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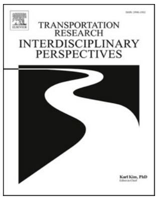

Sustainability transitions in coastal shipping: The role of regime segmentation

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ABSTRACT

Maritime transport has received little attention in sustainability transitions research. This sector is mature and heterogeneous, which suggests the need for a more nuanced perspective on socio-technical regimes to understand variation in conditions for adoption of novel technologies that may support sustainability transitions. We consider this important in order to develop more efficient policy to decarbonize the shipping sector. We develop a framework that explicitly differentiates task and institutional environment of user regimes, enabling us to identify regime segmentation and its influence on three key transition conditions: technology maturity and fit, system integration and infrastructure, and acceptability and legitimacy. We apply our framework to analyse development and uptake of battery-electric energy storage solutions within three segments (coastal ferry, coastal fishing, and offshore supply) of Norwegian coastal shipping. Our analysis suggests that the transition process unfolds along different pathways in different user segments, pointing to a need for segment-specific policy instruments.

Introduction

Socio-technical system perspectives have over the last two decades risen to prominence in unpacking and explaining the complex challenges that are associated with change towards more sustainable ways of providing key societal functions, such as energy, transport, and food (Köhler et al., 2019). This ‘sustainability transitions’ literature comprises a set of key approaches or perspectives, including the multi-level perspective and the technological innovation systems approach (for an overview, see Markard et al., 2012). In the realm of transport, sustainability transitions research has mainly devoted attention to innovation and change related to automobiles and personal mobility (see e.g., Kanger et al., 2019, Berkeley et al., 2017). More recently, however, sustainability transition scholars have begun to address sustainability transitions also in shipping (Pettit et al., 2018; Stalmokaitė and Yliskylä-Peuralahti, 2019; Bach et al., 2020, 2021).

For sustainability transitions to materialize, substantial changes in the socio-technical configurations of key societal sectors are required. Such changes have been conceptualized in terms of the multi-level perspective (MLP), where the concept of a ‘socio-technical regime’ has received special attention. This concept describes the rule sets that co-ordinate the activities of different actor groups and contribute to the stability of existing socio-technical configurations (Geels, 2002). In the transitions literature, regimes have for the most part been assumed to be relatively homogenous (van Welie et al., 2018). However, some recent writings have questioned this assumption. It has, for example, been argued that rules can vary between places (Späth and Rohracher, 2012, Carrosio and Scotti, 2019) and between different combinations of technologies and applications (Ghosh and Schot, 2019, van Welie et al., 2018). This paper adds to this line of thought by exploring another dimension of regime heterogeneity: regime segmentation. We, thus, focus our attention on heterogeneity within the “user regime” (cf. Geels, 2004).

Previous literature on innovation adoption have shown that user groups may differ in terms of, for example, functional preferences (Adner, 2002), attitudes and perceptions towards innovations (Rogers, 1962), and adoption motives, barriers and strategies (Palm and Tengvard, 2011; Bergek and Mignon, 2017). This especially applies to B2B

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markets, where users are firms-in-industries (Geels, 2014) that compete in different product-markets themselves. Different user segments can, therefore, involve quite different structural configurations in terms of key actors, technologies, and institutions (Dewald and Truffer, 2011). In turn, a better understanding of user segment specificities can help provide more targeted policy recommendations.

Despite the global importance of reducing greenhouse gas (GHG) emissions and other pollutants from maritime transport (see, e.g., Lin et al., 2021), most ships still run on fossil fuels – as they have for over a century (Endresen et al., 2007). Decarbonizing this sector would require widespread implementation of various low- and zero-carbon (LoZeC) solutions, for example battery-electric storage systems, biofuels, hydrogen, and various hybrids of these and/or conventional fuels and technologies, which currently play minute roles in the maritime shipping sector (MSS). What makes this case especially interesting from a regime heterogeneity point of view is that these LoZeC technologies would need to be implemented in a wide variety of user segments, ranging from inter-continental freight and bulk carriers to local passenger vessels, which differ in terms of market conditions as well as vessel types and operational profiles. Consequently, actors within the MSS, most notably the ship owners, operate under very different structural conditions. The main argument of this paper is that this implies that actors associated with different segments of a user regime operate under varying regime characteristics and therefore face differing pressures and, thus, different transition opportunities and challenges.

In previous literature, the regime concept has primarily been used to refer to the (*meso*-level) institutional environment (i.e. the "rules of the game") associated with an established socio-technical system, which guides the behaviour of different types of actors (e.g. Köhler et al., 2019, Turnheim and Geels, 2013, Turnheim and Geels, 2019). However, actors' behaviours are also influenced by the strategic and operational characteristics of their task environments (cf. Scott, 1992, Geels, 2014). This is also in line with the MLP, where the stability and inertia that characterize established socio-technical configurations do not only reside in rules, but also in socio-technical systems and actor networks (Geels, 2004). We therefore argue that more attention to task environments – in addition to institutional environments – can provide a better understanding of regime heterogeneity and the resulting differences in innovation adoption and implementation in a sector characterized by regime segmentation, such as shipping.[1]

The purpose of this paper is, thus, to analyse how regime segmentation, understood as variation in institutional and task environments within a user regime, influences whether or not different user groups (or segments) become involved in the development and uptake of novel technologies. More specifically, we suggest that segment-specific characteristics have an impact on three main aspects that condition adoption and hence sustainability transitions: (i) technology maturity and 'fit' with current segment conditions, (ii) system integration and infrastructure, and (iii) acceptability and legitimacy (Loftus et al., 2015, Turnheim and Nykvist, 2019).

Empirically we analyse the development and uptake of battery-electric (BE) energy storage solutions by Norwegian ship-owners in the three largest coastal shipping segments, in terms of both emissions and number of vessels: coastal ferry, offshore supply and coastal fishing (Grønt Kystfartsprogram, 2016). Norway is considered a forerunner in the development and uptake of LoZeC technologies in shipping, and it is especially within some of these user segments that the early phase of a potential sustainability transition – also for shipping more generally – can be witnessed.

The main contribution of the paper to the sustainability transitions literature is to explicitly address the influence of regime segmentation on sustainability transitions. The analysis shows that despite regime-level similarities, the three segments of the user regime differ in terms of the characteristics of their task and institutional environments, resulting in varying propensities to adopt BE technologies. This demonstrates that a more differentiated and nuanced perspective on socio-technical regimes is needed in order to understand variation in whether and how actors engage in the development and implementation of novel technologies that may support sustainability transitions (cf. Berggren et al., 2015).

Theoretical framework

Socio-technical transitions

Sustainability transitions can be described as "system innovations", i.e., reconfigurations of sectoral socio-technical systems that fulfil some societal function, such as energy supply, transport, or housing, towards more sustainable modes of production and consumption (Markard et al., 2012, Geels and Kemp, 2007, Geels, 2004). Once established, socio-technical systems are often characterized by stability and inertia due to technological interdependencies, complementarities and sunk costs (Geels, 2004), which tend to be mirrored by the organization of companies (Henderson and Clark, 1990). This makes it difficult to change one part of the system without large effects on other parts. Lock-in can, thus, stem from economic, organizational and infrastructural dimensions rather than merely institutional dimensions (Geels and Kemp, 2007, Geels, 2005). A key characteristic of transition processes is, then, also that they tend to unfold slowly and gradually over long time periods (Köhler et al., 2019).

In previous literature, particular attention has been given to the regime concept as the central source of this stability. While the regime concept is applied in various ways in the sustainability transitions literature (Geels, 2011, Markard and Truffer, 2008), it is generally understood as the "grammar" (Fuenfschilling and Truffer, 2014) or "deep structure" of established socio-technical systems, which accounts for the gaining of momentum and the resulting stability – or even lock-in – of such systems (Geels, 2011). Regimes consist of semi-coherent rule sets of independent regulatory, normative and cognitive rules,[2] which span technology, science, policy, culture and users and include problem agendas, standards, user preferences and consumption patterns, government regulations and cultural meanings (Geels, 2004, Turnheim and Geels, 2013, Kanger and Sillak, 2020). They guide actors' search and learning processes in certain directions, providing a joint perception of proper behaviour, binding contracts, or formal standards to which actors need to conform (Geels, 2004) and, thereby, represent the interdependence and linkage between different sub-systems and the associated coordination and alignment between social actor groups (Geels, 2005). Geels (2004) argues that different actor groups can have their own sets of rules, allowing for differentiation between "different regimes, e.g., technological or design regimes, policy regimes, science regimes, financial regimes and societal or user regimes." In this paper, we are specifically focusing on user regimes and differences within these (see section 2.2).

