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A socio-technical perspective on the scope for ports to enable energy transition

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ABSTRACT

The paper applies the multi-level perspective (MLP) in a descriptive study of three Norwegian ports, to shed new light on the sociotechnical processes that structure their efforts to develop into zero emission energy hubs. While exogenous pressures cause tensions over port governance, the studied ports utilize their full spectre of functions; as landlords, operators, authorities and community managers, to enable transition. The respective approaches vary, related to their local context, market situation and social networks, including port's relations with their owners. Individual orientations and organizational capacity further influence their engagement with radical innovation niches (e.g. OPS, hydrogen, LNG). The study highlights the active role of ports in sustainability transition. It shows how the interaction between geographical factors and institutional work influences the scope for new solutions around the individual port, and how this makes for different feedback loops and contributions to sustainability transition in wider transport and energy systems.

1. Introduction

Infrasystems, including physical infrastructure and the institutions regulating and managing it, can be both barriers and facilitators of radical change (Frantzeskaki & Loorbach, 2010). Yet, relatively little attention has been paid to the role of key infrasystem actors, such as ports, in research on sustainability transitions. Generally, there is a dearth of research on port sustainability performance (Lim et al., 2019). This is somewhat surprising, given the pivotal role of ports as engines of economic activity (c.f. Goss, 1990; van den Bosch et al., 2017). Ports face substantial challenges related to climate change, the transition from fossil-based to renewable energy systems, sustainable transport and logistics, local area development and relations to their hinterland. These processes and their effects are interrelated, calling for an integrated system perspective.

Loorbach and Geerlings (2017) present transition studies, comprising various system perspectives on socio-technical change towards sustainability, as a way to understand the challenges of ports. They discuss inland shipping at Rotterdam in a transition management perspective, which also frames a subsequent publication on bio-based transition pathways for the same port (Bosman et al., 2018). Our paper takes a different approach. In line with recent work applying the multilevel perspective (MLP) on sustainability transitions (Berggren et al., 2015; Penna & Geels, 2015; Turnheim & Geels, 2019), we are concerned with the role of incumbent actors in transitions. Ports, or port organizations, constitute a particular kind of incumbents that can take on different roles. Based on a qualitative case study of three ports, we discuss drivers, barriers and strategies for the development of ports as zero-emission “energy

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hubs" facilitating emission reductions in wider transport and industry networks. Thus, we meet the calls for more knowledge about infrasystems and actors and processes at the interface between different sectors in sustainability transition (Köhler et al., 2019; McMeekin et al., 2019). The aim is to provide new knowledge on the complex interactions that influence the scope for action and specific approaches taken by individual ports. We pay attention to exogenous pressures and tensions in the existing socio-technical system and associated institutions (rules, regulations etc.) around ports. Our main focus is on how these interact with geographical factors and institutional work influencing the engagement with specific measures and solutions, and how this, in turn, affects the ports' ability to contribute to transitioning the wider socio-technical system they are embedded in.

In the following section we present the background of the study and our analytical perspective on ports in transitions. Section 3 describes the research setting and methods employed. Section 4 presents and discusses the main findings on scope and strategies applied in the selected ports, while Section 5 discusses the implications of these findings in terms of reorientation and wider system change. In Section 6 we conclude and provide some pointers for future research.

2. Infrasystems and sustainability transitions

2.1. Changing perspectives on ports

More than 80% of world trade travels through ports (UNCTAD, 2018). In line with global economic growth and increase in maritime transportation, the competition among ports has grown (Jia et al., 2017). The governance of ports has also changed. Brooks (2004) discusses four models: The Service Port, the Tool Port, the Landlord Port, and the Private Service Port. These differ by (1) whether the services are provided by public sector, private sector or mixed ownership providers, (2) their orientation (local, regional or global), (3) who owns the superstructure and capital equipment, and (4) who provides dock labour and management.

Van der Lugt (2017) finds a paradigm shift: From a governmental perspective – seeing ports as key to regional development, basic infrastructure, and quasi-public goods - to the view that ports mostly provide private goods in a competitive environment. This may also be perceived as a changing balance between two rationalities or "institutional logics", based on the historical patterns of practices, assumptions, values and rules ports are produced and organized by (Fuenfschilling & Truffer, 2014). In practice van der Lugt (2017), as well as Bergqvist and Monios (2019), see port authorities more like development companies. This makes an argument for governmental involvement, while placing the port authority more centrally in the discussion on how to manage ports. As ports increasingly are privatised, they orient towards profit maximisation (Cullinane & Song, 2002; Van den Berg & De Langen, 2017). They also require strategies, related to the characteristics and economic activities in each port (van der Lugt, 2017). A key issue is the scope of the port company's activities related to other enterprises in the port and wider stakeholders (van der Lugt, 2017). According to Lim et al. (2019), ports take more progressive action to increase operational sustainability of recent, as shipping companies increasingly consider this aspect when deciding which port to use (Ding et al., 2019; Parola et al., 2017).

At the same time the perspective is shifting, from ports as standalone transport nodes to ports as elements in value-driven chain systems (Robinson, 2002) and independent yet interdependent 'port cluster elements' (Brett & Roe, 2010). As hubs in global value chains, ports can facilitate environmental upgrading through four functions: (1) as landlords (providing land and basic infrastructure); (2) as regulators (setting tariffs, environmental standards, spatial planning); (3) as operators (own fleets, equipment and basic infrastructure); and (4) as community managers (bringing together port stakeholders to improve collaboration and performance)

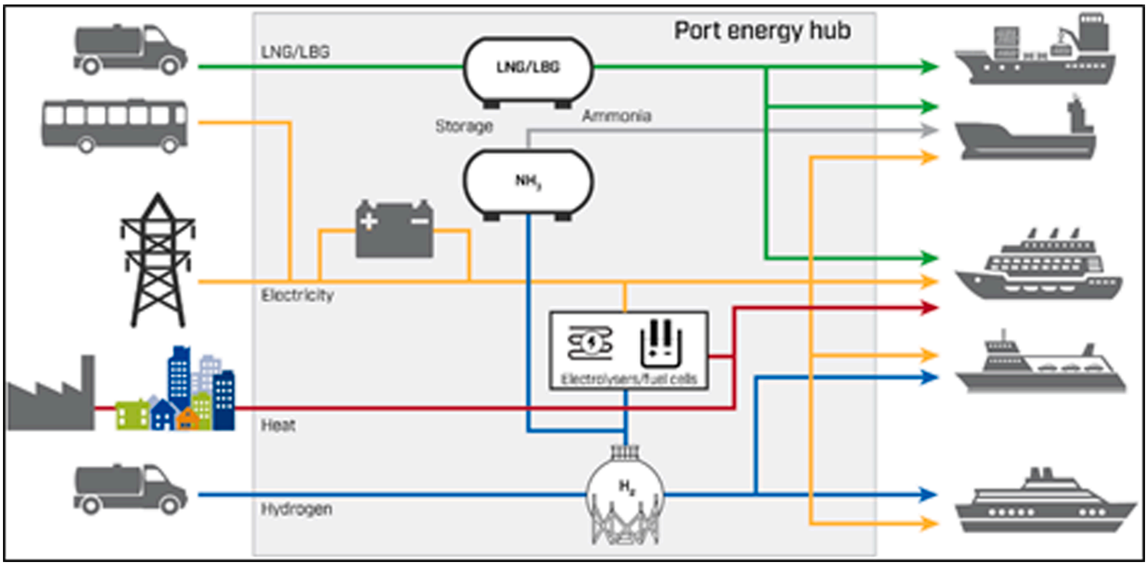

Fig. 1. Schematic representation of a port as energy hub. Source: Sverre Foslie, SINTEF.

