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Towards a sustainability transition in the maritime shipping sector: the role of market segment characteristics

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Abstract

Maritime transport is arguably a neglected empirical field within sustainability transitions research, despite the global importance of reducing greenhouse gas (GHG) emissions and other pollutants also from this sector. What makes this especially interesting from a sustainability transitions perspective is that low- and zero-carbon energy (LoZeC) technologies would need to be implemented in a mature, multi-segmented sector that, similar to onshore transport, is highly heterogeneous in that it includes vessels ranging from massive inter-continental freight and bulk carriers to small passenger vessels. This suggests the need for a more differentiated and nuanced perspective on socio-technical regimes as well as on the emerging technological innovation systems and their interaction with each other. More specifically, we focus on the particular task and institutional environments that characterize different market segments. In this article we analyze the evolution of battery-electric (BE) energy storage in the maritime shipping sector (MSS), employing a framework that combines the multi-level perspective (MLP) and the functions of technological innovation systems (TIS) approach. Taken together, our analysis suggests that the MSS transition process is likely to unfold along different pathways in different market segments, and that different market segments will have different impacts and influences on TIS functionality. In summary, we contribute to the sustainability transitions literature by explicitly addressing the influence of market segment characteristics on regime susceptibility and TIS functionality. From a policy perspective, this points to a need for segment-specific policy instruments.

1. Introduction

Maritime transport is arguably a neglected empirical field within sustainability transitions research, despite the global importance of reducing greenhouse gas (GHG) emissions and other pollutants also from this sector. To date, incremental innovations in the design and engineering of vessels/equipment has contributed to energy efficiency gains (Rusten, 2010), but most ships still run on fossil fuels (diesel or crude oil) as they have for more than a century (Endresen et al., 2007; Geels, 2002). The implementation of low- and zero-carbon (LoZeC) solutions – including battery-electric storage systems, biofuels, hydrogen, fuel cells, and various hybrids of these and/or conventional fuels and technologies – would enable the maritime shipping sector (MSS) to maintain its function while achieving de-carbonization. These LoZeC technologies currently play minute roles in the MSS, provide different environmental benefits and face different challenges (e.g. availability, technological development, investment costs) that need to be overcome for them to compete with conventional fuels.

What makes this especially interesting from a sustainability transitions perspective is that LoZeC technologies would need to be implemented in a mature, multi-segmented sector that, similar to onshore transport, is highly heterogeneous in that it includes vessels ranging from massive inter-continental freight and bulk carriers to small passenger vessels. Actors, and notably among them ship owners, within the sector therefore operate within heterogeneous task and institutional environments (Scott, 1992). This suggests the need for a more differentiated and nuanced perspective on socio-technical regimes (Berggren et al., 2015; Steen and Weaver, 2017) as well as on the emerging technological innovation systems and their interaction with each other and various context structures (cf. Bergek et al., 2015).

To analyze the evolution of LoZeC technologies in relation to the maritime shipping sector (MSS) (as part of a sustainability transition in maritime transport), we therefore use both the multi-level perspective (MLP) (Geels, 2002) and the functions of technological innovation systems (TIS) approach (Bergek, Jacobsson, Carlsson, et al., 2008). However, we suggest that the MLP has paid insufficient attention to the task environment (Scott, 1992)of actors operating within regimes, and therefore introduce an extended regime concept that includes both institutional and task dimensions. We apply this combined framework to analyze the development and uptake of battery-electric (BE) energy storage solutions in the Norwegian MSS, which is one of Norway’s strongest and most dynamic industries (Reve and Sasson, 2012). We focus on the three segments that constitute the bulk of the MSS (Grønt Kystfartsprogram, 2016) both in terms of vessel numbers and emissions, namely passenger, offshore supply and fishing vessels.

The analysis sheds light on how susceptibility to regime change varies considerably between and within different segments of the MSS, depending e.g. on ships operational characteristics, sailing routes and access to energy infrastructures at ports, availability of financial capital amongst both ship owners and technology developers, as well as policy context. The analysis of how such characteristics influence the BE TIS results in two main findings. First, the weaknesses and barriers confronting BE are in important respects market segment specific. Second, the characteristics of market segments significantly influence the roles played by policy and policy instruments in stimulating the development of innovation system functions.

Taken together, these two analyses suggest that the MSS transition process is likely to unfold along different pathways in different market segments. In summary, we contribute to the sustainability transitions literature by explicitly addressing the influence of market segment characteristics on regime susceptibility, TIS functionality and the role of government policy in the development of TIS functions. From a policy perspective, this points to a need for segment-specific policy instruments.

The remainder of the article is divided into five sections. In section 2, we develop our theoretical framework, focusing on the added value of combining MLP and TIS approaches as well as the need for a better understanding of differentiated market segments within established sectors or industries. In section 3 we outline our study design. Section 4 contains an analysis and discussion of the empirical findings and the conclusions are presented in Section 5.

2. Theoretical framework

2.1 Sociotechnical transitions

Transitions can be described as “system innovations” (Geels, 2004, 2005), i.e. reconfigurations of sectoral sociotechnical systems that fulfil some societal function, such as energy supply, transport, communication or housing (Geels, 2002, 2004, 2005). Such transitions involve co-evolutionary and gradual changes in (1) sociotechnical systems for the production, diffusion and use of technology, (2) supply- and demand-side actor groups that create, maintain and refine the elements of sociotechnical systems and (3) sociotechnical regimes that guide and orient the actions and interactions of actors (Geels, 2004; Geels and Kemp, 2007). Because these three dimensions are interlinked and aligned to each other, system reconfiguration does not occur easily (Geels, 2002). For new technologies to break through and become part of a new or reconfigured sociotechnical system, a combination of novelty generation (i.e. emergence and growth of new technologies) and a window of opportunity (i.e. destabilization of the current sociotechnical system, actor structure and regime) is therefore required (Geels, 2002).

2.1.1 Novelty generation through technological innovation systems

In the multi-level perspective, novelties emerge in so-called ‘niches’, which are embedded in regimes, yet protected from them. Niches “provide the seeds for change” (Geels, 2002, 2005) by offering protected spaces in which a set of dedicated actors can experiment with new technologies and learn from these experiments, develop joint visions and expectations and articulate demand, without being subjected to the selection mechanisms of the mainstream market (Geels and Schot, 2007; Kemp et al., 1998).

It is commonly assumed that niches are developed by new entrants and other actors that are ‘outsiders’ (i.e. not ‘incumbents’) with regard to an established socio-technical system. Markard and Truffer (2008, 610), for instance, suggest that “radical innovations are often promoted by actor networks that show little overlap with prevailing actor structure in a sector or technological field.” More recent contributions have however questioned this assumption (e.g. Berggren et al., 2015; Steen and Weaver, 2017). We, therefore, choose to conceptualize novelty generation by using a framework which emphasizes the collective aspects of the innovation process without making any *a priori* assumptions regarding what actors are involved in developing them (incumbents versus outsiders/new entrants): the technological innovation system (TIS) framework.

A technological innovation system can be defined as “a network of agents interacting in a specific *economic/industrial area* under a particular *institutional infrastructure* or set of infrastructures and involved in the generation, diffusion, and utilization of technology” (Carlsson and Stankiewicz, 1991, p. 111). The focus on a specific economic/industrial area implies that the main basis for defining a TIS is a focal technology or product (Bergek, Jacobsson, Carlsson, et al., 2008; Carlsson, 2006; Carlsson et al., 2002), but problem-solving networks rather than buyer-supplier relationships are in focus of the analysis (Carlsson et al., 2002).