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[1] While the focus of the paper is on the influence of the task and institutional environment, we fully acknowledge that innovation adoption and implementation decisions are also shaped by each actor's unique set of motives, resources, and strategies. Consequently, individual actors in the same user regime can respond differently to the same environmental pressures (see for example Nähyä, 2020). However, such intra-segment heterogeneity is not studied in this paper as it would require a detailed analysis of the resources and strategies of individual actors.

[2] Regimes can be described in terms of three institutional dimensions (Scott, 1995, cf. also Bergek et al., 2008, Geels, 2004) The *regulative* dimension includes formal rules and regulations, which are controlled by juridical systems (e.g. courts). The *normative* dimension includes values, norms, roles, responsibilities etc. Finally, the *cognitive* dimension includes rules and frames through which actors make sense of the world.

Defined like this, the regime concept primarily emphasizes actors as social and institutional beings. However, this perspective only provides a partial understanding of what guides the activities of actors – especially "firms-in-industries" (Geels, 2014) – in a sector. Indeed, actors are not only guided by their institutional environment, as emphasised by the current regime concept, but also by their task environment (Scott, 1992). Task environments are related to the activities actors perform to achieve organizational goals rather than to gain social legitimacy and support. As far as companies are concerned, these goals are mainly of an economic nature (most notably profit generation), whereas other actors, for instance public agencies or industry associations, might put social or environmental goals at the forefront.[3] Traditional notions of the task environment emphasize sources of inputs, markets for outputs, competition and some forms of regulation (Little, 1990; Carroll and Huo, 1986), with particular focus on the overall competitive pressures that motivate firms to adopt strategies to find a profitable position in an industry (Geels, 2014) and become more efficient and effective (Oliver, 1997). More recently, the concept of 'business ecosystems', which highlight the co-existence of competition and collaboration in value cocreation processes, have been put forward to describe "the part of the environment with which an organization interacts" (Demil et al., 2018, 1220). In such task environments, actors are problem-solving and task-oriented rather than social. Firms compete on price and performance (Turnheim and Geels, 2013) and are primarily rewarded for the quantity and quality of the goods and services they produce and exchange in markets (Scott, 1992). The task environment therefore includes strategic aspects, such as market size, growth and structure, industry structure (e.g. number of competitors, degree of concentration and specialization/integration), product diversity and degree of differentiation (Dess and Beard, 1984, Porter, 1980), as well as operational aspects, such as technical interdependencies and exchanges of critical resources between actors (Oliver, 1997). The latter perspective connects the task environment with the sociotechnical system and actor group dimensions of transitions.

Task and institutional environments are not independent. On the one hand, organizational goals, markets and other aspects of the task environment are shaped, created and organized by institutions (Scott, 1992). On the other hand, routines can be embedded in product characteristics and manufacturing processes (Geels, 2005), and institutions need to be put into practice in the task environment to be realized (Fuenfschilling and Binz, 2018). The two concepts are therefore best seen as complementary aspects of the environment (Zucker, 1987), which enforce different types of demands and requirements and which can be stronger or weaker in different industries (Oliver, 1997). Moreover, some aspects of the environmental can display either task-like or institutional characteristics. Most notably, some regulations are so closely related to the functioning of the market that actors perceive them as an integral part of their immediate competitive environment or even as a defining feature of their industry. In contrast, other regulations are perceived as broader societal pressures that do not influence the actors' immediate task-oriented activities but can have various consequences for them in the longer term, for example in the form of changes in legitimacy.

Considering the general emphasis on institutions in previous transition studies, we would argue that more explicit consideration to task environments would increase our understanding of actor-related transition patterns (cf. (Geels, 2005, Späth et al., 2016, Geels, 2014). We therefore suggest more explicit consideration of both task (strategic and operational aspects) and institutional dimensions of regimes. In practice, this implies analysing how, for example, sources of inputs, markets for outputs, competition, product market regulation, existing technical configurations, and supply chains (task environment), as well as regulatory, normative, and cognitive institutions (institutional environment) condition transition processes in specific sectors. Due to our focus on user regimes, our main emphasis in the remainder of this article is on the institutional and task environments of technology adopters, which in the MSS is constituted by ship-owners.

Perspectives on regime heterogeneity: Introducing regime segmentation

In contrast to the early transitions literature, which acknowledged the heterogeneous nature of regimes, regimes have over time tended to be conceptualised as overly homogenous (Smith et al., 2005, Geels, 2011, van Welie et al., 2018, 270). From an analytical perspective, this is unsatisfying, as the likelihood of sustainability transitions is contingent on the (in)stability of regimes. Indeed, for new technologies to break through and become part of a new or reconfigured sociotechnical system, a destabilization of the current sociotechnical system – a "window of opportunity" – is required (Geels, 2002). When much of the literature is "implicitly oriented at the overthrowing of a monolithic sectoral regime" (van Welie et al., 2018, 270), it becomes difficult to understand how such windows can open up in different spatial, technological and user settings. It also becomes difficult to understand under which conditions a transition would result in a more fragmented sociotechnical configuration, with different actor groups engaging with different sociotechnical systems under the guidance of different rule systems. Thus, rather than assuming regime uniformity, there is analytical merit in analysing (conditions for) cracks and differentiation in regimes that allow for change in different directions.

In previous literature, several different types of regime heterogeneity have been considered. Fuenfschilling and Truffer (2014) argue that societal sectors can be influenced by different coexisting, complementary or competing, institutional logics and demonstrate that actors in the same sector may vary in terms of which logic they consider most important. Other authors argue that regimes can be spatially heterogeneous in that rule sets vary between different localities and national socio-technical regimes, therefore, may consist of several different local configurations (Späth and Rohracher, 2012, Carrosio and Scotti, 2019). Yet other authors highlight that sectors can include several 'nested' technologies, which are associated with their own sub-regimes (Smith et al., 2005). For example, the energy regime could be considered to consist of a heat sub-regime and an electricity sub-regime (which in turn could be divided further into sub-regimes associated with, for example, wind power and nuclear power). Similarly, Ghosh and Schot (2019) argue that the public transport system in Kerala consists of three rather independent regimes around buses, metros and auto-rickshaws respectively, which differ in terms of sociotechnical systems, actor networks, and rules. Finally, van Welie et al. (2018) show how the sanitation regime in Nairobi is "splintered" into several "service regimes" (e.g. a domestic sewer regime, a shared on-site regime, and a public sanitation regime), which differ in terms of their particular combinations of technologies, user practices, organizational forms, and shared meanings and vary substantially both socio-economically and socio-spatially within the urban region.[4,5]

All in all, these contributions imply that different sub-sets of actors in the same sector may be subjected to incoherent pressures from the regime and, consequently, might respond differently to the same niche innovation (Altunay et al., 2021, cf. also Smith et al., 2005). This is in line with contemporary institutional theory, which emphasizes the

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[3] Companies can, of course, also pursue environmental and social goals, but not at the expense of economic performance. Moreover, in markets where customers value environmental sustainability, implementing 'green' technologies and other sustainability efforts can be a strategy to improve a company's competitive advantage (Lin et al., 2021).

[4] They also discuss "fragmented" and "polycentric" regimes, which demonstrate a higher degree of alignment within each service regime and between different service regimes respectively, as compared with splintered regimes.

[5] For a more elaborate discussion on how to draw boundaries between different regimes, see Konrad et al. (2008).

environmental complexity actors face in different market context as well as the "fragmented, contested, and dynamic" nature of institutional environments (Zhao et al., 2017).

Drawing inspiration from this previous work, we focus on another type of regime heterogeneity: *regime segmentation*. In this context, segmentation refers to the overall structure of an industrial sector characterized by heterogeneous user needs and a common but versatile technology that is adapted to different user segments based on the requirements of different applications (Sheth, 1985).[6] According to the MLP literature, new niche innovations develop cumulatively by successively being used in different applications and by different user groups (or segments) (Geels, 2002), defined as groups of technology adopters and users with similar preferences and needs. In the heavy vehicle sector (onshore transport), for instance, such distinguishable user groups are operators of buses (for public transport), long-haul trucks, and short-haul trucks. With reference to the previous section, we suggest that technology adopters in different user segments operate – at least partly – under quite different institutional and techno-economic (task) conditions. Our main argument is that such variation provides different "windows of opportunity" for novel technologies to break through into different user segments and, consequently, that the conditions for realising a transition varies between different segments of the overall sociotechnical regime. Referring to Geels (2004), we, thus, analyse segmentation within the "user regime".