(Acciaro et al., 2014; Poulsen et al., 2018; Verhoeven, 2010). Thus, ports may enable transition both by implementing new technologies and via other forms of institutional work (Fuenfschilling & Truffer, 2016), such as sanctioning and rewarding specific user practices; decreasing perceived risks of innovation; education, advocacy and the creation of rules and networks that define boundaries, status and identity within sustainable port development. However, the most common measures so far are technology improvements, infrastructure and monitoring (Gonzalez Aregall et al., 2018). This has been related to institutional pressures leading ports to focus on sustainability practices that lower costs, increase efficiency, ensure business and cargo flows, or avoid penalties, while hesitating to invest in initiatives without immediate payoffs (Vejvar et al., 2018).

2.2. Towards zero-emission "energy hubs"?

The literature on green ports has so far paid limited attention to their geographical context. Of the papers listing green ports measures, few include measures beyond the port area, such as modal shift (Acciaro et al., 2014; Bjerkan & Seter, 2019; Lam & Notteboom, 2014). Internationally, the notion of port "energy hubs" also turns on how to transform large ports that are pivotal in the trade and blending og refined oil products into sustainable energy ports. DNV GL (2020) portrays ports as future "decarbonization hubs", expecting that their transformation will involve direct and indirect electrification of port related activities, co-located industries and of maritime and inland ships. Since multiple sectors thus converge at ports, they may become frontrunners in the energy transition.

At a general level, an energy hub may be conceived as *"a unit where multiple energy carriers can be converted, conditioned, and stored. It represents an interface between different energy infrastructures and/or loads.."* (Geidl et al., 2007, 2-3). Applied to ports, the concept may be illustrated as in Fig. 1.

As the notion has both technical and social aspects which interact in complex ways, we apply a socio-technical perspective in this paper. The socio-technical transitions literature (Markard et al., 2012) has shown how sustainability challenges within large-scale, complex and highly durable sectors not only relate to new technology, but also to a myriad of non-technical challenges. In particular, existing socio-technical systems are aggravated by path-dependence and lock-ins (Klitkou et al., 2015). Mature technologies are interwoven with user practices, complementary technologies, value chains, business models, institutions and political structures: together these elements constitute a meso-level 'socio-technical regime' (Markard et al., 2012; Rip & Kemp, 1998)). Due to this complexity, technological change tends to be incremental, and the emergence of radical innovations requires structural change. Fuenfschilling and Truffer (2016), via the concept of institutional work, discuss how actors may play a mediating role between the two pillars of a socio-technical system. While the focus so far has been on individual technologies and systems, there is a growing interest in linkages and interactions across multiple systems (McMeekin et al., 2019). Here, ports as energy hubs provide an interesting case.

Loorbach and Geerlings (2017) see the situation of ports as a lock-in; enormous infrastructure investments have been made and practices and institutions have been developed to facilitate the current regime. However, given the external pressures linked to climate change and the development of niche innovations, it is likely that over time tensions in the current regimes will lead to systemic change. Bosman et al. (2018) discuss how such tensions affect the Port Authority in Rotterdam, where business-as-usual is combined with a transition "shadow track". Rotterdam is the largest port in Europe, government-owned, and intertwined with the petrochemical industry.

Norwegian ports are smaller, mostly owned by municipalities, and many enjoy a high degree of autonomy. The National Transport Plan (NTP) emphasizes modal shift and sees a future role for ports as zero-emission "energy hubs", with charging opportunities, onshore power supply (OPS) and alternative fuels infrastructure (MoT, 2017). Modal shift is of special relevance, as transport accounts for 31% of the national climate gas emissions and the Government aims to transfer 30% of current freight from road to sea by 2029. These ambitions are associated with an increasing need for coordination (NOU, 2018). A new Harbour and Fairways Act expands the mandate of the national Coastal Administration and gives municipal owners more control, while requiring an organizational distinction between the ports' role as public authority and commercial actor (Norwegian Government, 2020). This has been debated, and key stakeholders such as the Norwegian Ports Association doubt that it will lead to more sustainable blue-green transport. The controversies are associated with two forms of institutional work highlighted in previous research (Fuenfschilling & Truffer, 2016); mobilization of resources and the (de-)construction of rationales, i.e. the legitimation of a new role for ports.

2.3. A multi-level perspective on ports in sustainability transitions

The ongoing debates underscore that sustainability transitions are multiplex, disruptive and uncertain. We therefore apply the multi-level perspective (MLP), which is one out of four major research strands in sociotechnical transitions research (Markard et al., 2012). MLP addresses the systemic dimension of transitions and draws particular attention to the tension between stability and change, represented by the interplay of different degrees of structuration between technical and social elements at different levels of analysis: (1) niche developments, in terms of stakeholder interaction with radical innovations; (2) socio-technical regimes, which represent the stable meso-level of existing systems (e.g. maritime transport); and (3) exogenous socio-technical landscape developments (Geels, 2011). Different kinds of alignments between developments at these levels may lead to different transition pathways, whereby existing socio-technical systems (e.g. ports and maritime transport) are adapted or reconfigured to greater or lesser extent. While many studies tend to present regimes as rather monolithic, Fuenfschilling and Truffer (2014) emphasize that the level of structuration will have different effects on regime actors. Institutional work, that is negotiation across different institutional logics and purposive action to create, maintain, and disrupt institutions, impacts on system stability and change. Geels et al. (2016), likewise, suggest that the influence of landscape developments depends on timing (compared to niche and regime developments), but also on interpretation and mobilization by actors. Thus, an exogenous factor such as for instance the European Green Deal is not seen as a stable background variable, but as a factor of influence only through its interaction with other broad and more specific contextual factors, which determine how and to what extent it exerts a pressure on the actors in a specific case.

Whereas niche development mostly has been associated with new entrants, recent research shows that incumbent actors may facilitate radical innovation in various ways (Penna & Geels, 2015; Steen & Weaver, 2017; Turnheim & Geels, 2019). Their reorientation, understood as becoming involved in more radical socio-technical change, can have different ‘depths’, depending on the organizational elements that are adjusted (Geels, 2014). On the other hand, geographical perspectives (Hansen & Coenen, 2015) emphasize the influence of place-specific factors, such as local and regional natural resource endowments, infrastructure, industry specialization and varying customer demands. As regards infrasystems, previous research highlights the interplay of physical components, architecture and actors (Frantzeskaki & Loorbach, 2010), but less attention has been paid to the influence of contextual factors on their role in sustainability transition.