A TIS can be analyzed in terms of their structural composition at a particular moment or over time, i.e. in terms of actor network dynamics and institutional alignment. However, from the point of view of novelty generation, it is more relevant to assess TIS performance in terms of innovation. Although performance of course is influenced by the composition of the system, it is better captured by the so-called ‘functions framework’ (cf. Johnson, 1998, 2001; Johnson and Jacobsson, 2001). Functions are emergent sub-processes of the overall innovation process and contribute to the development, diffusion and utilization of new products (goods and services) and processes (Bergek, Jacobsson, Carlsson, et al., 2008; Johnson, 1998, 2001) within existing innovation systems or as part of emerging innovation systems.

Several sets of functions have been used in previous empirical analyses. In this paper, a modified version of the functions defined by Bergek et al. (2008) is used (see Table 1), in which functions are quite broadly defined and, thus, capture more aspects of the innovation process than in more narrowly defined versions of the framework (Bergek, 2012). By analyzing through which mechanisms these functions are served with regard to a specific product class or field of technical knowledge, a deep understanding can be gained of the main endogenous and exogenous drivers and barriers to novelty generation in the associated TIS.

Table 1. TIS functions

Function	Description
Knowledge development and diffusion	Broadening and deepening of the knowledge base of a TIS, sharing of knowledge between actors within the system and new combinations of knowledge as a result of these processes.
Entrepreneurial experimentation	Problem-solving and uncertainty reduction through real-world trial-and-error experiments at different scales with new technologies, applications and strategies.
Market formation	The opening up of a space or an arena in which goods and services can be exchanged in (semi-)structured ways between suppliers and buyers, including e.g. articulation of demand and preferences, product positioning, standard-setting and development of rules of exchange.
Influence on the direction of search	Mechanisms that influence to what opportunities, problems and solutions firms and other actors apply their resources, incentivizing and pressuring them to engage in innovative work within a particular technological field and determining what strategic choices they make within that field.
Resource mobilization	The system's acquisition of different types of resources that for the development, diffusion and utilization of new technologies, products and processes, most notably capital, competence and manpower and complementary assets (e.g. infrastructure).
Legitimation	The process of gaining regulative, normative and cognitive legitimacy for the new technology, its proponents and the TIS as such in the eyes of relevant stakeholders, i.e. increasingly being perceived as complying with rules and regulations, societal norms and values and cognitive frames.
Development of positive externalities	The creation of system-level utilities (or resources), such as pooled labor markets, complementary technologies and specialized suppliers, which are available also to system actors that did not contribute to building them up.

Source: Bergek (2018, forthcoming) (adaptation of Bergek et al. (2008))

These functions are influenced by actors, networks and institutions of the TIS as well as by various elements residing in its context (or environment) (Bergek and Jacobsson, 2003; Jacobsson and Bergek, 2011; Johnson and Jacobsson, 2001). Our knowledge about how different types of contexts influence TIS functionality remains rather limited (Markard et al., 2015), but similar to how transitions are described in the MLP, influences from related sectors (i.e. those in which the new products and processes developed within the TIS are expected to be used) are often considered especially important (cf. Bergek et al., 2015; Ulmanen and Bergek, 2018).[1] How such sectoral contexts could be conceptualized is, however, not very well developed in the TIS literature and we therefore turn to the transitions literature, in particular the MLP, to elaborate further on the sectoral context and its potential influence on novelty generation.

2.1.2 Inertia, destabilization and windows of opportunity

As was mentioned above, sociotechnical systems, actor groups and regimes at the sectoral level all have to change for transitions to happen. However, all of these tend to be very stable due to various self-reinforcing mechanisms (Geels, 2004). Once established, *sociotechnical systems* can develop a logic of their own and, thus, become difficult to abandon. They are often characterized by technological interdependencies, complementarities and sunk costs (Geels, 2004), which tend to be mirrored by the organization of companies (Henderson and Clark, 1990) and supply chains (Mylan et al., 2015; Wells and Nieuwenhuis, 2012). This makes it difficult to change one part of the system without large effects on other parts. Moreover, sociotechnical systems are affected by demand-side mechanisms like increasing returns to adoption (Arthur, 1988, 1994), which can lead to technological lock-in. *Actor groups* and individual organizations are embedded in networks and, thus, subjected to various forms of stabilization mechanisms in the form of social relationships, mutual expectations and commitments and vested interests (Geels and Kemp, 2007). They are also constrained by other cognitive and physical interdependencies (Geels, 2004), to up- and downstream supply chain actors as well as complementary innovators (Adner and Kapoor, 2010). Finally, *regimes* provide stability by guiding actors' search and learning processes in certain directions, providing a joint perception of proper behavior or providing binding contracts or formal standards, to which actor need to conform (Geels, 2004).

Of these three, the stabilizing effect of the regime tends to be most highlighted in the literature. Indeed, regimes tend to be described as very stable or even locked in, which is said to account for the gaining of momentum and the resulting stability of existing sociotechnical systems (Geels, 2002, 2005; Geels and Kemp, 2007). Radical novelties developed in niches or technological innovation systems therefore have little chance of breaking through without a destabilization of the current regime (Geels, 2004). However, such lock-in or closure is rarely everlasting; regimes might open up both as a consequence of pressures from the sociotechnical landscape, such as increasing fuel prices and growing environmental concerns in society, and due to changes, internal conflicts or tensions within the regime (Geels, 2002, 2004, 2005). A sociotechnical transition can, thus, only occur if niche-level dynamics, such as price/performance improvements or increasing returns to adoption, coincide with a "window of opportunity" at the regime level (Geels, 2002, 2005).

2.1.3 Towards a representation of the sectoral context: an extended regime concept

The regime is, thus, a central concept for understanding opportunities and limitations to innovation and transition. The underlying notion is that actors' perceptions and (inter)actions are both enabled and constrained by the institutional context in which they operate, including routines and rules of different kinds which they also reproduce through their own actions. Regimes are semi-coherent sets of interdependent rules, which are aligned to each other (Geels, 2004). They represent the

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[1] In addition, there can be both competitive and symbiotic interactions between innovations developed in parallel within different TISs (Bergek et al., 2015). This is also highlighted in the MLP, which describes how the breakthrough of an innovation from the niche level can benefit from hybridization with other technologies or from linking up to previously developed new technologies (Geels, 2005).

interdependence and linkage between different sub-systems and the associated coordination and alignment between different social actor groups (Geels, 2005).

Regimes include problem agendas, standards, user preferences and consumption patterns, government regulations and cultural meanings and span technology, science, policy, culture and users/markets (Geels, 2004). More specifically, they can be described in terms of three different institutional dimensions (Scott, 1995, cf. also Geels (2004) and Bergek et al. (2008b).): 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.

Over time, the scope of the regime concept has been widened in terms of which types of institutions are included and in terms of which actors' (inter)actions they align and coordinate (Geels, 2002; Geels and Kemp, 2007),[2] but the concept is still very much based on a sociological perspective of actors as primarily social and institutional beings. However, this perspective only provides a partial understanding of what guides actors' innovative activities in a sector. Indeed, actors are not only influenced by their institutional environment, as described 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 (often profit) rather than to gain social legitimacy and support (Scott, 1992). In such environments, actors are problem-solving and task-oriented rather than social, and they are consequently rewarded for the quantity and quality of the goods and services they produce and exchange in markets rather than for using correct structures and processes (Scott, 1992). Notions of the task environment tend to emphasise competitive pressures, which motivate firms to become more efficient and effective and require them to acquire and control critical resources (Oliver, 1997). The competitiveness of an industry or sector is related to sources of inputs, competition between direct rivals and substitutes and markets for outputs (cf. Porter, 1980). More specifically, key aspects of task environments are market size and growth, market structure (e.g. degree of concentration and the proportion sold via intermediates), industry structure (e.g. number of competitors, organisation of the supply chain, degree of concentration and specialization/integration) and product diversity and degree of differentiation (Dess and Beard, 1984; Porter, 1980). This means that technical interdependencies and exchanges of critical resources between actors are in focus (Oliver, 1997).