Understanding segment-specific transition conditions

Regime segmentation has important implications for understanding transition conditions within a sector. First, regime heterogeneity matters for novelty generation because it can be expected that different user groups will have different incentives to partake in technology development and implementation and face different barriers to do so. Second, regime heterogeneity matters when new technologies become available in terms of providing windows of opportunity for new solutions (Geels, 2004, Elzen et al., 2004). This calls for closer attention to conditions for adoption of new technologies across different user segments.

Here we draw inspiration from Turnheim and Nykvist (2019, 780), who suggested a set of key conditions "under which the realisation of transitions pathways may become more feasible, in terms of the critical real-world constraints at play and the specific hurdles and requirements that may be anticipated." These are maturity of options, system integration and infrastructure, and political and social feasibility, which are arguably generic features of socio-technical perspectives on sustainability transitions. While the original focus of this framework is to assess the feasibility of different potential transition pathways in a sector, we use it to assess the influence of task and institutional environments on the conditions for realising one specific pathway (battery-electric technology) in different user segments (ferries, offshore supply and fishing) in the same sector (coastal shipping).

Technology maturity/fit

The first dimension introduced by Turnheim and Nykvist (2019) is "maturity of options". They argue that it is critical to consider the readiness and commercial availability of an innovation at a particular point of time, as well as its current development trends. In this paper, we focus on key aspects of maturity as perceived by potential users when faced with a new technology, such as whether the technological option has matured enough to perform as needed, whether supply chains are in place so that 'off-the-shelf' solutions are available commercially or if adoption would imply becoming involved in experimental activities, if there are particular technical risks that users need to handle, and if the users' customers demand or incentivize technological change.

Moreover, Turnheim and Nykvist (2019) highlight that even if a technology is generally available off-the-shelf, it is often necessary to adapt it to the specific characteristics of different contexts, such as the different user preferences and practices in different user segments. We conceptualize this in terms of strategic and operational 'fit', i.e. the extent to which a new technology is aligned with the existing corporate- and business level strategies, value and supply chains, and use patterns of adopters in a specific user segment (Wadström, 2019; cf. also Bidmon and Knab, 2018; Kathuria et al., 2007). In the case of shipping (as an example), key questions relate to whether the (new) option fits with existing technical configurations (i.e., vessel) and operational profiles and satisfy the demands of end customers of, for example, a transport service.

System integration and infrastructure

The second dimension highlights the importance of integrating new technologies in existing systems and infrastructures, through adaptation of the former and/or transformation of the latter (Turnheim and Nykvist, 2019). We take this to imply that new technologies need to be able to access – and be compatible with – existing socio-technical systems in the entire value chain, stretching from the sourcing of natural resources, via production and distribution, to use. For example, in the case of electrification of shipping (or transport in general), this relates to system integration of ships with the energy production and distributions side (potentially including storage) in grids and charging devices. Since operating conditions differ between segments, the availability and accessibility of suitable systems and infrastructures are likely to differ as well. Moreover, we expect that users within different segments will be in different positions with regards to financing and implementing large-scale infrastructure investments.

Acceptability and legitimacy

The final transition condition combines two of the feasibility dimensions mentioned by Turnheim and Nykvist (2019): social acceptability and political feasibility. The former highlights the importance of considering "issues, controversies, or anxieties with the expected deployment and use of any particular option" among the general public, including perceived desirability and legitimacy of the technology and the actors advocating and implementing it (Turnheim and Nykvist, 2019, 780). The latter refers to "the likelihood of decisions supporting a particular path to become implemented, or conversely of obstacles that may result from the resistance of particular actors", where decisions could, for example, include public innovation and transition policies (Turnheim and Nykvist, 2019, 781). Bringing these two dimensions together, we conceptualize "acceptability and legitimacy" as different types of implicit and explicit collective commitments to and acceptance of a particular technological option in relation to specific user segments. In transport, a well-known legitimacy issue is for example range anxiety for battery-electric vehicles, which is less of a problem in urban than rural areas. Another aspect that may suggest variety between segments for instance in transport relates to whether or not transport/logistics companies serve customers in other sectors with strong or weak pressures to reduce their overall carbon footprint, thus potentially providing legitimacy to LoZeC solutions in general but no clear direction in terms of technology choice.

The influence of task and institutional environments on transition conditions

Taking stock of the preceding theoretical discussion, our analytical framework focuses on how "regime segmentation", i.e., variety between different segments of a user regime in terms of their task and institutional environments, influences three key transition conditions: technology maturity and fit, system integration and infrastructure, and acceptability and legitimacy (see Fig. 1). In operationalizing the analytical distinction between task and institutional environments, we suggest that key aspects of the institutional environment are regulatory,

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[6] This view of segmentation differs from that used in some parts of the marketing literature, where segmentation is seen as a strategy used by individual firms to divide the market into manageable groups.

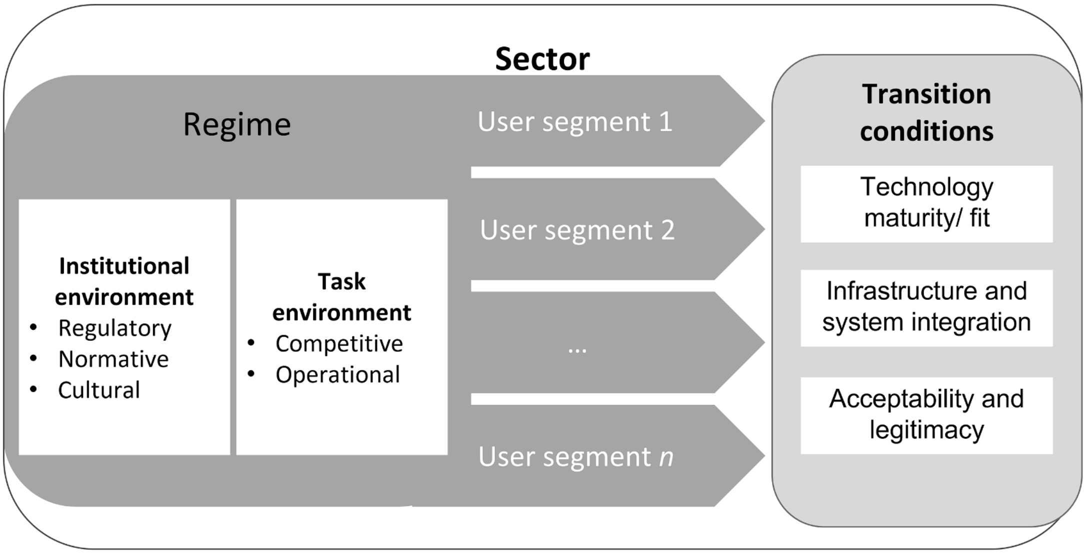

Fig. 1. Analytical framework for a segment-differentiated analysis of how task and institutional environments influence conditions for sustainability transitions.

normative and cognitive dimensions (e.g. rules, norms, and search heuristics), whereas the task environment includes critical competitive, strategic and operational dimensions (e.g. market size, technical demands for operations, infrastructure requirements, and regulations directly connected to the product market of each segment).

In this paper we apply this framework to an analysis of how segment characteristics influence the conditions for adoption of battery-electric (BE) solutions within Norwegian coastal shipping, but we suggest that it could equally well be applied in the analysis of transition conditions for other technologies entering other sectors characterised by regime segmentation.

Methodology

Study design and case selection

The empirical part of this paper is based on a qualitative case study. Qualitative research methods are highly appropriate when studying complex, ongoing processes of technological and industrial change. A case study approach (Yin, 2012) can allow for understanding inter-linkages between sectoral characteristics and technology development and diffusion.

The focus of the case study is sustainability transition processes in the Norwegian maritime shipping sector (MSS), which we in the following argue can be seen as a segmented regime (see Section 3.1.1). We have delineated the analysis to the three largest user segments within coastal shipping and the development and implementation of battery-electric solutions within these segments (see Section 3.1.2).