Köhler et al. (2019) call for more research on spatial variety in regime configurations and their effects on transition outcomes. We address these issues by discussing the scope for ports to enable transition in their regional, national and international contexts. In so doing, we conceive ports as multi-faceted: (1) as particular sites of economic activity, (2) as nodes in transport and industrial networks, (3) as heterogeneous networks of actors, and (4) as individual actors (port administrations). The first understanding underscores that no ports are alike. Geographical location and on-site economic activities have implications for ports’ opportunities and challenges in sustainability transition. The second implies that detailed knowledge of their networks is needed to assess the feasibility of different solutions in specific port locations. The third understanding directs attention to synergies, competing interests and time horizons, and the need for coordination and co-development. The fourth suggests that port administrations are key actors both in their own right and in terms of coordinating other actors. With this combination of perspectives, we aim to understand how different patterns of transition emerge, and provide new knowledge on the role of ports as *localised* incumbent actors, embedded in an environment where both institutional and geographical factors exert a strong influence on their strategies and scope for action.

3. Research setting and methods

Norway has around 130 ports reporting freight traffic (MoT, 2015), with 32 defined as trunk ports. We focus on three of these – Oslo, Kristiansand and Narvik. As depicted below (Fig. 2) they are in different regions, with different economic and transport system characteristics. They also vary in size and shipping segments.

The port of Oslo is in the capital region and constitutes a central node in the Norwegian transport system. In terms of total freight volume, it is however surpassed by the port of Narvik. The latter is in a small town with around 19 000 inhabitants, but ships around 20 mill tons of iron annually, from the Swedish mining industry. Narvik is also a main logistics centre, as the last stop on the only railway from the Gulf of Bothnia to the Atlantic and the northernmost railway in Norway. Kristiansand is a town of 92 000 inhabitants where the total freight through the port is one third of that in Oslo. Being the port closest to the European continent, Kristiansand is also an important intermodal hub.

A case study approach is useful for investigating contemporary phenomena in their real-life context, especially when the

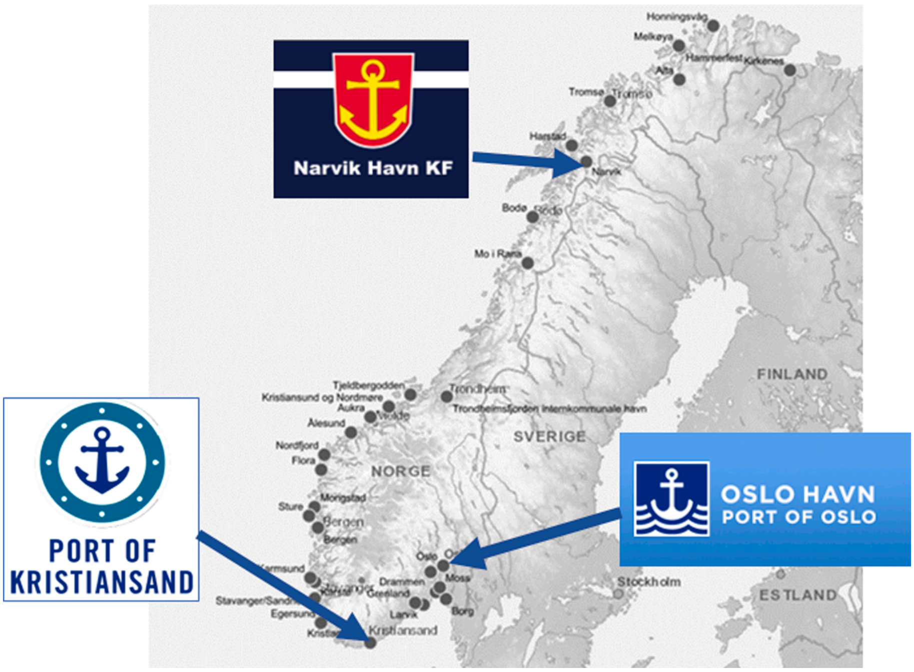

Fig. 2. Case ports and 32 trunk ports in Norway. Source map: the Norwegian Coastal Administration, www.kystverket.no.

boundaries between phenomenon and context are fluid and complex (Yin, 2014). Our research design followed three steps:

(1) An initial mapping, with a one-day site visit to each port with observations (port layout, infrastructure, equipment, key processes) and group discussions with central actors, as well as study of relevant documents.
(2) Semi-structured interviews, with a total of 39 stakeholders (categorized in Table 1). The sample was fairly equally distributed across the three ports, and also included representatives of national institutions.

The interviews lasted around one hour, and most were carried out via videoconferencing. The interviews were recorded, and detailed notes were subject to content analysis based on a coding scheme informed by the theoretical assumptions. The coding was done in NVivo, a software that allows bottom-up allocation of text parts to each category, so that the coding scheme may be continuously refined.

(3) Three 1–2-day workshops with representatives from the case ports, the Norwegian Ports Association, and the Norwegian Coastal Administration. These involved presentations by both researchers and practitioners, and discussions of the challenges and opportunities for ports in energy transition.

In the following we present our empirical analysis, before turning to a discussion of the ports' scope for action in terms of the above-mentioned challenges and perspectives.

4. Ports in transition

4.1. Increasing exogenous pressures

The transition efforts by the case ports are influenced by a wider landscape of exogenous developments. The knowledge and awareness of global warming, its impacts, and its implications is increasing steadily (IPCC, 2018). Prevailing energy scenarios have had a strong impact on energy and transport policies, pushing for reduction of the fossil fuel sectors and facilitation of zero- and low emission alternatives. In parallel with the processes around the Paris Agreement, the global economy has seen decreasing prices on renewables and a rapid development of low-emission technologies. Still, the needed scale and speed of change is unprecedented. This is associated with general as well as more specific economic and socio-political pressures to reduce emissions in and around ports (Bjerkan & Seter, 2019; Bosman et al., 2018; Loorbach & Geerlings, 2017).

Emissions from maritime transport are predicted to increase 50–250% by 2050 (IMO, 2015). The International Maritime Organization (IMO, 2018) has a target to reduce CO2-emissions 50% by 2050. OECD (2019), in their pathways to zero-carbon shipping by 2035, recommends a mix of technology, operational and alternative energy measures, including OPS, electric charging systems and alternative fuels. In the EU, the Port Services Regulation of 2017 aims to increase transparency and promotes charging of environmental costs based on vessel performance. The requirement of prior state aid control has been relaxed to allow ports to provide vessels with electricity, hydrogen, or LNG, and since 2014 the Connecting Europe Facility has awarded €1.1 billion to improve rail and inland waterways connections to ports and develop alternative fuel facilities (Mayet, 2017). The European Green Deal and ambition to reduce CO2-emissions from transport with 90% by 2050 is a huge opportunity and challenge, and the EU Strategy for Sustainable and Smart Mobility, to be published 9th December 2020 is expected to provide further direction and support. Although not a member state, Norway is strongly influenced by the EU, and some Norwegian ports are connected to the Trans-European Transport Network (TEN-T) and wider European transport networks. How these more macro-level changes influence specific ports will however depend on their alignment with national and local-level dynamics. For example, the requirement for core TEN-T ports to provide OPS by 2025 has exerted a stronger pressure in the case of Oslo, where large ferry and cruise traffic provide feasibility and substantial impact, than in Narvik, where dry bulk is dominant. The IMO target makes a more important driver for Narvik, as a mainly deep sea shipping port, than for those with predominantly coastal traffic, more influenced by national measures and climate obligations.