To some extent, the existence and importance of task environments is implicitly acknowledged also in the traditional transitions framework described above. As mentioned previously, sociotechnical systems, which include both technical and economic task environment dimensions, are described as both enabling and constraining action, and firms are described as making strategic investment decision with the aim to earn money and gain market position (Geels, 2004). In addition, lock-in is described as being partly due to economic, organizational and infrastructural dimensions (Geels, 2005; Geels and Kemp, 2007). Moreover, several of the regime definitions stress that routines are embedded in, for example, knowledge bases, product characteristics and manufacturing processes (cf., e.g., Geels, 2002, 2005), i.e. in elements that are very closely related to the task environment. However, in order to fully

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[2] For a somewhat contrasting perspective, which primarily emphasizes the cultural-cognitive dimension, see Fuenfschilling and Binz (2018).

understand actor-related transition patterns (cf. Geels, 2005), more explicit consideration to task environments is needed.

Although the conceptual distinction between task and institutional environments is useful, it should be recognized that they are not independent. Organizational goals, markets and other aspects of the task environment are shaped, created and organized by institutions (Scott, 1992) and institutions need to be put into practice in the task environment to be realized (Bonfirm et al., 2016; Fuenfschilling and Binz, 2018). The two types of environments are therefore best seen as complementary dimensions enforcing different demands and requirements, and any sector can be strong or weak in either or both of these dimensions (Oliver, 1997). We therefore suggest conceptualizing the sectoral context in terms of an "extended regime", which includes both the task environment and the institutional environment.[3] In practice, this would imply analyzing how, for example, sources of inputs, markets for outputs, competition and product market regulation, as well as regulatory, normative and cognitive institutions contribute positively or negatively to the functionality of a specific TIS.

2.2 The role of market segments in transitions

According to mainstream MLP literature, new niche innovations develop cumulatively by successively being used in different market niches (or segments) (Geels, 2002). This indicates that the importance of market segmentation for transition is (at least) twofold: (1) The 'window of opportunity' for specific niche innovations to break into existing sociotechnical regimes differ between segments and (2) the development of new technologies in technological innovation systems is to some extent segment-specific – otherwise an emerging technology would be equally well adapted to, and have the same chance of breaking into, all segments at any given point of time. We will elaborate on both these aspects in the following.

The lack of markets for new (sustainable) technologies is acknowledged as a key barrier both within the MLP (e.g. Geels, 2002) and TIS (e.g. Bergek, Jacobsson, Carlsson, et al., 2008). For emerging technologies, or technologies undergoing substantial transformation, markets may be greatly undeveloped or simply not exist. Potential users have not developed preferences and may not articulate demand or be capable of doing so. Other key barriers confronting a novel technology are inability to compete on price and performance, and that market development often requires institutional change such as the formation of standards. As discussed previously, this creates a need for nursing markets, e.g. natural niches or markets stimulated through public support (Bergek et al. 2008; Hekkert & Negro, 2008), wherein technological development can co-evolve alongside the development of user experience, buyer-customer relationships, standards and institutions.

However, both the TIS and MLP approaches have been criticized for not paying sufficient attention to market formation processes. In the MLP, market formation processes have typically been

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[3] This is similar to the "triple embeddedness framework" presented by Geels Geels, F.W., 2014. Reconceptualising the co-evolution of firms-in-industries and their environments: Developing an inter-disciplinary Triple Embeddedness Framework. Research Policy 43, 261-277. and applied by Turnheim and Geels Turnheim, B., Geels, F.W., 2013. The destabilisation of existing regimes: Confronting a multi-dimensional framework with a case study of the British coal industry (1913–1967). Ibid. 42, 1749-1767.. However, while these authors conceptualize the environment of an industry in three dimensions (the socio-political environment, the economic environment and the industry regime), we combine the latter two into the notion of the task environment, in line with Scott Scott, W.R., 1992. Organizations. Rational, Natural, and Open Systems, 3rd ed. Prentice-Hall Inc., Engelwood Cliffs, N.J..

conceptualized as occurring in sheltered niches, with new entrants as principal agents of change. In a review of empirical TIS research to date, Bergek (2018, forthcoming) finds that the TIS literature as a whole “does not provide any detailed understanding of the market formation process.” Dewald and Truffer (2011) suggest that a “(…) more elaborate understanding of market formation has to be aware of potential interactions and co-dynamics between technological, institutional, political and user-related aspects of a new technology. These processes have to be conceptualized as evolving socio-technical systems instead of mere market structures.”

This calls for a more open approach to understanding market formation processes. More specifically, and following Dewald and Truffer (2011), it is important to recognize the (potentially significant) differences in sub-system structures or *market segments*. Dewald and Truffer define market segments as (op.cit., 286) “those sub-system structures that serve specific user segments and that are characterized by specific product forms and related actors, networks and institutions.” This furthermore means that market segments can appear in very different forms, from small local market niches to international market structures dominated by large and dominant producers. According to this conceptualization, market segments also differ significantly regarding their interaction with the generation-oriented parts (upstream) of a TIS. In some segments technology manufacturers may cooperate closely with end-users, whereas pure market transactions will dominate other market segment. If a technology has been proven in one market segment (application domain), barriers will be reduced for other market segments. Market segment interaction may however not be supportive, for example if there is competition over resources.

Because market segments are likely to vary not only in terms of the demand side (end-users), but also on the supply side (the actors, networks and institutions delivering products and associated services to end-users), different market segments (provided they exist) are likely to generate different support (or, contrariwise, barriers to) the overall functionality of the TIS. This calls for closer attention to market segment specific structures (actors, networks, institutions), processes (development stages and interdependencies between market segments) and functionality (contribution to TIS functions) (Dewald and Truffer, 2011). However, in the context of sustainability transition of an established sector (here the shipping sector), closer attention needs to be paid not only to the structural dimension of market segments, but also to key characteristics in terms of task environments. Within established sectors, preferences and needs regarding e.g. energy may vary depending on the task environment. For example, within the energy-intensive process industry some segments (e.g. titanium) currently rely on the burning of coal to generate high temperatures, whereas other segments (e.g. aluminum) do not have this need. As we will elaborate in the empirical section that follows, the immense variety in the maritime shipping sector indicates not only heterogeneity in terms of institutional and task environments between particular market segments, but even within those. This suggests that different market segments within an established socio-technical regime can be more or less susceptible to landscape pressures and to threats from emerging technologies and, thus, more or less open to specific emerging niche innovations. TIS structure and functionality can then also be expected to differ between market segments. Firms and other actors in innovation systems can choose a ‘focus’ strategy, in which they develop their products with a particular customer segment in mind (cf. Porter’s (1980) “strategic groups”). This implies that a particular TIS can include a number of more or less disconnected actor networks, each focusing on one or a few market segments. As explained above, these networks can also be subjected to partially different task and institutional environments. We might, thus, see the emergence of a set of different sub-TISs, with quite different functional dynamics (cf. Dewald and Truffer 2011). Contrariwise, actors may choose a broad strategy, which would not result in sub-market structures with different actor constellations in the upstream dimension. But because this will be an empirical question, we focus on the downside (demand) side of markets, implying that our point of departure is seeing market segments as primarily constituted by groups of buyers with similar preferences and needs.

2.3 Analytical framework

Taking stock of our preceding theoretical discussion, we develop an analytical framework that focuses on how variety in the form of different market segments within a socio-technical regime influences TIS functions (see Figure 1). This framework makes two main contributions to the literature by (1) further conceptualizing the sectoral context of a TIS in terms of an extended regime, which compared with the current focus within MLP-oriented transition studies on the institutional dimension of regimes explicitly includes also the task environment, and (2) drawing attention to potential differences between market segments within an established sector in terms the sectoral context and how it influences TIS functionality.