Maritime shipping as a segmented regime

In order to talk about a segmented regime, we first need to establish that there are clearly distinguishable applications with separate user groups that have different preferences and needs with regard to technology. In the MSS, we can distinguish several user groups that differ for instance with respect to types of vessels, ownership and end customers. These include, for example, coastal and ocean-going fishing, car and passenger ferries, fast ferries, different categories of offshore supply and freight vessels, and workboats and other vessel types used in aquaculture. These application areas differ with regard to operational profiles and resulting range and power requirements, while different vessel categories also differ in terms of potential for retrofitting, available space for fuel/energy storage, and other onboard equipment that energy solutions need to be suitable for. Consequently, different user groups within the MSS have quite different technology needs. This means that they qualify as user segments according to our definition (see Section 2), and that variety can be expected with regards to technology maturity/ fit, system integration and infrastructure, and acceptability and legitimacy (Turnheim and Nykvist, 2019).

We then need to show that these user segments are part of an overarching maritime shipping regime rather than independent regimes in their own right (cf. Ghosh and Schot, 2019). In the case of the MSS, we argue that such an overarching regime has existed for a long time, as displayed through several characteristics that bridge all user segments:

(1) The user segments in the maritime shipping sector are strongly aligned regarding sociotechnical configurations. Until recently, practically all commercial ships operating in Norwegian shipping used the same propulsion technologies (diesel-mechanic or diesel-electric) and fossil fuels, a situation which also applies globally for all modern commercial vessels. This means that across different segments, ship-owners and operators have shared many of the same needs in terms of technology, infrastructure requirements, and knowledge demands.

(2) Even if ship-owners and operators operate in different markets, they are still co-organized in the same industry associations, such as the Norwegian Shipowners' Association (Rederiforbundet) and the Norwegian coastal shipowners (Kystrederiene).[7] This signals that they to a large extent consider themselves to be part of one community, defined by their identity as shipowners and the task-related and institutional pressures and challenges they share.

(3) Ship-owners and operators are influenced by many shared rules and regulations, regardless of which user segment they belong to. The main state regulatory bodies are the same and all shipping is subject to many of the same overarching institutions governing for instance health, safety, and environment (HSE) regulations and emission requirements. The maritime sector is also treated as one sector in policy discussions about the potential to introduce market-based measures to reduce greenhouse gas emissions from ships both nationally (e.g. NFD, 2015) and internationally (cf., e.g., Psaraftis et al., 2021).

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[7] For instance, both the Norwegian Shipowners Association and the Norwegian Coastal Shipowners organize shipowners within different segments of freight, offshore supply/maritime services and passenger shipping.

(4) User segments also share the same upstream actor networks (e.g., technology suppliers, ship design companies, and shipbuilders). Whereas there are specialised supply chain actors that primarily deliver products and services to certain ship types (i.e., shipyards being specialised in building cruise or bulk cargo ships), maritime equipment suppliers in general serve the sector as a whole. There is, thus, very little supply-side segmentation.

(5) Finally, there was until very recently no or very limited articulation of demand for greenhouse gas emission reductions from the segments' respective end customers, i.e. no user segment was particularly exposed to distinct pressures from its specific task or institutional environment to reduce their carbon footprint.

In sum, the user segments in the maritime shipping sector have until recently been part of a fairly stable sociotechnical configuration, using the same generic type of energy technology (combustion engines) with many shared actor networks, and institutions – as well as limited pressures to change. This underscores the validity of conceptualising maritime shipping as a segmented regime rather than being comprised of independent regimes.

Case delineation and limitations

Within the MSS, we focus the analysis on coastal shipping. Coastal shipping is a large and highly important part of the MSS in Norway, not least given the abovementioned linkages to other important sectors. Moreover, maritime transport is part of the core infrastructure for the movement of goods and people along Norway's long and jagged coastline. In an international perspective, the largest GHG emissions from maritime transport are beyond doubt from inter-continental deep-sea shipping (Johansson et al., 2017), but low-carbon solutions are generally regarded as highly difficult to implement in this part of the maritime sector and LoZeCs are, so far, by and large considered immature for vessels that operate across vast oceanic distances (DNV GL, 2017). We would, however, argue that coastal shipping offers opportunities for developing and adopting LoZeC technologies that can subsequently (potentially) also be adopted in other parts of the shipping sector. This resembles onshore transport: BE and hydrogen systems were first implemented in (small) passenger cars before being used in more heavy transport with different needs in terms of for example range and reliability.

Two further case delineation decisions were made. First, while it is expected that several new LoZeC technologies (such as battery-electric solutions, biofuels, hydrogen, and various hybrids of these)[8] will be needed for shipping to reduce its emissions, we decided to focus on one of these (battery-electric (BE)) to simplify the analysis. This includes both full electrification and hybrid solutions. With full BE, batteries must be charged while a vessel is docked, whereas hybrid solutions can use plug-in solutions (requiring larger batteries) or make use of battery charging from an engine.

Second, the analysis is focused on the three largest domestic segments in terms of both numbers of vessels and fuel use (FU): coastal ferries (22% FU), offshore supply (16% FU) and fishing (10% FU) (DNV GL, 2016). BE solutions have been applied in all these segments although to a varying extent. Furthermore, these three segments are relevant also in many other geographical contexts such as, for example, Canada (coastal ferries), Brazil and the US (offshore supply), and Portugal and Japan (fishing).

Finally, it should be noted that we do not explicitly consider interactions with other sectors and their respective sociotechnical regimes even though such interactions can have large impact on the development and implementation of new technologies (Andersen and Markard, 2020, Ulmanen and Bergek, 2021, Wirth and Markard, 2011). In our case, some of the focal user segments could very well be considered part of other sectoral regimes as well as the maritime shipping regime. Most notably, the coastal fishing segment provides services related to the food sector and the offshore supply segment contributes to oil and gas extraction and, thus, to the energy and transport sectors. While we fully acknowledge that such connections might influence the transition conditions of these user segments, it is outside the scope of the paper to include them in the analysis. However, while the maritime shipping regime is foregrounded, the analysis does not only cover maritime-specific aspects of the segments' task and institutional environments but also some aspects that are related to adjacent sectors.

Data collection and analysis

Data collection for this paper was conducted as part of a larger research project on sustainability transitions in coastal shipping (all segments) in Norway, which in addition to BE focuses on biofuels and hydrogen.[9] Qualitative data collected through semi-structured interviews (see example of interview guide in appendix 2) forms the core of our empirical material. 72 interviews, typically lasting 60–80 min, were conducted in the period 2015–2019 (see appendix 1) which is also the core time period covered by the analysis. All interviews were conducted with different research questions and analytical frameworks in mind. While this could imply trade-offs in terms of depth versus breadth, the relatively generic nature of questions posed in interviews (see appendix 2) resulted in the entire primary data set being relevant to this paper.

Interviewees were selected using different strategies, including strategic sampling (based e.g. on media articles), through personal and professional contacts, and snowballing. Most interviews were done by small teams of two or three researchers either face-to-face or via telephone/video conference. Private sector informants were mainly high- or middle-level managers or key personnel in charge of development or investments in new vessels or technologies. Public sector informants included, for example, actors in charge of public procurement and investment support schemes. We also interviewed technical experts at universities and research institutes to understand the development of LoZeC alternatives for maritime transport. Representatives of different industry associations provided important information about both task and institutional environments in different user segments, and also about different groups of actors involved in the maritime shipping sector (e.g., ship-owners, technology suppliers, technology specific interest groups). Although not all interviews focused on BE technology per se, BE was a key topic in most interviews (see appendix 1, where all interviews wherein 'new technology focus' is classified as 'generic' touched upon BE to larger or lesser extent).

To increase the credibility of the research, the study is triangulated both with respect to data (several informants within each segment), investigators (most interviews were done by at least two researchers), and by using different qualitative methods. Besides interviews, data was collected from a systematic review of media articles on LoZeC technologies in the MSS in leading maritime media[10] and other document studies (research reports, public documents etc.). We also collected data from non-participatory observations at various events (conferences, seminars), including at workshops with MSS stakeholders organized within the research project. In these project workshops we also discussed preliminary findings and analysis with both firm and non-firm MSS actors.

