefficient, r_s, is the nonparametric version of the Pearson correlation coefficient. Measures the strength of a monotonic relationship.

$$\rho = 1 - \frac{6\sum d_i^2}{n(n^2-1)}$$

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