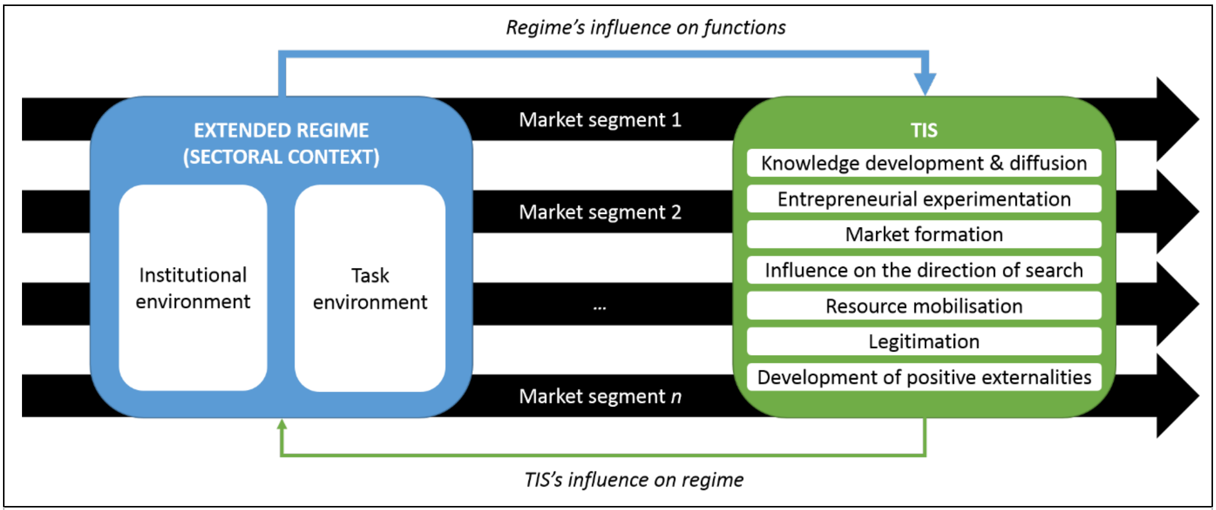

Figure 1: Segment-differentiated analysis of TIS functionality in the context of an extended sectoral regime

3. Methods and data

Qualitative research methods are highly appropriate when studying complex, ongoing processes of technological and industrial change (Steen, 2016), as is the case with the 'green shift' in the Norwegian maritime sector. Moreover, whereas quantitative indicators can shed light on the status of various TIS functions, detailed qualitative data are needed in order to establish the causal mechanisms between a TIS, its environment and the effect of that environment on TIS functions (Bergek, 2018, forthcoming).

Qualitative data produced through semi-structured interviews therefore forms the core of our empirical material. Approx. 50 interviews were conducted in the period October 2015 to March 2018, with the main bulk carried out since June 2017. A number of research team members[4] were involved in this

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[4] Researchers participating in interviews: Anna Bergek, Teis Hansen, Tuukka Mäkitie, Jens Hanson, Olav Wicken, Øyvind Bjørgum, Tyson Weaver, Tone Merethe Aasen, Lone Sletbakk Ramstad, Assiya Kenzhegaliyeva, Markus Steen.

work, and the majority of interviews were done by small teams of two or three researchers. The interviews were primarily conducted face-to-face during intensive fieldtrips involving multiple interviews in a given city or region. Most interviews were done in four regions: the Oslo and Trondheim city regions, (northern) Rogaland and Hordaland (including the city region of Bergen) and the north-Western region of Sunnmøre (including the city of Ålesund). Some interviews were done via telephone/internet in order to reduce the need for (air) travel.

Although not all interviews focused on battery-electric (BE) technology per se, BE (often hybrid variants) was a key topic in the majority of interviews. The interviews covered a broad range of both public and private actors involved in the maritime shipping sector. Our private informants were mainly high- or middle-level managers or key personnel in charge of development of or investments in new vessels or technologies. Public sector informants included, e.g., actors in charge of public procurement and investment support schemes. We also interviewed technical experts at universities and research institutes to understand the development phase and feasibility of various low- and zero-carbon energy solutions for maritime transport.

Interview data is triangulated with and supported by data from document studies (media articles, research reports, public documents etc.) and data from non-participatory observation at various events (conferences, seminars, workshops). A systematic review of media articles on LoZeCs in the MSS in leading “maritime media” such as TU.no, Sysla.no and Skipsrevyen.no was performed. Events are a valuable source of insights on how different stakeholders within an industry or different actors that are involved in the development of new technological solutions perceive and frame opportunities and barriers (Karlsen, 2018). These events were (often jointly) organized by environmental NGOs, industry associations, technology specific networks and government agencies, and provided important opportunities to listen in on discussions between different actors, informal conversation and access to informants for later interviews.

4. Empirical findings and analysis

4.1 The Norwegian maritime shipping sector and the battery-electric TIS

The MSS is one of Norway’s strongest and most dynamic industries, covering the entire value chain from research, technological development and design to shipbuilding, equipment, control systems, operations and knowledge intensive services (Reve and Sasson, 2012). In 2013, the maritime sector employed approx. 112 000 people, of which 48 000 were employed by shipping companies and the rest in various service, technology supply and shipbuilding (NFD, 2015). The MSS is highly internationalized[5] and is characterized (together with O&G and aquaculture) as one of Norway's "global knowledge industries" (Reve and Sasson, 2012). A key characteristic of the Norwegian MSS is that the fleet is comprised of a high share of advanced vessels, and that Norwegian service and product providers are in the global forefront of technological development for maritime application (Mellbye et al., 2015). Previously, the fishing industry served as the "test bed" for advanced technology. In later decades, the offshore O&G industry has articulated the strongest demand for sophisticated vessels, machinery and solutions (Reve and Sasson, 2012). Important funding sources for knowledge

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[5] For example, 90% of the NOK 80 billion turnover among Norwegian ship equipment manufacturers in 2014 came from markets outside of Norway. This also means that the industry is exposed to considerable international competition (Mellbye et al., 2015).

development, experimentation and investments (both in vessels and infrastructure) include the Research Council of Norway, the Norwegian NOx-fund (where shipping is the largest receiver of funds for investments into technology that reduces emissions), and the public agencies Enova and Innovation Norway.

Several broad market segments – i.e. application areas for vessels with different types of propulsion technologies – are easily distinguishable within maritime transport. In this article we focus on the three largest markets segments in terms of numbers of vessels operating primarily within Norwegian maritime borders: passenger transports (e.g. small ferries, speed boats and large cruise ships), offshore supply (e.g. platform supply vessels) and fishing (coastal and sea-going). These are also the three segments that use most fuel in Norwegian waters (22%, 16% and 10% of the fuel use in 2013 respectively) (DNV GL, 2016).

The need to improve the environmental performance of the MSS sector was described above. So far, numerous mainly incremental innovations in the design and engineering of vessels and equipment have contributed to energy efficiency gains (Rusten, 2010), but most ships still run on fossil fuels (diesel, crude oil) – as they have for the last century. A number of different low- or zero-carbon energy (LoZeC) technologies could contribute to a sustainability transition in the MSS, including batteries (electric), biofuels, hydrogen and various hybrids of these and/or conventional fuels/technologies. These LoZeC technologies provide different environmental benefits (see Table 2) and face different challenges with regard to, e.g., availability, technological development and investments cost that need to be overcome for them to compete with conventional fuels. Currently, they all play minor role in the MSS (DNV GL, 2015), both nationally and globally.

Table 2. Evaluation of LoZeC technologies (current status) compared with (conventional) diesel.