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[8] These technologies provide different environmental benefits (e.g. in reductions of CO_2, NO_x, SO_x) and face different challenges (e.g. availability, technological development, investments costs) that need to be overcome for them to compete with conventional fuels.

[9] For an analysis of all three 'technologies', see Steen et al. (2019).

[10] For the 2015–2019 period (i.e. corresponding with interviews) we collected 214 media articles on LoZeCs in the context of shipping in Norway, of which 120 were focused on BE.

There are naturally firm-level differences among shipowners with regards to change towards sustainability. In this article we however focus on similarities and differences at the *meso*-level of sectors, particularly aiming to identify patterns at the level of segments within a user regime. Given this objective, data analysis followed three steps. Initially, transcribed interviews were coded (using manual NVivo software) according to LoZeCs (e.g. legitimacy, types of activity (experimentation, implementation, etc)), user segments and context structures (with particular focus on the sectoral context).. Second, context and segment codes were assessed in terms of being (primarily) related to task or institutional environment. As a third step, we assessed the influence of task and institutional environments on segment-specific transition conditions (e.g., technology maturity and fit). Here, we operationalized task environment as consisting of characteristics of inputs, markets, industry structure, competition, operational requirements and regulations directly connected with the product market of each segment, while institutional environment was operationalized as formal rules and more general regulations, societal norms and values, as well as cognitive frames. This coding of primary data was triangulated with analysis of secondary data as mentioned above.

Empirical findings and analysis

The Norwegian maritime shipping sector and battery-electric solutions

The MSS is among Norway's largest industries, covering the entire value chain from research, knowledge-intensive business services, technological development and design to shipbuilding, equipment, control systems, operations, and services. In 2016, the maritime sector employed 89,000 people and represented 25% of Norway's export earnings. The Norwegian MSS is characterized by a high share of advanced vessels and its service and product providers are at the global forefront of maritime technological development, including LoZeC solutions for maritime application (Mellbye et al., 2018). The understanding of Norway as a global leader in the maritime industry has created legitimacy for pioneering the introduction of LoZeC energy solutions both for decarbonization and new value creation (e.g. Maritim21, 2016; Mellbye et al., 2016; NFD, 2015).

An important environmental benefit of BE solutions is the absence of direct emissions. If energy is produced from renewable sources (the Norwegian energy system is primarily based on renewable hydropower), BE contributes to very high reductions of GHG emissions and other pollutants (e.g. NO_x and SO_x). In addition to emission reductions, BE systems (full or hybrid) can reduce maintenance costs compared with conventional combustion engines.[11] Electrical engines are furthermore highly energy efficient and battery technology has also improved significantly in price and performance in recent years. The feasibility of introducing BE systems has also been enhanced by weight-reducing innovations in shipbuilding, including single-hull constructions and the use of materials such as carbon fibre.

Whereas the fishing industry traditionally served as a "test bed" for advanced technology, the offshore petroleum industry has more recently articulated the strongest demand for sophisticated vessels.. There is substantial R&D activity on BE systems (for maritime and other applications), involving key Norwegian research institutes (e.g. IFE, SINTEF) and universities (e.g. NTNU) (Bach et al., 2020). Important funding sources for knowledge development, experimentation and investments include the Research Council of Norway, the Norwegian NO_x-fund[12], and the public agencies Enova and Innovation Norway. In general, these funding sources are available to actors within all user segments. Practically all early tests of BE and also other alternative energy solutions (e.g., LNG, H_2/fuel cells) has occurred in publicly funded projects involving close cooperation between a few dedicated ship-owners, research organizations and technology developers.

Key actors linked to BE for shipping include ship-owners, yards, technology suppliers, service providers, R&D institutes/universities, and public agencies. Most of these actors are involved in the development and construction of different types of vessels in which BE systems are applied, and there are no clear strategic groups focusing on specific segments. Most private actors are established firms, of which several are divisions of multinationals (e.g., ABB, Wärtsila, Siemens, and Rolls-Royce) where the Norwegian branch has been given global responsibility for 'maritime cleantech'. For example, Siemens has established its new maritime battery division in Norway. Therefore, positive externalities are already in place in the form of specialized developers, and suppliers of (power) electronics for maritime and offshore applications have been supplemented by the entry of new entrants specialized in BE (e.g., ZEM, and Corvus).[13] Several networks and cluster organisations promoting BE have been established since 2011, including a Maritime Battery Forum and the cluster organisation NCE Maritime Cleantech. Finally, a general characteristic of the MSS is a culture of openness concerning sharing knowledge and user experience, suggesting that there are fertile conditions for knowledge diffusion across user segments.

Segment-specific transition conditions

In the following, the influence of specific segment characteristics on the involvement of actors to develop and adopt BE in coastal shipping are analysed. We distinguish between influences emanating from task and institutional environment dimensions and pay attention to three main aspects: the maturity and segment fit of BE, infrastructure and system integration requirements, and acceptability and legitimacy. Note that additional quotations from the empirical analysis can be found in Appendix 3.

In general, key technical challenges for widespread adoption of BE in maritime transport relate to battery capacity, charging time and onshore charging infrastructure (Bach et al., 2020; DNV GL, 2015). The BE solutions used in the different segments are supplied by the same firms (e. g. Siemens and Corvus), and the average life expectancy for a battery package is, dependent on usage, approximately 10 years (Siemens et al., 2017).

The coastal ferry segment

The coastal ferry segment is comprised of approximately 500 vessels, including a mix of small ferries, fast ferries and large cruise ships. The bulk of fuel use and emissions in this segment stems from about 300 relatively small vessels (1,000–25,000 GT[14]). Most of these smaller vessels are relatively old (29 years on average) and use diesel-mechanic propulsion. The life expectancy of a new ferry is typically 30–40 years,

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[11] A BE system can compensate for load fluctuations and thus enable more optimized loads on combustion engines, thereby reducing fuel consumption. Also, batteries can act as reserve generators that can be engaged instantly to provide peak power required by ships when e.g. docking or performing lift operations.

[12] The NO_x-fund was established in 2008 as an agreement between 15 business organisations and the Norwegian Ministry of Climate and Environment. Firms pay a rate to the fund instead of paying fees to the state and are eligible to apply for support for NO_x reducing measures through the fund.

[13] Battery cells are not produced in Norway but imported mostly from Asia, whereas custom-made battery assembly and "stacking" is done domestically.

[14] GT refers to gross tonnage, i.e. a measure of a vessel's overall internal volume. The world's largest ships (supertankers, container and cruise ships) are ≈ 200,000–300,000 GT.

and the average length of a tender contract is typically 8–10 years. We focus our analysis on passenger car ferries, which according to the Norwegian Government's maritime strategy is central to the initial implementation of LoZeC technologies and subsequent diffusion to shipping in general (NFD, 2015).

Task environment. Several aspects of the task environment influence the perception of the *maturity/fit* of BE technology with regard to the coastal ferry segment. On the negative side, only a few ferries have diesel-electric configurations, which allow for easier retrofitting with BE hybridization. In addition, the short layover time and high frequency for many ferry routes make it difficult to test new BE solutions and thereby improve the maturity of the technology in the ferry segment. On the positive side, a defining characteristic of the task environment is the short distances of many ferry routes, allowing for full BE solutions. As expressed by an interviewee (TS3), "*small ferries that go back and forth and that can be charged: of course, battery is best; it doesn't take much space, is not too heavy, very high-power efficiency, everything is good.*" Because of this fit, this segment has become an important pioneering market for BE solutions in general and for full-BE in particular. By contrast, BE is not considered a feasible option in the fast ferry segment due to speed and range requirements, at least not in the current task environment. Another positive aspect is that the significant competition between shipping companies has led to advantages for zero-emission solutions such as BE over low-emission solutions: winners of contracts following calls for tenders to operate specific ferry routes are in some cases going far below the set minimum environmental requirements to maximize their chances of success.