4.2. National policy developments

Norway's climate targets are to reduce emissions with 50–55% by 2030, and with 80–95% by 2050 (MoCE, 2020). Reduced

Table 1
Overview of interviewees, in terms of stakeholder category.

Category of stakeholders	Number
Port administration representative	7
Port users (logistics operators, transport)	13
Port users (industry)	6
Municipality	3
County-level administration	2
National stakeholders	2
Energy providers	5
Other (knowledge institution)	1

emissions from transport and a “green shift” in the maritime sector are priority areas, and the 2019 Action plan for green shipping aims to reduce the climate gas emissions from coastal shipping 50% by 2030 (Norwegian Government, 2019b). The strong focus on transport is related to Norway’s unique energy situation: 95% of stationary power supply is covered by hydropower and there is considerable potential for new renewable energy.

Norwegian energy policy has strong emphasis on electrification reflecting the dominance of renewables and need to reduce emissions from e.g. transport (MoPE, 2016). On the other hand, the petroleum sector plays a key role in the economy. There is increasing focus on greening the petroleum sector through new technologies, such as carbon capture and storage (CCS), and hydrogen. Moe (2015) sees two strong forces in Norwegian energy policy – one pulling in the direction of electrification, and another advocating for alternatives that may aid transition in the petroleum sector and contribute to regional development. These tendencies have also influenced the maritime industry, which aims to be a frontrunner in sustainable technology. Of the first 50 LNG propelled vessels ever built, 95% were Norwegian. Norway is also in front when it comes to battery-electric and hydrogen fuel cell vessels, which require alternative landing and refuelling/charging infrastructures (Bach et al., 2020). This forms part of the background for the focus on ports as zero-emission “energy hubs”.

While the national port strategy of 2015 emphasizes the development of ports as intermodal transport hubs (MoT, 2015), the recent National action plan for green shipping and National plan for infrastructure for alternative fuels in transport highlight electrification (Norwegian Government, 2019b). Norway will take a special responsibility when it comes to hydrogen bunkering facilities and aim for zero emission ports by 2030 (Norwegian Government, 2019a). Largescale production and bunkering of hydrogen will be more relevant for some ports than others (mainly in the West and selected ports in Northern Norway), due to the distribution of renewable energy, existing grid capacity and industry clusters (AFRY, 2020). In the current NTP (MoT, 2017), around 760 mill euro are set aside for new port and fairway projects. However, several of the interviewees noted that funding for the maritime remains limited (3% of the total) compared to that for road infrastructure.

The new Port and Fairways Act (Norwegian Government, 2020) aims to improve national coordination and facilitate active ownership, while maintaining predictability for port users. This leaves port authorities with less authority, while municipalities get more say regarding investments and environmental requirements. There is an incentive scheme for modal shift, and several large support schemes for low- and zero emission ship solutions (Bjerkan & Seter, 2019; Steen et al., 2019). With reference to green shipping, the overall state funding has increased significantly. In 2019, the government also set up a support scheme of around 5 mill euro to promote environment-friendly ports.

Thus, in line with Loorbach and Geerlings (2017) and Bosman et al. (2018), we find increasing and tensions in the sociotechnical regime around ports, pulling in different directions. With the emphasis on modal shift, ports’ relative importance vis-à-vis other parts of the transport system increases. There are increased funding opportunities for port collaboration and zero-emission solutions in ports. At the same time, concerns are raised regarding the role and relative autonomy of ports, motivating legislation that gives their owners more room to intervene. This is in line with the competing institutional logics (Fuenfschilling & Truffer, 2014) in the overarching discourse on ports, noted above (van der Lugt, 2017).

4.3. Place and geographical context

While promoting ports as “energy hubs”, the NTP priorities for the specific planning period will have different implications for different ports. The promoted strategies and solutions will also work differently for ports in different regional and local contexts.

Oslo as capital port has considerable traffic in passenger transport and freight. Due to population growth and densification, the port area will decrease in coming years. This has already motivated innovation at the container terminal, by way of electrification, automation, and vertical expansion. With five international ferry services, OPS has a substantial impact, as well as co-benefits in terms of reduced local pollution and improved environmental reputation for the actors in the port. Within the port, large actors in the building and construction sector are prominent. Their activities are associated with ship types and operations that so far are less suited for OPS, technically and economically. Some of this transport could also be shifted to road or channelled through neighbouring ports. Hence it may be challenging to balance environmental requirements and promotion of sea transport.

Kristiansand is also well positioned for OPS, as a ferry/roro port close to offshore industry and potential new ocean-based activities. There is a local industry cluster and knowledge institutions keen to develop the region’s capacity in sustainable energy solutions. Narvik’s focus on modal shift is related to its location relative to the eastward railway and transport to/from northern Norway. The port sees a huge potential for increasing the traffic from China, Russia and the other Nordic countries. Currently, there is limited handling at the port - mostly at a separate terminal run by Swedish mining giant LKAB - and it is difficult to adapt emission reduction measures to the irregular visits by a large number of relatively new dry bulk ships, which may have a lifespan of 30–40 years. On the other hand, the port is constructing new quays, where the time is right to prepare for future solutions. A combination of surplus renewable energy, mineral industry, aquaculture, and extensive truck transport make a multifuel energy station including hydrogen stand out as a relevant option.

These findings are in line with previous research, on the close connection between sustainability transitions and physical infrastructure (Frantzeskaki & Loorbach, 2010; Hansen & Coenen, 2015; Turnheim & Geels, 2019). Since the architecture of transport infrasystems is characterized by multidirectional flow, such systems tend to transition through better use of existing designs. Innovation involving alternative use and design is relatively rare (Frantzeskaki & Loorbach, 2010). For ports, the traffic type and lifecycle of vessels, availability of space and state/maintenance phase of quays are some of the specific factors at work. These may represent lock-ins or windows of opportunity, depending on time and timing, relative to the development of niche solutions, such as OPS and alternative fuels. At the same time, the natural resource base, most notably the availability of renewable energy, and the connection with local/regional industrial activities influence the ports' scope for action. The location relative to other pre-existing infrastructure (e.g. the neighbouring railway and truck terminal in Narvik, and the proximity of other ports and well-developed road network around Oslo) is also associated with specific opportunities and limitations. Thus, considering their material dimensions, we find four interacting site-specific factors that provide important premises for ports' ability to facilitate transition: Traffic, pre-existing infrastructure, industry, and availability of renewable energy sources (Fig. 3).

As we shall see in the following sections, these factors further interact with local institutional relations and the roles and responsibilities taken by different port actors.

4.4. Networks and institutional settings

Their geographical setting and scale orientation has implications in terms of number and kinds of stakeholders each port must relate to, and how it may develop and contribute to transition as a network or assemblage of actors. The port of Narvik's efforts to facilitate modal shift involves wide international networks where the port itself has limited influence. "Misinformation" by other stakeholders was considered as a challenge. When it comes to OPS in Kristiansand, a few key customers and strategic partners in other northern European ports play a larger role. The mix of measures and strong focus on local emission reductions in Oslo implicates a complex network of local stakeholders, but here the port has a more central position and may exert a stronger influence.