	Biofuels[b]	Electric (full)	Electric hybrid[c]	Hydrogen[d]
Reduction of climate gases[a]	High	Very high	Moderate	Very high
Reduction of NO_x[a]	Negative	Very high	Moderate	Very high
Reduction of SO_x[a]	Very high	Very high	Moderate	Very high
Investment cost	Low	High	Moderate	High
Fuel cost	High	Low	Moderate	Moderate
Availability (incl. infrastructure)	Low	Moderate	Moderate	Low

[a] The environmental benefits of electric power (battery) and hydrogen depends on the source of electricity used

[b] Biofuels comprises biogas, biodiesel, bioethanol etc.

[c] Electric hybrid refers to a combination of a conventional (fossil) engine and a battery-electric propulsion system.

[d] Hydrogen refers to hydrogen produced via electrolysis from renewable energy.

Sources: DNV GL (2015), Dahl et al. (2013), NFD (2015).

In this article we focus on battery-electric (BE) technologies. In environmental terms, an important benefit of BE solutions is that they do not produce any direct emissions provided that energy is produced from renewable energy sources. BE can therefore contribute to very high reductions of climate gases and other harmful pollutants such as nitrogen and sulfur dioxide (see Table 2). Electrical engines are furthermore highly energy efficient, and battery technology has improved significantly in recent years both in price and performance (REF). Key remaining challenges for widespread adoption of BE in maritime transport relate to battery capacity, charging time and onshore charging infrastructure (DNV GL, 2015). It is, however, important to differentiate between full electrification and hybrid solutions. With full BE, batteries must be charged while the vessel is docked, whereas hybrid solutions can use plug-in solutions (which requires larger batteries) or make use of battery charging from an engine.

The Norwegian BE TIS consists of a varied set of actors ranging from ship owners to yards, technology manufacturers, service providers and public funding agencies. Most of the private actors are established firms, whereas entrants primarily are battery suppliers.[6] A formalized "Maritime battery forum" was established in 2014, and now comprises approx. 50 members. Moreover, several innovative projects involving BE solutions have grown out of the publicly funded cluster "NCE Maritime Cleantech" (established in 2011, received status as NCE (Norwegian Centre of Expertise) under the publicly funded cluster program in 2014, currently 74 members) and the public-private partnership "Green Coastal Shipping Program" ("Grønt Kystfartsprogram" – established in 2015 and currently has 26 members and 12 observers). None of the programs/networks are market segment specific, and there appears to be limited overlap in terms of network/cluster membership with the exception of certain key actors such as the maritime consultancy firm DNV GL and the Norwegian Maritime Authority. Unlike solar PV in Germany, where market segments differ in terms of actors in both upstream and downstream dimensions (Dewald and Truffer, 2011), many upstream actors in the Norwegian MSS (e.g. designers, yards, technology suppliers) are involved in the development and construction of different types of vessels. A more detailed analysis of supply chains is, however, warranted to investigate whether any strategic groups can, in fact, be identified.

According to a comprehensive assessment made by DNV GL (2015) on the feasibility for various LoZeCs in maritime transport, all shipping segments are relevant for BE solutions. The appropriateness of BE for all market segments is reflected in the internal structure of the BE TIS, where there are no clear strategic groups (i.e. groups of actors focusing on specific segments). Instead, most actors are targeting all segments. There is nonetheless considerable variation between and within segments in terms of how well BE technologies ‘fit’ particular vessels. This is primarily dependent on a key aspect of the task environment: the operational profile of ship engines. Accordingly, the ships that have most to gain from BE (in terms of reduced fuel consumption and emissions) are ships that have either highly varied power output (due to ship operations such as handling cranes, e.g. offshore supply vessels and ferries) or periodically low engine utilization (due to long periods of “standstill”, e.g. fishing or freight vessels). In the following, we will analyze how these and other specific characteristics of the task and institutional environments of each segment influence the functionality of the BE TIS.

4.2 Segmented TIS analysis

4.2.1 The passenger transport segment

The passenger transport segment is comprised of approximately 500 vessels, including a heterogeneous mix of small ferries, speed boats and large cruise ships. The main share of fuel use and emissions in the passenger segment stem from about 300 relatively small vessels (1000-25000 GT[7]). Most of these smaller passenger vessels are relatively old (29 years on average) and use diesel-

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

[7] GT is an abbreviation for gross tonnage, which is a measure of a vessel's overall internal volume. The world's largest ships (supertankers, container and cruise ships) are in the size of 200000-300000 GT.

mechanic propulsion. Only a few have diesel-electric configurations, and these are the only ones with technical potential to be retrofitted with BE.

We will focus our analysis on ferries, which according to the NFD maritime strategy is a key sub-segment for initial implementation of LoZeC technologies (MTIF, 2015). It is expected that the use of LoZeC in ferries will result in technological development that will lower the cost of use of LoZeC in shipping in general (MTIF, 2015).

Regarding the *task environment*, an important characteristic of this sub-segment is that the vessels to a large extent are owned by national, regional and local public administrations that use development contracts and tenders when purchasing new ferries and awarding operation contracts for specific routes. With regard to the former, "innovative procurement" was introduced in 2010,[8] and the use of this policy tool, first by the Norwegian Road Administration (Interview, 10.4.2018) and then by several county municipalities, has been instrumental in articulating demand for LoZeC technologies in the passenger transport segment (market formation). Innovative procurement was, for example, used for the first battery-electric car ferry Ampere and is currently used for the first hydrogen car ferry as well as a fast ferry route in the region of Trøndelag. Regarding calls for tenders to operate specific ferry routes, the significant competition between shipping lines has led to advantages for zero-emission solutions such as BE over low-emission solutions: winners of contracts are not simply living up to minimum environmental requirements but are in some cases going far below the set limits to maximize their chances of success (market formation).

Another defining characteristic of the task environment is the short distances of many ferry routes. This has made this segment an important pioneering market for BE solutions in general and for full-BE in particular (market formation). However, the short layover time for many ferry routes is a challenge regarding charging. This has incentivized development efforts aimed at improving charging infrastructure technologies (influence on the direction of search) and experimentation with multiple technological options (entrepreneurial experimentation). To exemplify, the development of Ampere contributed to knowledge development and problem solving related to charging solutions and onshore power supply and Ampere was built with two different charging systems and uses onshore battery packages rather than grid upgrades (Kirkengen, 2017). However, the high frequency of many ferry routes makes testing difficult (entrepreneurial experimentation).

Finally, electrification of ferries is linked to investment needs in complementary technology and infrastructure (resource mobilization). A report assessing electricity grid and power sector capacities suggests that the grid capacity is insufficient and that the electrification of 52 ferry services would require approximately 900 MNOK of grid investments (DNV GL, 2015). On certain routes, both length and infrastructure investment requirements constitute a barrier to BE implementation (resource mobilization).

Regarding the *institutional environment,* public development contracts by the Norwegian Public Roads Administration have led to the development of important complementary assets, such as different forms of energy control systems and control automation, among firms with previous experience in aviation, train and maritime transport, specifically in relation to electrification of ferries (knowledge

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[8] "Innovative procurement" was launched in Norway in 2010 and has been used on a broad variety of procurements by different public administrations or agencies. One of the aims of the instrument is to contribute to reduced emissions. http://innovativeanskaffelser.no/om-oss/

development). These contracts have in some cases also explicitly created room for documentation, tests and modifications of the technologies among the shipyards and other TIS actors (entrepreneurial experimentation). The increasing importance attributed to reducing noise and emissions, in particular in sensitive environments such as fjords and urban areas, has made electrification a more attractive solution vis-à-vis low-emission alternatives (market formation) and has also provided incentives for shipping lines to engage in tests of battery electric solutions (entrepreneurial experimentation). However, existing regulations limit the space for experimentation, 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. Another challenge confronting BE in the passenger segment is that optimal technical system configuration on vessels would require variable charging times that would result in fixed ferry routes having to be changed, and even made flexible (legitimacy).