With regard to *system integration and infrastructure*, the short layover times of many ferries make charging challenging given current charging technologies. However, instead of becoming a solid barrier to adoption, this has incentivized experimentation with multiple technological options and development efforts aimed at improving charging infrastructure technologies. To exemplify, the development of Ampere (the world's first 100 % battery-electric ferry) contributed to knowledge development and problem solving related to charging solutions and onshore power supply (OPS), and Ampere was built with two different charging systems and uses onshore battery packages rather than grid upgrades (Kirkengen, 2017). Such efforts have improved BE infrastructure but charging nevertheless remains a core challenge for BE given the frequency of many ferry routes. In addition, the need for high charging capacity at specific geographical locations poses challenges for the electricity grid. As many Norwegian ferry crossings are peripherally located, electrification of ferries creates significant investment needs in complementary technologies. A report assessing electricity grid and power sector capacities suggested insufficient grid capacity and that the electrification of 52 ferry services would require approximately 900 MNOK of grid investments (DNV GL, 2015). Thus, on certain routes infrastructure investment requirements constitute a barrier to BE implementation.

Finally, *acceptability and legitimacy* are positively influenced by a unique characteristic of the task environment in the coastal ferry segment: the important role of national, regional and local public administrations in articulating demand for LoZeC technologies, which signals political feasibility. This includes the use of development contracts, aimed at technology development and verification, as well as tenders when purchasing new ferries and awarding operation contracts for specific routes (Bjerkan et al., 2019). "Innovative procurement" by use of development contracts was introduced in 2010 by the Norwegian Road Administration for the first BE car ferry Ampere and is currently used for the first hydrogen car ferry.

Institutional environment. With regard to *technology maturity/fit*, existing ferry regulations limit the space for experimentation and further development of BE technology, since closing down a ferry route for a few hours during the night to allow for testing requires special permission from the Norwegian Public Roads Administration. Moreover, the tradition for regularity in ferry routes leads to public opposition to changes in departure and arrival times, which challenges optimization of BE systems in this segment, as a more flexible schedule would allow for better utilization of energy output and charging time. On a more positive note, the parliamentary decision to facilitate implementation of LoZeC technologies in the coastal ferry segment (NFD, 2017) has significantly stimulated development of BE technology, and also positively influenced *system integration and infrastructure* by encouraging increased investments e.g. in the power grid.

The decision has also signalled political feasibility and, thereby, contributed to increasing *acceptability and legitimacy* of BE solutions in the coastal ferry segment. Subsequent parliamentary resolutions stipulating that zero-carbon technologies should be used whenever possible, have increased this further, by stimulating development of important BE complementary assets, such as different forms of energy control systems and control automation. They have also encouraged the emergence of specialised BE suppliers and prioritisation of BE technology among industry incumbents, resulting in the development of a pool of shared labour with strong BE competencies that also benefits other shipping segments. Further, whereas the reduction in CO_2 emissions from ferries has been driven by policy decisions at the national and regional level, the increasing importance attributed to reducing noise and emissions, particularly in sensitive environments such as fjords and urban areas, has made electrification a more attractive solution vis-à-vis low-emission alternatives. These advantages of BE are considered of particular importance in the ferry segment due to its greater exposure towards the wider public: "*The experienced environmental effect is big because the ferry goes close to shore*" (SY3). This has also provided incentives for shipping lines to engage in tests of BE solutions.

The offshore supply segment

The Norwegian offshore fleet is the second largest in the world and consists of around 600 vessels (Norwegian Ship-owners Association, 2015) operating in all phases of offshore petroleum activities and increasingly also as service vessels for offshore wind farms. Most vessels in this segment are in the range of 3,500–5,500 DWT[15] (DNV GL, 2016) and are tailor-built for specific purposes. In 2013, the average vessel age was about 12 years. Although the vessels are built to last at least 30 years, the average lifetime of vessels in this segment is highly dependent on the state of the industry. During downturns, even fairly new vessels risk to be taken out of service for a long time period while the opposite is true during good times. We focus on offshore supply vessels (OSVs), which provide various services to offshore petroleum installations. The first BE system was installed on an OSV in 2012.

Task environment. Several operational, financial and structural aspects influence the perceived *maturity/fit* of BE solutions in the offshore supply segment. Most vessels built after 2005 have diesel-electric engines, which makes integration of BE solutions easy compared with vessels that have diesel-mechanic propulsion. Adding a battery to the conventional setup (i.e. a hybrid solution) provides a number of advantages in relation to the vessel's operational tasks (cf. Lindstad et al., 2017). About 35% of an OSV's operational time is spent at zero or low speed in standby mode nearby offshore installations (DNV GL, 2016). Since OSV's operational tasks need to be performed with high reliability (including vessel positioning) at nearly any sea state, vessels are equipped with advanced, computer-controlled dynamic positioning (DP) systems using propellers, thrusters, and multiple combustion engines. To handle variations in waves and wind and avoid critical events in proximity to offshore

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[15] DWT (deadweight tonnage) is a ship weight measurement, which refers to displacement at loaded condition minus the weight of the ship minus e.g. fuels, cargo and passengers.

installations during DP mode, vessels using conventional fuel must keep a greater number of engines running than is necessary. This is because thermal generators take time to start up. In these critical operational modes, a BE solution provides an instantaneous back-up power system which substantially reduces fuel usage, as illustrated by one ship-owner: *"[…] over a one-year period we have measured 27.5% savings in fuel usage"* (SO4). The current high fuel usage in DP mode thus incentivizes ship-owners to test and invest in technologies that reduce fuel consumption. Thus, the technological fit is obvious when considering operational aspects of the current task environment.

In addition, this segment consists of privately owned companies operating several vessels and forms a central part of the offshore petroleum value chain. This has given ship-owners adequate financial resources and financial flexibility, which is a positive condition for adopting BE solutions. However, it also makes the segment vulnerable to external changes such as sudden declines in oil prices. This is illustrated by the downturn in the Norwegian petroleum sector that began in 2014, which led to financial constraints among OSV ship-owners, and eventually reduced capital available for investment in BE systems.

Although a BE system reduces operational costs, the technology's maturity in terms of installation costs is still too high for it to be fully competitive, thus limiting its attractiveness for potential users. As illustrated by one ship-owner: "*Especially in periods with low oil prices and cost reductions, we use the cheapest solution, and that has not been green*" (SO2). This is also connected to how contracts are designed in this segment. Ship-owners compete on both long- and short-term contracts. For long-term contracts (typically five years), oil companies organize a request for tender in which ship-owners are invited to submit their offer based on specific tender criteria. Historically, these criteria have not included specific requirements related to fuel usage and emissions, as petroleum companies have paid all fuel costs for OSVs (DNV GL, 2016). This has limited the economic incentives for ship-owners to test or invest in emission reducing technologies, and thus created poor conditions for embedding BE in the segment. As stated by one interviewee: "*We would have installed battery packages earlier if we had paid the fuel costs ourselves, because then we would have kept the income*" (SO4). Here, the recent oil crisis has also had some positive effects, since it incentivized petroleum operators to reduce overall operational costs, including for fuel use on OSVs. This, in addition to other legitimacy issues (see below), explains why the dominant oil company in Norway (Equinor) in June 2017 for the first time required OSV shipowners to install batteries on their vessels in order to compete for long-term contracts. This resulted in seven new vessels with hybrid BE solutions and sent a strong *legitimacy* signal to ship-owners interested in receiving contracts with Equinor in the future.

The task environment also affects opportunities to integrate BE technology with existing *systems and infrastructure*. Large investments have been made in OPS systems, thus, charging of OSVs from shore in Norway does not currently constitute a significant barrier. However, OSV companies compete in a global industry with operations in faraway locations such as Brazil or Angola where the environmental focus is lower and power supply infrastructure might be lacking. This negatively influences conditions for infrastructure investments since the full benefits of BE systems (that come with additional costs) cannot be exploited in many markets.

Institutional environment. Concerning *technology maturity/fit*, both the Norwegian offshore petroleum sector and the offshore-oriented maritime sector is characterised by a risk-taking culture and willingness to test and implement new technologies, and the Norwegian offshore fleet is consequently the most modern in the world. As illustrated by a ship designer (SD1): *"Norwegian offshore shipping companies are uniquely positioned in terms of quality relative to foreign competitors. A crucial reason for this is that they have been willing to take risks on new technology."* Thus, the institutional environment appears to positively influence the embedding of BE.

The OSVs in Norwegian waters operate out of dedicated petroleum supply bases and harbours in larger cities (e.g. Bergen), and local public and political pressures for emission reductions for ships while at dock have mounted notably in latter locations. This has resulted in onshore power supply investments and thus positive *system integration and infrastructure* developments.