Generally, the networks around the three ports vary considerably. The port of Oslo has extensive networks. Internationally these extend mainly to other actors in the port- and maritime sectors. At the national and local levels, a high number of industry and logistics operators, as well as knowledge institutions and public stakeholders are involved. The port has the capacity to participate in a wide range of forums. It is also engaging with the third sector, e.g. formal collaboration with environmental NGOs, to boost awareness and explore new opportunities in transition. Until recently, there was limited collaboration with other local ports, but in 2020 the port of Oslo initiated a project where seven ports, including that of Kristiansand, explore options for climate collaboration, especially common conditions for use of OPS and charging facilities. There is a port users' forum, as well as formal and informal dialogue with larger users regarding emission reduction measures.

The port of Kristiansand is also engaged broadly, but the collaboration with other stakeholders is less formalized and more case- and business based. The port of Narvik emphasizes Arctic collaboration and is engaged in many regional development initiatives involving sustainable transport and port development. As this is a small town with many multi-tie relations, informal networks are important.

These findings are in line with previous research showing that relations on different scales matter in transition (Hansen & Coenen, 2015; Truffer & Coenen, 2012). Different constellations will be important, depending on the strategic fit between the relevant measures and other regional development goals. In both Narvik and Kristiansand, the ambitions for port energy transition are associated with local technological and industrial specialization. In Narvik, the university seems to take a coordinating role, whereas the initiative in Kristiansand is more distributed. The importance of intermediary organizations and universities is highlighted in previous transitions studies (Kivimaa et al., 2019). McCauley and Stephens (2012), especially, emphasize the role of regional cluster initiatives as conveners and coordinators of niche activities, and as intermediaries connecting niche activities with regime institutions.

In Oslo, the municipality aims to be a world leader in urban green transition. The municipal council gives strong direction and the port authority works actively as a development company. The port has 123 employees with a high competence level, including a dedicated manager for environmental and energy/climate issues, and solid financial capital reserves. In Kristiansand, the municipality seems less active than in Oslo. The port is financially robust and rather market oriented, with a lean organization with 28 employees, which could be one reason why efforts are more ad hoc. The port of Narvik has only 17 employees, since most of the activity is operated by LKAB. Due to dispositions in recent years, less funds are available for new investments. The port enjoys a relatively high degree of autonomy, and the governmental perspective stands strong. However, in 2019 the municipality initiated a collaboration called "Smart Narvik", which amongst other involves more formalised collaboration with the port and local energy provider to facilitate sustainable transport. Moreover, the influence of individual resource persons was mentioned in the interviews regarding all the case ports. The different network characteristics may also be related to local history and culture. The port of Oslo is in proximity to national offices and has traditionally ranked high in importance and resources. Due to its strategic position, the port of Narvik was bombed in World War II and has a special role in local identity and culture. The port of Kristiansand is rooted in a shipping community and aims to be lean and flexible, with a high willingness to risk and test new technologies. Thus, resonating with previous studies (Fastenrath & Braun, 2018; Späth & Rohracher, 2010) the ports' scope for action is influenced by both formal and informal localised institutions, in addition to their various network characteristics. As illustrated in Fig. 4, these social factors interact with the material factors discussed in the previous section, in various ways.

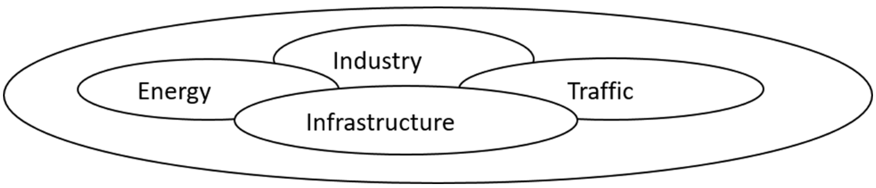

Fig. 3. Four site-specific material factors influencing the scope for ports to enable sustainable energy transition.

4.5. Port functions and roles

The differences in network management may, in turn, be related to the overarching institutional logics and above-mentioned functions or roles attributed to ports. (Acciaro et al., 2014; Poulsen et al., 2018). The three ports in this study use the full spectre of functions to facilitate sustainability transition. As regulators, the ports in Oslo and Kristiansand apply the Environmental Ship Index (ESI) for cruise ships. The port of Oslo implemented a differentiated price system punishing less environment-friendly ships in the course of 2019, and both will implement the Environmental Port Index (EPI) for cruise ships. This index was co-developed with DNV GL and introduced in some Norwegian ports from 2019. Whereas ESI estimates potential emission reductions based on ship characteristics, EPI calculates the actual emission reduction linked to for example use of new technology and may eventually replace ESI. The port of Narvik is following and aims to implement in due course. The ports play a role in spatial planning and collaborate in a national OPS forum. They may also impose speed restrictions, to reduce emissions in their section of the fairway. The ports still have a duty to receive all ships, but the municipality may use differential fees to punish ships that fail to meet environmental standards, and also limit their time at quay.

As operators, the studied ports are well on the way with the electrification of port equipment, and Oslo got its first fully electric harbour cleaning boat in 2019. The port of Oslo recently implemented ISO 14001, and Kristiansand is eco-certified, and the only Norwegian port listed in Eco-Ports. The ambitions and impacts of electrifying port operations are higher in these container ports and less in Narvik, where there is less handling. As noted above, the Port and Fairways Act may increase the sense of ownership, but also lessen ports' freedom to test and implement front-end technologies, as municipalities prioritize between needs in different sectors.

The case ports, like most Norwegian ports, fall into the category landlord ports (Brooks, 2004; Hatteland, 2010). As such, they also take most action to enable transition in their role as providers of land and infrastructure. The port of Oslo has an ambitious climate strategy, developed with other departments in the municipality. The strategy has 17 measures, including OPS, electrification of port operations, and charging facilities and biofuel for ten local ferries. The port of Kristiansand has an advanced OPS action plan. Narvik does not have a dedicated plan document but is exploring multiple measures and preparing for OPS. While certain customers in the ferry segment push actively for OPS, solutions for other segments are less mature. The focus on OPS reflects the national policies discussed above. It may also be related to the observation in previous research, that ports tend to prioritise measures with high visibility and low tool complexity (Poulsen et al., 2018). Some stakeholders suggest that organizational measures, such as more efficient landing systems also might have a large effect, especially on general cargo trade. However, these may be more complex, impinge on port interests and have less immediate co-benefits.

As community managers, the case ports bring together a variety of port users to collaborate for sustainable energy transition. The port of Oslo works through its port users' forum, as well as bilateral meetings, while the ports in Narvik and Kristiansand bring users together on a more irregular basis. The port authority is the central and most influential actor within the port of Kristiansand. The influence of the port authority in Narvik is more limited, in that LKAB is the major player. In Oslo, the container terminal is operated by a foreign-owned multinational, which thereby has an influential role.