4.2.2 The offshore supply segment

The Norwegian offshore supply fleet is the second largest in the world and consists of around 600 vessels (Norwegian Ship-owners Association, 2015) which are used in different applications in all phases of petroleum activities such as seismic surveys, supply, anchor handling and subsea operations. Most vessels in this segment are in the range 3.500 – 5.500 dwt[9] (DNV GL, 2016) and are tailor-made according to the operational profile of the vessels. In 2013, the average vessel age was about 12 years.

In this paper, we limit the focus to platform supply vessels (PSVs), which deliver necessary supplies to the excavation and construction units located in the North Sea. This is the largest sub-segment and the one with most use of alternative fuels, and the majority of the PSVs built after 2005 have diesel electric configurations. Most of the PSVs operating in Norwegian waters are owned by Norwegian companies, or international firms with Norwegian subsidiaries, and the ship owners vary in size operating from 5-10 and up to 150 vessels. Some of these ship owners have been frontrunners in the testing and implementation of alternative fuel technologies. The first PSV using LNG was built in 2003, while fuel cells was installed and tested on one vessel in 2009, and the first battery installation happened in 2012.

Regarding the *task environment*, adding an electric battery to the conventional setup (i.e. a hybrid solution), could provide a number of advantages in relation to the vessels operational tasks (cf. Lindstad et al., 2017). PSVs typically spend a lot of time at zero or low speed,[10] as they are often in a standby mode nearby an oil platform either loading/unloading cargo waiting to do so (DNV GL, 2016). These operational tasks need to be performed with high reliability at nearly any sea state which is why PSVs vessels are equipped with advanced, computer-controlled dynamic positioning (DP) systems (DP). The DP system automatically maintains the vessel's position using its own propellers and thrusters, and with multiple combustion engines which must run when vessels are in close proximity of O&G installations (even at calm sea) to handle variations in waves and wind and avoid critical events to happen. In these operational modes, having a battery solution might save around 30 % of fuel usage in DP/standby-operations (Interview, 7.11.2017) and can also reduce maintenance costs compared with conventional combustion engines.[11] The current high fuel usage when

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[9] 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, passengers.
[10] Approximately 35 % as estimated by Lindstad and Eskeland (2016).
[11] A battery could compensate for load fluctuations, enabling the combustion engine to run at a more optimized load and avoid running it at very low loads. This reduces fuel consumption. In addition, batteries engage

loading/unloading cargo in DP mode thus provides incentives for development of less fuel intensive solutions (influence on the direction of search) as well as incentives for ship owners to test and invest in new technologies (entrepreneurial experimentation, market formation). Some shipowners are explicitly committed to continously developing more environmental solutions and therefore are open to testing new fuel solutions (entrepreneurial experimentation).

However, although the first BE ships have proven that having a battery electric system does lead to lower operational expenditure (e.g. Lindstad & Eskeland, 2016; DNV GL, 2016) and better maneuverability of the ships (Interviews), the installation costs are still too high for them to be fully competitive (market formation) and so far, all battery installations in PSVs have been dependent investment support from Enova or the NOx-fund.

The offshore supply segment consists of privately owned companies with several vessels, which have the financial resources and financial flexibility needed to invest in BE solutions (resource mobilization). However, the incentives for them to do so are limited. In the offshore supply 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 (RFT) in which ship owners are invited to submit their offer based on specific tender criteria. These criteria usually do not include specific requirements related to fuel usage and emissions that ship owners must meet. Indeed, the oil companies normally pay all fuel costs (DNV GL, 2016), which means that there are no direct economic incentives for ship owners to invest in or test emission reducing technologies (market formation, influence on the direction of search). However, in June 2017 the dominating oil company in Norwegian waters (Statoil) for the first time required batteries to be installed in all seven contracts it awarded. This resulted in seven new vessels with BE solutions and sent an important signal to ship owners interested in receiving contracts with Statoil in the future (market formation).

The PSVs in Norwegian waters operate out of dedicated oil and gas supply bases and harbors in larger cities (e.g. Bergen) along the coast. However, the PSV companies operate in a global industry, which implies that a PSV’s next contract might be in far-away locations such as Brazil, the Gulf of Mexico or Australia where other conditions apply. This has a negative influence on market formation for BE, since PSVs cannot be equipped with a battery-electric system only but is dependent on other energy sources such as conventional fuel.

Regarding the *institutional environment*, the increasing attention to reducing emissions for offshore vessels has highlighted the need to develop BE solutions (influence on the direction of search). The Norwegian government has also implemented a number of policy instruments to stimulate such developments. Most notably, it provides funds for research and development of BE solutions and fuel reductions for offshore vessels through ENOVA and other public programs (resource mobilisation). Indeed, all early tests of alternative fuels have been the result of publicly funded research projects involving close cooperation between a few dedicated ship owners, research organizations and technology developers (knowledge development & diffusion, entrepreneurial experimentation). In addition, changes have been made in the regulatory framework to the benefit of BE. 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), which not only gives

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instantly and can provide peak power required by the DP system and make it possible for a PSV in DP mode to have only one combustion engine running at low loads instead of two, since the battery can act as reserve generator.

incentives to adopt BE (market formation), but also sends an important signal that BE solutions are safe (legitimation).

4.2.3 The fishing segment

The Norwegian fishing fleet basically covers two main sub-market segments: the coastal fleet and the sea-going fleet. The coastal fleet comprises roughly 3,000 relatively small vessels (9-15 meters long) with an average age of approximately 30 years. It is dominated by single-vessel owners. The sea-going fleet consists of approximately 2,000 vessels.

Recent estimates suggest that emissions from the coastal fishing fleet part of the fishing market segment can be halved using hybrid BE solutions. In the fishing segment as a whole, only a handful of vessels have installed BE-systems, but several vessels with hybrid diesel-electric systems and/or mechanic and BE are in the design or building phase as of early 2018.

Regarding *the task environment*, the conditions in the two sub-segments are quite different. From a technical and operations point of view, the coastal fishing fleet is well suited for BE solutions (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 such as hauling lines and nets or freezing the captured fish. However, although BE solutions can reduce operational (fuel) costs and increase profitability, these advantages are in reality limited due to the fact that the coastal fishing fleet receives a total of 430 MNOK per year (approximately 50 million Euro) in the form of a refund of the mineral oil tax on fossil fuels.[12] As a consequence, “there are no incentives for environmental technology in fishing” (technology supplier representative speaking at a 2017 event) (market formation, influence on the direction of search). Moreover, the upfront investments in vessel upgrading/retrofitting are considered relatively large, which is a limiting factor for small ship owners (resource mobilization). Among the pioneering fish vessel owners that have invested (or are investing) in vessels with BE, key motivations appear to be to create a better working environment for the fishing staff (reduction of noise, smoke and vibrations) and to save fuel.

In contrast, the sea-going fishing fleet differs from the coastal fishing fleet in certain key respects. First, ship owners have stronger incentives to reduce fuel expenses, since the sea-going fleet does not get a refund on the mineral oil tax (market formation, influence on the direction of search). In addition, ship owners within this sub-segment often operate several vessels and, therefore, potentially control or have better access to financial resources that can be invested in new technology such as BE (resource mobilization). However, the sea-going fleet is not allowed to fish within 12 nautical miles of the coast due to industry regulations, which results in long sailing distances to far-off fishing sites in the Barents Sea and the Northern Atlantic Ocean. This means that vessels can be out at sea for over a month at a time, implying that a large-size battery that requires frequent loading from other sources than an onboard generator is currently not an option (market formation).