In parallel with the increased use – and demonstrated viability – of BE solutions in the offshore supply segment, the regulatory framework has been developed, providing additional momentum for the diffusion of BE in OSVs. Most notably, in 2016 the Norwegian Maritime Authority and DNV GL changed the regulations for offshore vessels to allow batteries to replace one combustion engine in DP mode (Stensvold, 2016). This not only gave incentives to adopt BE, but also sent an important signal that BE solutions are *mature* and safe, thus also increasing *acceptability and legitimacy* of the technology.

Moreover, broader segment conditions have incentivized users in the offshore supply segment to become involved in the development and adoption of BE. The Norwegian petroleum sector has come under increasing pressure to reduce its domestic emissions and its legitimacy in more general terms is being questioned, influencing thus *acceptability and legitimacy* for developing and adopting BE and other LoZeC solutions for vessels. For example, early adopters with this segment (e.g. Eidesvik and Østensjø) appear to have been driven by firm-internal aspirations of operating more sustainably in light of growing public awareness around GHG emissions from the petroleum sector, rather than formal regulations or requirements.

The coastal fishing segment

The Norwegian coastal fishing fleet comprises roughly 3,000 relatively small vessels (9–15 m long) suitable for BE solutions (Siemens et al., 2017) with an average age of approximately 30 years, and new-built vessels are expected to be in use for at least 30–40 years. The coastal fishing fleet employs about 6,000 people and is dominated by single-vessel owners. Moreover, the fleet operates out of approximately 550 ports and harbours. Recent estimates suggest that emissions from the coastal fishing fleet can be halved using hybrid BE solutions. Very few fishing vessels have installed BE-systems, but several vessels with hybrid-electric systems are in the design or planning phase.

Task environment. There are several aspects affecting the perceptions of the *technology maturity/fit* of BE solutions for this segment. From a technical and operational point of view, the conditions for embedding BE solutions in the coastal fishing fleet are considered to be good (see, e.g., Siemens et al., 2017). These vessels operate relatively near shore – often only a couple of hours from port – and spend considerable time at the fishing sites operating at low speeds with varying energy demand during different operations (e.g. hauling lines/nets, processing fish). Under such conditions, a (hybrid) BE system lowers both diesel consumption and maintenance costs. However, in spite of the good operational fit, the upfront investments in vessel upgrading/retrofitting are considered relatively large, signalling that BE systems remain too immature for this segment, which is a limiting factor for small ship-owners with few vessels.

The task environment of the segment also influences the conditions for integrating BE technology with existing *systems and infrastructures*. Due to limited operational range, power demand and opportunities to charge while docked at night, the prospects of integrating with existing systems and infrastructure are regarded as positive within the coastal fishing segment from the perspective of the task environment.

Finally, among the pioneering ship-owners that invest in fishing vessels with BE, another key motivation appears to be improving working environment for crewmembers. A transition to BE is considered a highly beneficial development due to reductions of noise, smoke and vibrations. This suggests favourable transition conditions in terms of acceptability and legitimation from the perspective of fishing crews. However, a challenge for the coastal fishing fleet is that end consumers to very limited extend articulate demand for sustainably (in GHG emission terms) captured fish. This does nothing to improve the legitimacy of BE technologies or other LoZeCs among end consumers. This characteristic of the task environment signals weak conditions for *acceptability and legitimacy* and further reduces the fishing fleet's incentives to adopt BE solutions.

Institutional environment. With regard to *technological maturity/fit*, a number of institutional features weaken the conditions for embedding BE solutions within coastal fishing. First, most vessel owners are small organizations with limited tradition for experimenting with new technology, suggesting that the segment is risk-averse and conservative. Further, there is a lack of tradition among fishing vessel owners in general of seeking for example investment support from public funding sources. Second, the coastal fishing fleet receives a total of approximately €60 million in the form of a refund of the mineral oil tax on fossil fuels. This tax refund reduces the operational costs of using conventional fuel, and thus limits the economic incentives for a ship-owner to invest in BE solutions. The consequences of this are summed up by a shipyard (SY1): "*there will be no technology shift before policy instruments supporting the old-fashioned way of operating are removed*". The latter trait of the institutional environment contributes to weak demand, and therefore hampers maturing and development of BE as well as development of *infrastructure*. Additionally, fishing vessels tend to visit different ports, depending on where they fish, and the development of sufficiently widespread charging infrastructure is seen as a barrier.

Finally, the institutional environment also influences the *acceptability and legitimacy* of BE in the coastal fishing segment. While some ship-owners have invested in BE solutions at least in part motivated by a wish to contribute to more sustainable fishing, a widespread opinion among owners of fishing vessels is that the environmental impact of fishing in terms of e.g. GHG emissions is already considerably lower than other forms of animal protein production. In other words, environmental demands are mainly connected to the produce from this segment, rather than the vessels. This results in low legitimacy for BE and other LoZeC technologies among owners of fishing vessels.

Discussion

The results of the preceding analysis are summarized in Table 1, which shows a wide variety of enabling and hindering factors for the development and uptake of (in this case) BE technologies within three user segments in the context of Norwegian coastal shipping: coastal ferry, offshore supply and coastal fishing. These results illustrate three main points.

First, there are important differences in both task and institutional environments within the user regime of the maritime shipping sector (MSS), which create substantially different transition conditions for the BE pathway in different user segments. Most notably, there is considerable variation between segments in terms of the fit or appropriateness of BE solutions and the level of technological maturity that different groups of ship-owners can readily accept, the possibilities for integrating BE solutions with broader systems and infrastructures, and the acceptability and legitimacy of BE technology (cf. Turnheim and Nykvist, 2019). This confirms the importance of considering the role of regime segmentation in sustainability transitions and thereby complements recent attempts to conceptualize and explore the heterogeneity of socio-technical regimes (e.g. Späth and Rohracher, 2012, Fuenfschilling and Truffer, 2014, van Welie et al., 2018, Carrosio and Scotti, 2019, Ghosh and Schot, 2019).

Second, the results highlight the role of task environments (Scott, 1992) for regime segmentation. Indeed, by paying explicit attention to the competitive and operational conditions of potential users (Oliver, 1997), we identified clear differences between segments concerning susceptibility to BE solutions, which in turn have important implications for BE adoption and transition conditions. One key difference concerns the type and structure of vessel ownership in each segment. In general, ship owners that have multiple vessels and also stronger financial capacity (as in offshore supply) are better positioned to experiment with and adopt novel BE solutions than ship owners that have one or a few vessels and lack financial resources (as in coastal fishing). Thus, due largely to task environment characteristics, user segments differ in their ability to accept the uncertainties and risks associated with investing in new technologies. In the MSS, technology fit is also very much dependent on features such as sailing routes (short, fixed vs. long, varying) and power needs (relatively constant vs. variable), i.e. BE aligns better with use patterns in some segments than others. While a full BE solution is achievable for many vessels in the coastal ferry segment, hybrid solutions (with conventional fuels or other LoZeC technologies) appear more feasible in the offshore supply and fishing segments.

Another notable difference regarding task environments includes the nature and articulation of demand for more sustainable transportation services (e.g. strong in ferry, growing in offshore supply) or end products whose environmental footprint is affected by vessel emissions (weak in fishing). While all user segments show some elements of demand articulation and formation of nursing markets, they differ both in how and by whom demand is articulated and in terms of technological requirements, such as the prerequisite of having a battery installed for gaining a long-term contract for OSV services with Equinor. It is also interesting to note that even the inherently institutional transition condition of acceptability and legitimacy is highly influenced by each segment's task environment, albeit in different ways. In the offshore supply segment, articulation of demand by a dominant customer strengthened the legitimacy of BE. In contrast, a lack of customer demand is a barrier to legitimation of BE solutions in the fishing segment but the increasing importance of improving working conditions has helped to legitimise the use of BE solutions also in this segment. These findings challenge the sustainability transitions literature's tendency to focus almost exclusively on the influence of institutional environments on regime susceptibility to change (Geels, 2014).