The case ports also work actively to facilitate transition in their hinterland. In Oslo, this is part of the integrated climate effort in the city, carried out in a systematic, plan-based manner. The port works with a range of industry and logistics partners. In Kristiansand, the effort has been case-based and linked to specific opportunities, such as the recent reopening of a local railway to the port, whereby 5000 truckloads were taken off the road. In Narvik, it is linked to regional development and the development of international transport corridors, as well as efforts to shift more of the region's fish transport from road to sea. Thus, the studied port companies act as intermediaries in transition. Contrary to the observation by Poulsen et al. (2018), they do look beyond the individual port to reduce emissions, also where visibility and local environmental impact may be limited. Given that the transport on the land side tends to be more regular and repetitive, ports' efforts here may yield comparatively high emission reductions. On the other hand, the land side may be more complex than the seaside when it comes to green strategies, given the range of measures, stakeholders and regulations that may come into play (Gonzalez Aregall et al., 2018). In infrasystem terms (Frantzeskaki & Loorbach, 2010), the studied ports use their multiple functions or roles to facilitate change both through system improvements, enhancing one element or technology at a time; through system synergies, enhancing services through coordination of different systems; and through social innovation, such as new demand-forming processes and new forms of interplay between interest groups. These efforts have material aspects, but also entail different kinds of institutional work, especially linked to the roles as regulators (sanctioning and rewarding user practices), landlords (decreasing perceived risks of innovation) and community managers (advocacy, creation of conducive forums and networks). As illustrated in Fig. 5, the specific approaches are linked to the geographical context (Hansen & Coenen, 2015, van der Lugt, 2017), and the localised formal and informal institutions in each case (Fastenrath & Braun, 2018; Späth & Rohracher, 2010).

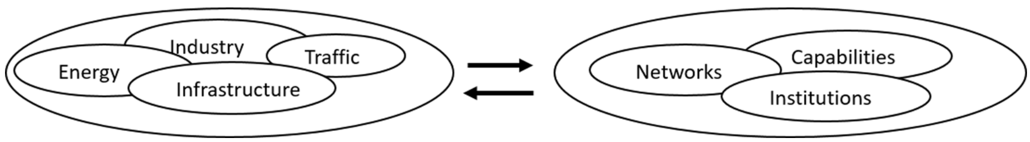

Fig. 4. Localised social factors (on the right), interacting with material factors linked to site and location (left) and influencing the scope for the individual port to enable sustainable energy transition.

4.6. Engagement with niche innovations

The studied ports engage actively with the niches where sustainable innovations emerge. Oslo takes part in several long-term research and development networks, including a public-private partnership called the Green Shipping Program (GKP) and a national research centre (FME MoZEES) for zero-emission transport. The port has strong environmental competence and capacity to absorb knowledge and in other ways benefit from research partnerships and consultants. It has sought state funding for larger projects and runs its own support scheme to incentivise users. Kristiansand's engagement is more *ad hoc*, with a high willingness to risk and test innovative technologies and participation in EU- as well as nationally funded research and development projects. The port of Narvik has links with the local university and other researchers and consultants, as well as Arctic Energy Ports, recently established by the Port of Tromsø and their energy provider to facilitate and operate new energy solutions in Northern Norway.

Regarding the concept of "energy hub", the port of Narvik and the regional LNG distributor have worked actively to secure a stable demand from local industry to enable investment in bunkering facilities. In 2020, the port, regional grid operator and LKAB received support for an innovative pre-project, combining high-voltage OPS for cruise and other possible users, including dry bulk ships. Beside preparations for OPS, there are joint efforts to establish a multifuel station including hydrogen. The port of Kristiansand installed Europe's largest high voltage OPS facility in 2018 and has a roof solar PV system of 85 000 kWh. It is ready to provide LNG, and there are ongoing efforts to improve energy management and further modernize the container terminal, with national and EU support. The ambition is to develop a port where full electrification is the core, combined with alternative fuels and hybrid solutions (Port of Kristiansand, 2016). In 2020, an additional three OPS units were ordered, and according to plan all ships can be provided with shore power by 2024.

Oslo aims for 85% reduction of GHG emissions by 2030 and to have a zero-emission port by 2050 (Port of Oslo, 2018). In partnership with the terminal operator and users with equally ambitious goals, the port administration is assessing a port concept with a fully integrated zero-emission energy system. This includes OPS, electrification of port equipment and electrical charging and biogas for heavy vehicles, as well as alternative fuels (e.g. liquid hydrogen) for ships. Solar PV panels and waste heat from a nearby wastewater treatment plant will also be utilised, together with vehicle-to-grid, stationary battery packs, a port data centre and smart system integration. While the implementation and impact of this concept remains to be seen, the measures already planned and approved will result in a total reduction of 46 700 tons CO2e by 2030. The port is also engaging in more specific innovation projects with their users, such as a recent pilot where two local freight ships were retrofitted with hydrogen propulsion systems.

Thus, the "energy hub" concept is addressed differently, depending on local opportunities in terms of demand and supply, as well networks, resources within and around the port organisation, and institutional capacity. While Oslo has the owner's push and user support to aim towards a path-breaking, integrated zero-emission energy system, the ambition in Kristiansand is centred on their current priority area and the possibilities for adding new technologies. At the port of Narvik, OPS to meet future demand and a multifuel station with hydrogen serving initial users on land are the current focus areas. These findings are in line with previous studies showing that incumbent actors can play a crucial role in the development of radical alternatives, both by strategic diversification (Penna & Geels, 2015) and formulation of specific visions that can guide actions (Turnheim & Geels, 2019), in addition to the forms of institutional work discussed in the previous section. In all cases, the ports' efforts go beyond mere technology implementation, to involve active engagement in the development of niche networks and solutions. In the terms of Kivimaa et al. (2019), the ports work as regime-based transition intermediaries, tied to the prevailing socio-technical regime but interacting with a range of niches or the whole system, as illustrated in Fig. 6.

The approach taken in the different ports is strongly influenced by the geographical context and institutional setting around each port. Despite specific lock-ins, as discussed above, the ports work to facilitate transition both by mobilising resources, and to a varying degree by constructing new rationales (Fuenfschilling & Truffer, 2016) regarding ports and port management.

5. Scope for ports to enable system change

The case ports face increasing pressures to facilitate sustainability transition. At the same time, there is a strong drive to implement

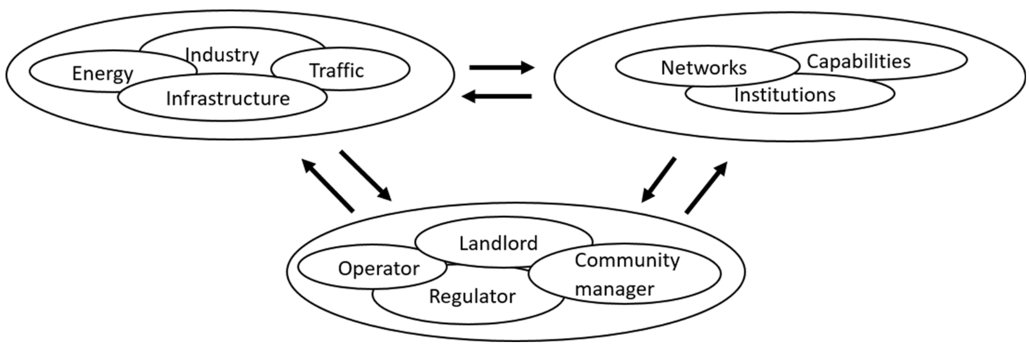

Fig. 5. Illustration of how institutional work associated with different port functions or roles, interact with the material and social dimensions of the specific port context.