Regarding *the institutional environment*, a common challenge is that consumers seem to pay limited attention to environmental issues, which further reduces the fishing fleet’s incentives to adopt BE technology (market formation). In the coastal fleet, some ship owners who have invested in BE

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[12] In the maritime sectors roadmap to the Government-appointed council on “green competitiveness”, it is suggested that this refund, which was introduced in 1988, should be replaced with a subsidy for investing in LoZeC solutions.

nevertheless do this at least in part to contribute to more environmentally-friendly fishing (market formation). In contrast, the sea-going fleet seems to have its mind set on rationalizing the fleet (reducing the number of vessels) and improving existing solutions rather than substituting fossil fuels with other energy solutions, as evidenced by the recent *Climate Roadmap for the Norwegian Fishing Fleet* (Thompson, 2017), which was commissioned by the sea-going fishing fleet association Fiskebåt (market formation).

4.2.4 Common aspects

In addition to the segment-specific characteristics identified above, TIS functions are also influenced by some mechanisms that are common to all segments.

Regarding the *task environment*, the Norwegian MSS is a frontrunner in terms of developing advanced maritime vessels for several purposes. Therefore, positive externalities are already in place in the form of specialized developers and suppliers of (power) electronics for maritime and offshore applications. This value system is now being supplemented by the entry of specialized BE actors (e.g. ZEM, Corvus and PBES). According to reports providing a background for R&D priorities of the Research Council of Norway (Maritim21, 2016; RCN, 2016) , there is also a potential to link up to ongoing R&D on batteries. Moreover, the feasibility of introducing electrification has been generally enhanced by weight-reducing innovations in boat design, including single-body constructions and low-weight materials such as carbon fiber (market formation).

Regarding the *institutional environment*, the understanding of Norway as a global leader in the maritime industry has created legitimacy for taking up the challenge of leading the maritime industry towards a LoZeC future (legitimation). Indeed, several reports highlight expectations of combined value creation and domestic emission reductions in the MSS (e.g. Maritim21, 2016; Mellbye et al., 2016) . Investments in BE for newbuilds and retrofits in all segments as well as for onshore infrastructure is supported through investment subsidies from Enova and the NO_x fund (market formation). Actors in all market segments also have access to funding for R&D and pilot/demo support from the Research Council, Innovation Norway and Enova (via the Pilot-E program and the Green Coastal Shipping Program) (resource mobilization). Finally, a general characteristic of the MSS is a culture of openness with regards to sharing knowledge and user experience. As stated by the Board Director of one of Norway's leading shipyards, "one of the characteristics of the maritime sector is that it has always been very open in terms of sharing information and knowledge, with close relationships between customers and suppliers; this is beneficial with current challenges in mind" (Kjersti Kleven, Enovakonferansen 2016). This suggests that knowledge diffusion across market segments has fertile conditions.

4.3 Discussion

The analysis above shows that the passenger transport, offshore supply and fishing segments within the maritime shipping sector differ in important ways in terms of their task and institutional environments (Scott, 1992). It also shows that this results in differences in susceptibility for different parts of the maritime transport regime as well as in different influences on functionality of the BE-TIS. We will discuss both these results in turn.

4.3.1 Segment differences regarding task and institutional environments

Notable differences regarding *task environments* include for example nature of demand for transportation services, articulation of demand for more sustainable transport. Whereas passenger vessel operators provide a service to public buyers, offshore supply vessels provide services to O&G operators or other firms within that industry. By contrast fishing vessels operate independently and there appears to be little articulation of demand for more environmentally friendly fishing from buyers of fish, whether wholesalers or end customers. Another difference is the types of ship owners and their characteristics. Both passenger and offshore supply ship owners typically operate fleets of many vessels. This provides some flexibility for ship owners, however whereas this flexibility is paramount to offshore supply, most passenger vessels operate fixed routes on lengthy contracts. Many fishing vessel owners typically only have one boat on which they also spend most of their work hours. The scope of geographical market areas also differs considerably, with the offshore supply segment being highly international, whereas the passenger and fishing segments are mainly local/regional.

It is also important to take note of the considerable (and rather mundane) differences in terms of vessel types (size, operations etc.) and status of different conventional drivetrains. This results in important differences between market segments in terms of the feasibility of implementing BE via newbuild or retrofit. In both offshore supply and passenger, vessels are sufficiently large in terms of volume and storage capacity to retrofit with hybrid-BE solutions. However, whereas most offshore supply vessels are diesel-electric (enabler for BE retrofit), a number of passenger vessels are diesel-mechanic, making them less appropriate for BE retrofit. Fishing vessels, by contrast, are generally much smaller, and have limited space due to both having a lot of equipment onboard but also to ship owners primarily wanting to save space for that which generates profit: fish.

We also find important differences between market segments in terms of the influence of the *institutional environment.* To give but a few examples here, the segments differ considerably in terms of legitimacy for BE (or other LoZeCs), and especially in market demand and demand articulation. Market growth for BE is definitively strongest in the passenger market segment were high policy-set emission reduction targets at various scales (national, regional) have resulted in public procurement instruments that have prioritized emission reductions over cost.

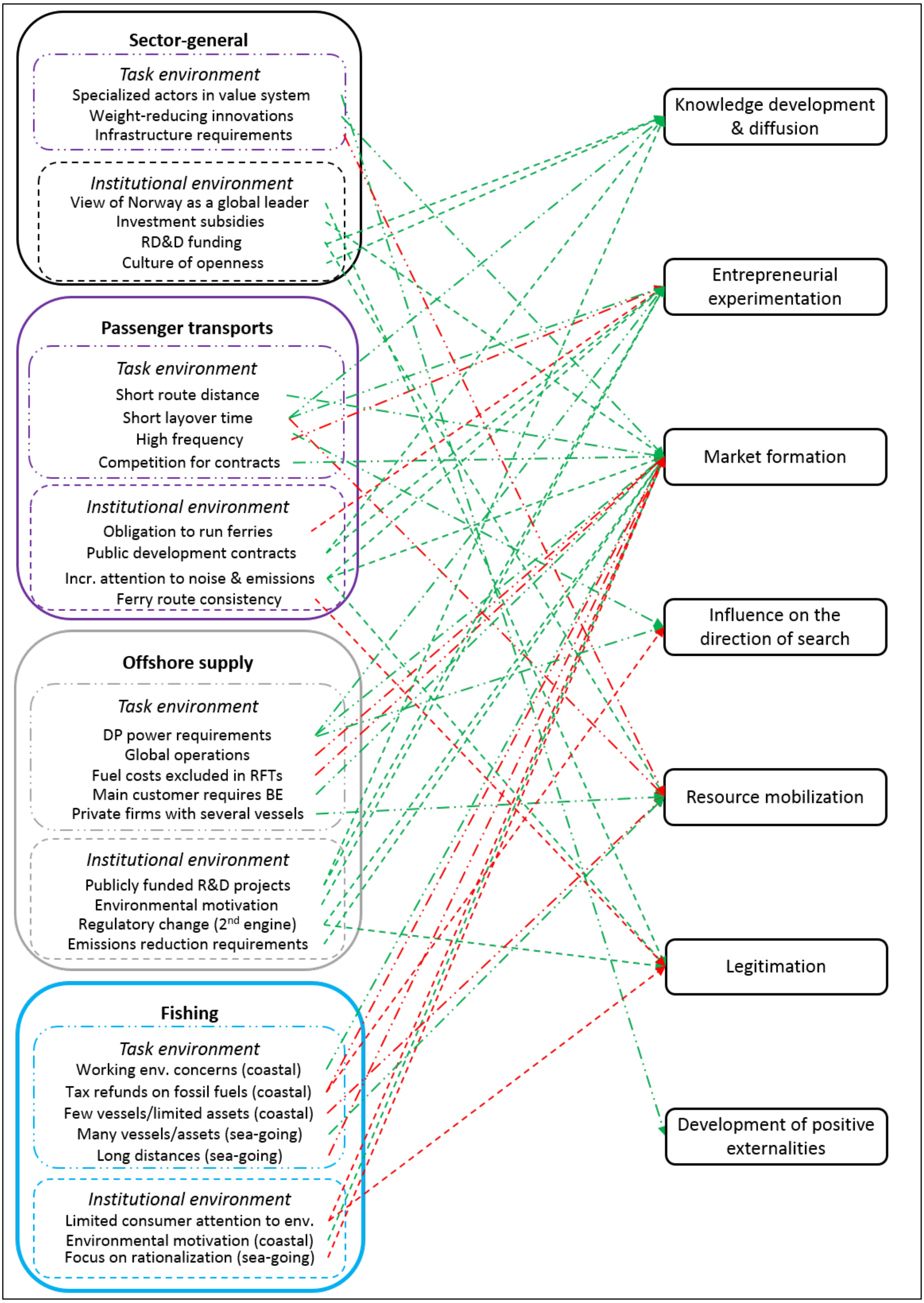
Whereas it was beyond the scope of this article to address the broader institutional and political context, there are clearly considerable differences between the segments in terms of e.g. the passenger and fishing segments being heavily influenced by transport and fishing policies respectively.