Third, despite similarities in overarching regulations and institutions (that we did not focus upon in our analysis), the segments vary in terms of certain regulations directly and indirectly targeting emissions and ensuing implications for technology adoption. For example, whereas existing regulation in the coastal fishing segment negatively influences BE adoption, regulatory changes in the offshore supply segment have opened up for BE hybrid solutions. In the coastal ferry segment, high emission reduction targets set by national and regional authorities have resulted in public procurement practices that have prioritized emission reductions over costs, although existing regulations for ferry operations simultaneously restrict experimentation. In terms of norms and values, all three segments experience similar sustainability drivers and pressures, but they also have unique characteristics, for example in the form of public resistance to change ferry schedules to adapt to new technologies (coastal ferry), high risk-willingness (offshore supply) or lack of tradition for seeking investment support (coastal fishing). In contrast, regulations that influence system integration and infrastructures, for example charging infrastructures, are only to a limited extent segment specific. While it was perhaps not surprising to find that institutional environments matter (cf., e.g., Fuenfschilling and Truffer, 2014, Geels, 2011, Fuenfschilling and Binz, 2018), our results nevertheless identified the key institutional differences that contribute to creating different transition conditions for the BE transition pathway in different user segments.

Conclusions

This article set out to shed light on how user segment characteristics influence sustainability transition processes within established sectors.

Table 1

Segment comparison of task and institutional environment influences on transition conditions.

	Segment	Maturity and fit	System integration and infrastructure	Acceptability and legitimacy
Task environment	Coastal ferry	Users consider BE technology sufficiently mature and have been strongly involved in first full-scale application. Good fit due to operational profile (routes), allowing both full and hybrid BE.	Need for significant investments in grids and infrastructures, notably for full BE. Challenges with infrastructure development especially in peripheral areas.	Demand for sustainable transport articulated by state and regional authorities via public procurement.
	Offshore supply	BE fit (hybrid) is very good due to operational profile (varying power demand), and is perceived as a low-risk technological solution.	No major challenges domestically, hampered by global market orientation.	Increasing attention to cost reductions has legitimatised BE adoption.
	Coastal fishing	Users do not consider BE sufficiently mature and are limited by financial constraints but BE fit (notably hybrid) is good.	No major challenges.	Limited consumer demand for sustainably captured fish → weak incentives to adopt BE.
Institutional environment	Coastal ferry	Expectations of regular ferry operations limits scope for experimentation with BE solutions.	Policy decisions stimulated infrastructure developments and investments.	High political feasibility of implementing BE technology. High public acceptability of BE in particular in urban and scenic areas.
	Offshore supply	Willingness to test new solutions.	Local public/political demand for emission/ pollution reduction in ports → infrastructure investments.	External pressure to reduce emissions from activities in the petroleum sector.
	Coastal fishing	Limited culture of taking risk/testing new solutions. Existing taxes disincentivise BE adoption.	Infrastructure developments hampered by lacking demand. Need for charging at different ports.	Fishing considered a low-emission form of animal protein production → weak incentives to adopt BE.

An important point of departure for this article was that there has been a tendency within the sustainability transitions literature to view regimes associated with established sectors as relatively homogeneous (Geels, 2011, van Welie et al., 2018). Important differences within established sectors regarding susceptibility to change have thereby been overlooked. In recognition of one potential dimension of regime heterogeneity – regime segmentation – we developed a framework that includes both task and institutional environments (Scott, 1992) and applied this to an analysis of how transition conditions may differ between segments in a user regime. Whereas current MLP studies tend to emphasize the institutional dimension of regimes (cf., e.g., Fuenfschilling and Truffer, 2014, Geels, 2011, Fuenfschilling and Binz, 2018), our analysis revealed that additional and stronger focus on task environments can provide important new insights into sectoral change (as previously suggested by, for example, Geels (2014) and Späth et al. (2016)).

Our analysis of three segments in Norwegian coastal shipping – coastal ferry, offshore supply and coastal fishing – revealed several distinct differences concerning both task and institutional environments, indicating a clearly segmented user regime within this sector. Regarding task environments, key differences included operational profiles, degree and nature of competition, customer demand and shipowners' investment opportunities. Variation in institutional environments were related to regulative, normative and cognitive dimensions and pointed also towards important differences in broader segment-specific context structures. These differences – particularly those related to task environments – translate into differentiated susceptibility to change within the MSS.

Based on our findings we postulate that segment variety could be more commonplace in established sectors (e.g. construction, energy-intensive processing industry) than acknowledged in sustainability transitions research. Further, without downplaying the importance of institutional environments, we do believe that important commercial, operational and strategic aspects that relate to actors' task environments have been neglected in transition studies. Whereas such aspects may be relatively mundane, as for instance in operational profiles, they clearly influence the likelihood of actors becoming engaged in the development and adoption of new (sustainable) technologies. More explicit attention to user segment characteristics and task environments may also enable the sustainability transitions research community to more actively engage with the business community in addition to policy makers.

Adding explicit attention to task environments contributes to nuancing the regime concept and illustrates how segmentation leads to variation in actor-related transition patterns. While Geels (2004) notes that regimes may be differentiated according to differing actor groups, we show that such differentiation also happens within one actor group, in this case within a user regime. Therefore, while regime heterogeneity has been observed in previous contributions (e.g. van Welie et al., 2018, Ghosh and Schot, 2019) we add regime segmentation as an important source of such heterogeneity and show that this enables identification of segments that constitute "cracks" in the regime. Our perspective demonstrates how such "windows of opportunity" are not equally distributed across segments in a regime at a given point in time. Rather, explicit attention to differences in both task and institutional environments allows for pinpointing specific segments where emerging LoZeC technologies have a better 'fit' with current segment conditions, are easier to integrate in the entire value chain, and are more acceptable and legitimate in the eyes of different stakeholder groups (Turnheim and Nykvist, 2019). In the current analysis, this explains why coastal ferries were early adopters of BE technology, while, conversely, coastal fishing is a later adopter.

It follows from this analysis that emerging technologies can benefit from policy mixes (see e.g. Rogge and Reichardt, 2016) being attuned to the traits of different user segments. In some (more susceptible) segments, new technologies might flourish by means of market incentives, while other (less susceptible) segments may need more fundamental changes to the existing institutional environment, such as the removal of policies supporting existing technologies. For instance, emission restrictions for OSV vessels could be enforced in the entire domestic petroleum sector, whereas the indirect fossil fuel subsidy in fishing via the mineral oil tax refund should be removed. Attention to differences between segments may also help to focus initial policy support aimed at stimulating early adopters towards segments with better conditions for implementing specific LoZeC technologies.

This does not preclude the relevance of certain sector-general recommendations. One such recommendation is the introduction of a CO_2-fund applicable to all sectors not covered by the EU emission trading scheme (such as transport). This would incentivize the uptake of LoZeC technologies in general and provide important investment support to user segments wherein firm financial resources are limited.[16] Moreover, it appears that the coastal ferry and offshore supply segments' positive impacts on the development and uptake of BE for maritime application contribute to important spill-over effects and positive externalities that other segments, such as fishing, can benefit from. This implies that strengths specific to one segment could potentially be leveraged to

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[16] For a comparative analysis of different market-based measures that could be used for this purpose, see Psaraftis et al. (2021)

address blocking mechanisms and weaknesses in other segments (also those that were not covered here, such as freight and aquaculture). However, whereas it was beyond the scope of this article to address the broader institutional and political context structures (Bergek et al., 2015) influencing segment fragmentation, there are clearly differences between the segments, with the coastal ferry, offshore supply and the coastal fishing segments being influenced by transport, petroleum and fishing policies respectively. This implies that the development of sector-general policies and policies to exploit synergies between segments would require policy coordination between different ministries and governmental agencies.

Finally, it should be noted that our analysis was restricted to a single emerging technological field and did not differentiate between maritime-specific incentives and pressures and those originating in other sectors, such as food (e.g. related to coastal fishing) or energy (e.g. related to offshore supply). As highlighted in previous research, transitions often concern multiple technologies and sectors, which can interact in different ways – not least in relation to emerging technologies (Andersen and Markard, 2020, Ulmanen and Bergek, 2021). More explicit attention to how such interactions influence the transition conditions within and across sectors could be a fruitful line of further investigation. Given the importance of regime segmentation, and the lesser degree of susceptibility to BE solutions in some segments, future research could in particular look closer at the role of user segment characteristics for multiple (competing) technologies that potentially offer different advantages and disadvantages in relation to the task and institutional environments characterizing different segments in the same overarching regime. Future research might also analyse whether similar results would be found in other countries with a variety of coastal shipping segments such as, for example, Canada, the UK or Japan. While we would expect differences in task and institutional environments to matter in all contexts, *how* they matter would likely vary geographically (Hansen and Coenen, 2015)

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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