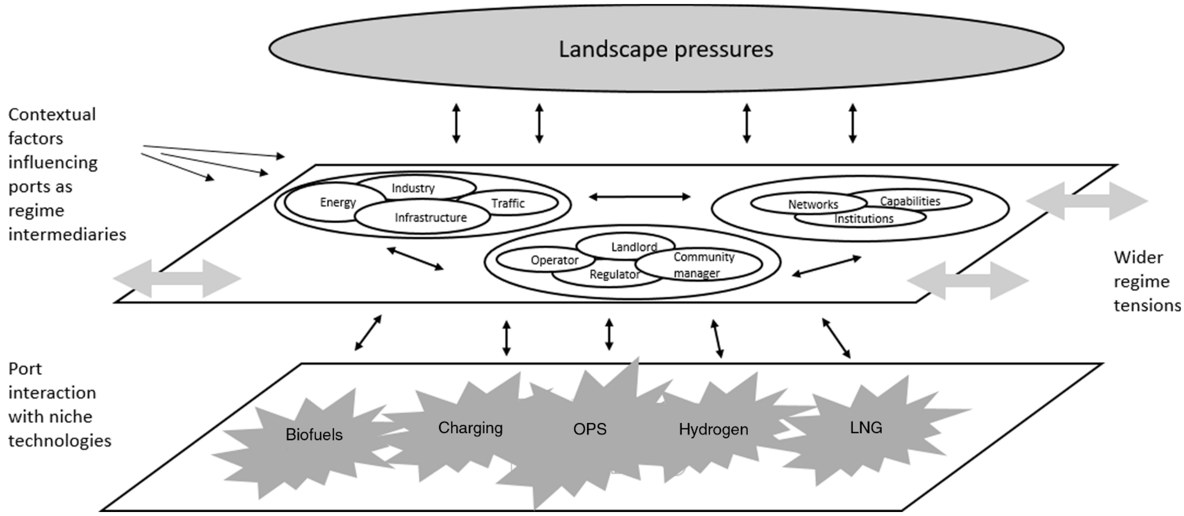

Fig. 6. Schematic illustration of contextual factors shaping ports' role as regime intermediaries.

alternative solutions linked to the ambitions in the maritime industry, availability of renewable power and need for a green shift in the petroleum sector. This is associated with tensions at the socio-technical regime level, in the form of different institutional logics regarding port governance; seeing ports as mainly public authorities, versus seeing them more as operators in a competitive environment, which require national coordination (van der Lugt, 2017).

The recent regulatory changes in Norway will reduce the authority of ports, while increasing national coordination and granting municipalities more control. This corresponds with Bergqvist and Monios (2019) and van der Lugt (2017), who argue that ports increasingly turn into development companies.

The prevailing institutional logics influence how the case ports make sense of and act in the face of the impending climate and energy challenges. As landlords (Brooks, 2004), most Norwegian ports earn a relatively large part of their income from leasing out infrastructure and equipment. This is also where they so far have placed most emphasis in their efforts to reduce greenhouse gas emissions. However, the studied ports also utilise their functions as regulators, operators, and community managers. All the three port organisations in this study are working to engage other stakeholders in transition processes, both within the ports and in wider

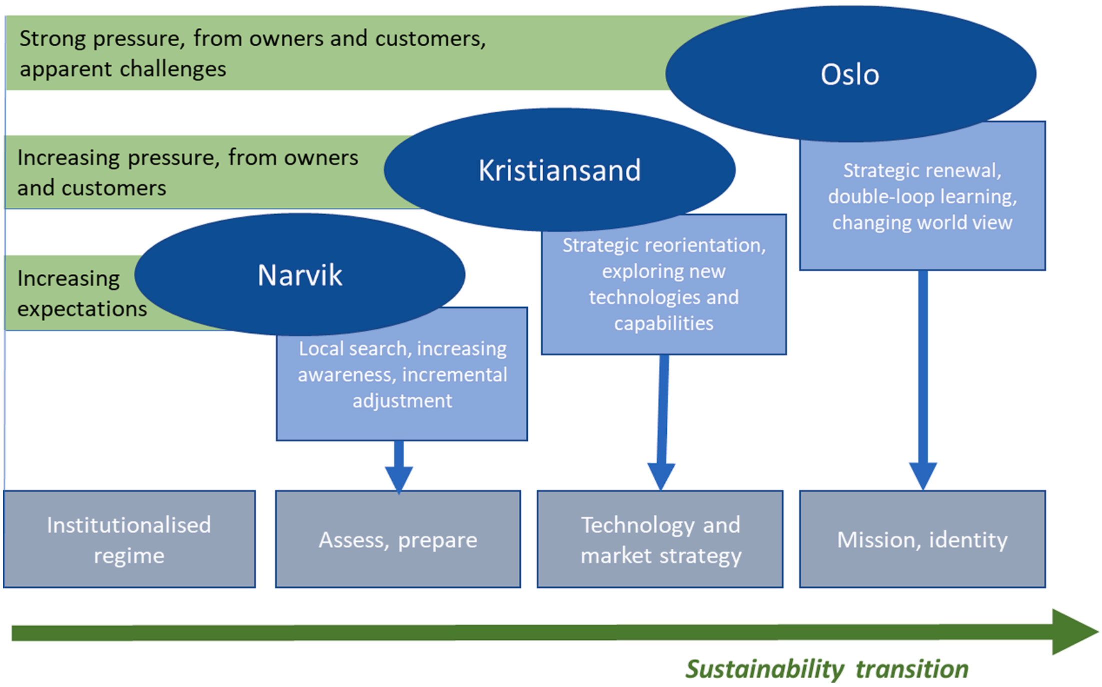

Fig. 7. Dynamics of strategic reorientation. Inspired by Geels et al. (2016).

networks. This underscores ports' potential to address emissions from hinterland transport (Bergqvist & Egels-Zandén, 2012) and contribute to transition in the industry clusters and value chains they are part of (Poulsen et al., 2018).

The study highlights how the scale and scope for this may vary. The geographical context of each port is associated with specific opportunities and lock-ins (Klitkou et al., 2015), such as the surplus of renewable energy and existing systems around the dry bulk ships that dominate in Narvik, and the opportunity to achieve substantial emission reductions and limit local pollution through OPS in Oslo. The influence of time and timing, emphasized in MLP research (Geels et al., 2016), is also apparent. While regime tensions are building and alternative solutions generally are maturing, we also find spatial variation in this dimension: OPS is a relatively mature technology and Oslo municipality has been a frontrunner in climate strategy. The port of Kristiansand had the foresight and good fortune to seize upon a particular funding offer to build their profiled high-voltage facility. On the other hand, hydrogen, which is on the agenda in all ports, is still relatively immature for maritime applications (Bach et al., 2020).

The selected approach also depends on local networks, institutions and capabilities. The scope for the studied ports to enable transition is significantly influenced by their relations with other port actors, especially their municipal owners. In Oslo, very strong expectations from the owner come with specific emission reduction targets and strong involvement in port planning. In Kristiansand, expectations are centred on OPS and the port's work is more case-based and technology-oriented. In Narvik there is more autonomy and expectations have so far not been very specific articulated, but the port is active in local initiatives for sustainable transport and logistics. While Oslo and Kristiansand have users who are more visible and exposed when it comes to environmental performance, LKAB's main concern has been to cut emissions from their core activity. The dry bulk tramp shipping which is the main shipping segment in Narvik has more distant operators and limited focus on alternative solutions so far. Thus, the ports' efforts are strongly influenced by the extent and timing of the responses from other regime actors. This is in line with the above-mentioned research on how the architecture and multidirectional character of the infrastructure tend to influence the role of transport infrasystem actors in transitions (Frantzeskaki & Loorbach, 2010).