4.3.2 Segment differences regarding influence on TIS functionality

The segmented functions analysis is summarized in Figure 2. Considering the focus on market segments, it is perhaps not surprising that the analysis revealed many mechanisms influencing the *market formation* function. To summarize, market formation is strong and positive for the passenger market segment, emerging and seemingly positive for offshore supply, and emerging but unclear in terms of traction for the fishing segment. The strength of the market formation function in the passenger market segment clearly has positive influences on a number of other TIS functions, also for other market segments. *Entrepreneurial experimentation* began in the passenger and offshore supply segments. Interestingly, within offshore supply the first movers (e.g. Eidesvik) were under no regulatory pressure or customer-demand to reduce fuel consumption and emissions but appear to have been driven by firm-internal (strategic) aspirations of operating more sustainably. This (the lack of external incentives) changed when the O&G operator Statoil in 2017 demanded installation of BE-solutions on offshore supply vessels that would be awarded long-term contracts for operations on the Norwegian continental shelf. In the passenger segment, public procurement in the form of development contracts with strict environmental targets were key to the first attempts at implementing BE solutions. In the fishing segment, entrepreneurial experimentation began with a few first movers who were involved in R&D projects where vessels functioned as pilot and demonstration objects. The first hybrid-BE fishing vessel *Karoline* was built under a private-publicly funded R&D project that involved R&D institute SINTEF, Siemens (maritime solutions headquartered from Norway) and Selfa Arctic (a shipbuilder and early mover within battery assembly). Also, most experimental and early-phase development projects have been undertaken within the frames of dedicated innovation and R&D programs, such as the Green coastal shipping program, the maritime Pilot-E program, and within the cluster organization NCE Maritime Cleantech. Within these programs we find several projects involving actors in (especially) the passenger and offshore supply segments, but very few in the fishing market segment.

Although actors within all segments have equal access to financial support (e.g. from Enova and the NOx-fund) for the additional costs associated with new technologies, *resource mobilization* clearly differs between market segments, depending in large on task environments. Whereas shipowners in offshore O&G and passenger can take on substantial investments on their balance sheets, fishing shipowners are less well positioned in that regard. Also, whereas physical infrastructure for charging batteries is being partly or fully funded by various public actors for offshore supply and passenger, it is highly unclear how infrastructure will be developed for the thousands of fishing vessels that operate out of approx. 550 smaller fishing ports. In their report on “electrification of the fishing sector” Siemens et al. (2017) suggest that the development of infrastructure at first should be focused on the ports that have most calls. Whereas this would be logical from a cost-benefit point of view, it would also result in a highly spatially differentiated build-up of infrastructure to enable technological change in the fishing market segment. Another challenge for the fishing segment is that most are small organizations with limited administrative capacity, and where the ship owner primarily works at sea. According to a shipowner who recently ordered a hybrid-BE vessel, one of the biggest hurdles was understanding guidelines and rules and finding the time to apply for support from Enova.

Legitimation clearly appears to be strongest within the passenger market segment, where decisions in the national Parliament and also in country municipalities that have set GHG emission reduction targets in line with (or higher than) the Paris agreement have been decisive in stimulating market formation. In offshore supply, the legitimacy of BE or other LoZeCs for transport services appear less clear. The Norwegian O&G sector has come under increasing pressure to reduce emissions from extraction on the Norwegian continental shelf, and its legitimacy in more general terms is being questioned. The recent oil-crisis resulted in O&G operators that previously had few incentives to minimize costs (due to high-very high oil prices) to also look at reducing costs for offshore supply services, including fuel use. In the fishing segment, there does not be a very strong incentive to reduce emissions. However, BE solutions appear to be increasingly endogenously legitimized because of user experiences. These (positive) experiences include aspects such as reduced noise, smoke and vibrations on vessels, thereby improving working conditions for crew members (and experiences for passengers). User experiences also include cost savings due to reduced fuel consumption and less need for maintenance.



N.B. Red = negative influence. Green = positive influence. Line dashes differ between task and institutional environment.

Figure 2: Functional analysis with focus on influences from market segment-differentiated sectoral context

5. Conclusions

This article set out to shed light on the neglected topic of market segment characteristics within established sectors for sustainability transition processes. It is fair to say that within the sustainability transitions literature, there is a tendency to view established sectors or industries as relatively homogeneous (Berggren et al., 2015; Hansen and Coenen, 2015; Steen and Weaver, 2017), thereby overlooking important differences within socio-technical regimes with regards to susceptibility to change. Using the Norwegian maritime shipping sector (MSS)and three different market segments (passenger, offshore supply, fishing) within the MSS as our case, our analysis highlighted the value of a more differentiated view on established sectors and the importance of an extended conceptualization of regimes that explicitly recognizes the (potential) presence of various sub-system structures or market segments (Dewald and Truffer, 2011). Also, whereas current MLP studies tend to emphasize the institutional dimension of regimes, our proposed extended regime concept pays attention to both (differing) task and institutional environments (Scott, 1992) within regimes.

Our analysis revealed several distinct differences between market segments within the MSS. Differences in task environments include sailing routes, operational profiles, market demand and potential to invest in more environmentally friendly energy solutions such as battery-electric (BE) systems. Whereas our focus was on the task environment, we also highlighted differences in institutional environments, such as the role of public policy and procurement practices for market formation processes in the passenger segment and hinted at important differences in broader context structures.

These market segment characteristics, therefore, have crucial influences on TIS functionality. Although we identified several sector-general influences on TIS functionality, attention to market segment characteristics highlighted important differences, such as the very important role of the passenger segment for market formation processes for the BE-TIS, whereas the fishing segment appears to be confronted by several blocking mechanisms such as limited incentives to change due to e.g. lack of consumer attention to environmentally-friendly fishing and current fossil fuel subsidies. However, the positive role of the passenger and offshore supply segment for TIS functionality in terms of strengthening knowledge development and diffusion, entrepreneurial experimentation and market formation, could potentially be leveraged to address blocking mechanisms and segment-specific weaknesses in fishing. Experimentation and knowledge development within specific market segment appear to be generating spillover effects and positive externalities that other market segments (and actors within those) can benefit from. Nonetheless, it follows from the analysis that policy (mix) recommendations need to be attuned to the traits of different market segments. For example, emission restrictions in the offshore supply segment need to be extended beyond the corporate strategy of one O&G operator, whereas the indirect fossil fuel subsidy in fishing via the mineral oil tax refund should be removed. This does not preclude the relevance of certain sector-general recommendations. One such recommendation is the introduction of a CO2-fund for the maritime sector, that could be used to offer investment support also to those market segments (such as fishing) were firm financial resources are limited.

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