Together with the local context, these factors impact on the ports' ability to influence the wider socio-technical regime. Fig. 7 illustrates how the situations of the different case ports may be associated with different learning/feedback loops in sustainable energy transition:

The port of Narvik is facing increasing expectations without much direct pressure from their owners and users, and responding with increasing search and adjustment, by electrification, preparing for new solutions and promoting modal shift. Illustrated in the middle of the figure, the port of Kristiansand is experiencing increasing pressure from their owners as well as certain customers, and has a focus on new technologies and capabilities. This is associated with reorientation, in the sense that more radical choices are made, in terms of technology and/or market. The third loop illustrates the situation for the port of Oslo, where there is a high pressure, related to specific climate targets for the port and the city, as well as highly visible challenges, such as local air pollution. This gives rise to strategic renewal and experimentation with the ports' role in energy management, resulting in a changed identity and, potentially, with a deeper, more radical impact on the regime.

These findings are in line with previous MLP research, emphasizing that different kinds of alignments between developments at landscape, regime and niche level lead to different transition pathways (Geels & Schot, 2007). Our study shows how alignments may vary between ports, both due to geographical factors (Hansen & Coenen, 2015) and through being enacted by actor-networks who are differently positioned in the socio-technical system. As the figure indicates, all the case ports contribute to regime change, albeit in different ways. This underscores the inherent complexity and contextuality of infrasystems, which may be challenging from a transition management perspective (Frantzeskaki & Loorbach, 2010), but which also may hold considerable potential for learning and radical innovation. As noted by Frantzezkaki and Loorbach (ibid.), the pathways core infrasystems might go through to satisfy future demands will possibly be a combination of both system improvements, system synergies, and social innovation with alternative designs and uses of infrasystems.

In terms of impact, a parallel may be drawn to the concept of different loops of learning (Argyris & Schon, 1974) Though active and creative in its own right, the response in Narvik has so far resulted in system improvements, awareness raising and intensified search for new alternatives in wide networks, but without affecting 'the rules', as in first-loop learning. The efforts in Kristiansand can be associated with a deeper impact, in that the range of services is expanded and the interface between transport and electricity infrasystems is changing. Consequently, new questions arise about the 'rules' for port management vis-à-vis customers and grid operator, as in second-loop learning. The institutional work in the port of Oslo, which includes more explicit changes in strategic vision and relations, as well as exploration of radically new port energy concepts, may be associated with a third loop of learning, with a yet deeper impact on the socio-technical construction of ports and port responsibilities, with further implications for the uptake of niche technologies.

Although their overall impact on emission reductions may be limited so far, the efforts in the studied ports may have considerable influence, amounting to more than a transition "shadow track" of new principles embraced by some and co-existing with but having limited influence on business-as-usual. (Bosman et al., 2018). This may be related to their size, ownership and lack of petrochemical industry, as well as Norway's strong focus on electrification and sustainable maritime technology. Ports, as incumbent actors, can play diverse roles and contribute crucially to enabling sustainability transition. While transport infrasystems are multidirectional and difficult to change, the three port companies play upon the full spectre of port functions to facilitate change. Exactly how they do this is strongly influenced by the geographical conditions and institutional frameworks each port is embedded in, and how these are understood and negotiated in the institutional work between actors and stakeholders at different system levels.

6. Concluding remarks

The study shows that ports can help enable sustainable energy transition in multiple ways. While high visibility and low complexity measures have received most attention up to now, the ports in Oslo, Narvik, and Kristiansand play upon a broad spectre of port functions – as regulators, landlords, operators and community managers – to facilitate transition in wider transport and industrial networks. While the latter is associated with considerable potential, it has so far had limited focus in research and policy on ports in energy transition.

Previous research has shed light on changing port management paradigms and the implementation of specific measures and technologies for environmental upgrading. The relatively few studies that have taken a socio-technical perspective emphasize the persistence of lock-ins to existing infrastructure and practices. Our application of the multi-level perspective (MLP) provides insight into the multiple factors and processes that shape the strategies and scope for climate action in the studied ports. These include wider landscape factors as well as interactions between sectors, policies and alternative technologies at the national level; and how these in turn interact with existing systems and actor-networks in each port context.

The kinds of alignment between developments at these levels varied across the ports. Approaching ports as both geographical sites, nodes in transport and industry networks, individual actors, and heterogeneous assemblages of actors, allowed an empirically rich discussion of the main barriers, opportunities, and conceptions of ports as zero-emission energy hubs in each case. The availability of renewable energy, existing infrastructure, traffic, as well as local industry were influential. However, we also found that ownership, strategic orientation, social networks, local culture and institutional capacity impacted strongly on the ports' transition efforts. This is in line with recent research on the role of institutional work in sustainability transitions.

Given their durability and multidirectionality, transport infrasystems are associated with lock-ins (Klitkou et al., 2015). Time and timing are therefore crucial. At the same time, the multi-actor setting is well suited for institutional work (Fuenfschilling & Truffer, 2014) in the form of risk reduction, sanctioning and rewarding user practices, advocacy, and new forms of interaction between stakeholders. All the case ports work along these lines, although their scope for implementing alternative solutions (e.g. OPS and hydrogen) and capacity to explore innovative port energy concepts vary. The ports thus play a crucial role as intermediaries in sustainability transition, linking actors and activities to create momentum for change. Their impact in terms of regime change depends on the depth of reorientation in each case, but we argue that all contribute significantly towards wider system transition.

The paper provides new knowledge on the factors shaping ports' efforts to enable sustainable energy transition, and on how relatively small ports work towards different concepts of zero-emission "energy hubs", based on the limitations and opportunities in specific port contexts. Introducing a multi-level system perspective adds new dimensions to the ongoing discourse on sustainability performance and management in ports. It also contributes to key analytical perspectives in socio-technical transition studies, suggesting that insights from institutional approaches and the geography of transitions should be combined to increase our understanding of spatial variety and the role of localised actors in regime configuration.

Energy and transport systems are transforming and becoming more complex. There is an ongoing shift from one or a few key technologies (e.g. fossil fuels) towards a mix. In a transition perspective, this process is in early stages, as reflected in our case study. The need to implement, coordinate and integrate a wide set of energy solutions poses new challenges and roles for ports. While this paper has shed new light on the interplay of factors and processes involved, there is the need for more research on the role of ports as "energy hubs", i.e. key infrasystem intermediaries that need to cater to the needs and demands of a plethora of stakeholders and operate within a complex multi-scalar governance framework. More knowledge on how governance frameworks should be developed to facilitate such interactions is also urgently required, if we are to meet the climate goals for the transport sector.

CRediT authorship contribution statement

Sigrid Damman: Conceptualization, Methodology, Investigation, Writing - original draft, Project administration, Funding acquisition. **Markus Steen:** Conceptualization, Methodology, Investigation, Writing - review & editing, Project administration, Funding acquisition.

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