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Abstract

Recent literature in sustainability transition studies has suggested that established industries may provide resources for innovation in low-carbon technologies. This literature, however, has this far not explained why such resource redeployment takes place. Literature in evolutionary economic geography and management studies, however, have discussed such interactions through the notion of relatedness as an underlying factor. Drawing on these literatures we develop an integrated framework for the analysis of multidimensional relatedness between innovation systems in the context of sustainability transitions. Using semi-structured interviews, we study the technological, institutional and network relatedness between the oil and gas industry and the offshore wind power technology in Norway. Our results show that despite the high relatedness in offshore technologies, low relatedness in terms of institutions has challenged the resource redeployment from the Norwegian oil and gas industry to offshore wind power. We thus suggest that relatedness, understood in multiple structural dimensions, can help to understand why resource redeployment from established industries to technological innovation systems may, or may not, take place.

Keywords: multidimensional relatedness, innovation systems, sustainability transitions, oil and gas industry, offshore wind power

JEL codes: O33, Q55

1 Introduction

Sustainability transition studies are concerned with fundamental transformations in key socio-technical systems such as energy, transport or food (Markard et al., 2012). Accumulating evidence of rapid advancement in climate change and other environmental challenges show that such transitions need to be accelerated to avoid dangerous tipping points in the earth system (EC, 2016; Steffen et al., 2018). Low-carbon technologies play a key role in sustainability transitions. Such niche-technologies are often understood to develop outside of the mainstream markets and sectors (Kemp et al., 1998). Recent contributions have nevertheless demonstrated that established sectors may support the formation and growth of low-carbon technologies (Berggren et al., 2015; Hanson, 2018; Mäkitie et al., 2018; Leitch et al., 2019), and indeed, thus accelerate sustainability transitions e.g. through the utilization of their vast resource bases (Fagerberg, 2018; Geels, 2018).[1]

However, there is still limited knowledge about which factors enable or hinder such flows of resources from established sectors to low-carbon technologies. This constitutes an important gap in the literature regarding sustainability transitions. Also, to comprehend how policy can induce increased resource flows from established sectors, we need a better understanding of the conditions that incentivize firms in established sector to redeploy resources to emerging low-carbon technologies. In this paper we explore this issue by drawing on and integrating three distinct academic literatures: evolutionary economic geography (EEG), management studies and innovation studies especially in terms of (technological) innovation systems.

EEG has argued that firms and other actors in a region diversify by typically redeploying resources into technologically related activities which at more aggregate level explains countries' and regions' industrial path dependence (Hidalgo et al., 2007; Boschma & Frenken, 2011). The core proposition thus is that the degree of technological relatedness determines the scope of the challenge that regions and countries face when moving from one industry to another (Kogler, 2015). Recent research, however, argues that also other dimensions of relatedness—such as market linkages and institutional arrangements—may also be important for resource redeployment (Tanner, 2014; Binz et al., 2016; Content & Frenken, 2016). While multiple forms of relatedness are acknowledged, there is so far limited research on this topic (Boschma, 2017).

Management studies has, however, since long acknowledged such a broader understanding of relatedness which includes multiple dimensions, such as products (Magnusson et al., 2005; Tanriverdi & Venkatraman, 2005), markets (Nayyar & Kazanjian, 1993), manufacturing and assembly (Carroll et al., 1996; Magnusson et al., 2005), business management (Prahalad & Bettis, 1986; Markides & Williamson, 1996) and marketing and retail (Carroll et al., 1996). We build on this multidimensional perspective on relatedness to analyze how it may encourage the engagement of established sectors in low-carbon technologies, and lead to resource redeployment.

Recent research on technological innovation systems (TIS) has started investigating how a TIS interacts with its context, i.e. how other technologies, sectors, politics, geographies etc. may influence the TIS, and vice versa (Andersen, 2014; Bergek et al., 2015; Binz et al., 2016). We thus build on these advances that explore the interaction between TISs and established sectors (Wirth & Markard, 2011; Hanson, 2018). We conceptualize emerging low-carbon technologies as TISs and established sectors as sectoral

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[1] Note that we use the terms sector and industry interchangeably.

innovation systems (Malerba, 2002; Markard & Truffer, 2008). While recent empirical studies demonstrate that resource flows from an established sector to an emerging TIS can take place (Stephan et al., 2017; Hanson, 2018; Mäkitie et al., 2018; Leitch et al., 2019), the underlying drivers of such resource redeployment have not been discussed. We suggest that the conceptualization of (multidimensional) relatedness between innovation systems can help to better understand such phenomena.

Building on the above mentioned literatures, we articulate an integrated analytical framework where multiple dimensions of relatedness between innovation systems—here a technological and a sectoral—are conceptualized in terms of the relatedness between the structural elements of innovation systems, including institutions, technology, networks and actors (Jacobsson & Bergek, 2011). We suggest that the overall relatedness between innovation systems can encourage or obstruct the resource redeployment of established industry actors in emerging low-carbon technologies. Crucially, different dimensions of relatedness can support and constrain each other in terms of how they may influence resource redeployment. Hence, the employment of a multidimensional perspective enables the identification of potential variation in the degree of relatedness across structural elements. We also argue that the multidimensional relatedness between innovation systems can result in challenges for managers and policymakers that currently go underappreciated in the study of sustainability transitions and innovation systems.

We apply this framework to a case study of the relatedness between the established oil and gas (O&G) sector and the emerging offshore wind power (OWP) TIS in Norway. These innovation systems have previously been shown to be technologically related (Steen & Hansen, 2014; Hansen & Steen, 2015). However, in a previous study we found indications that despite the technological relatedness, some institutional factors such as firm identities, visions, and collaboration patterns were limiting the extent of resource redeployment (Mäkitie et al., 2018). The case thus provides a unique opportunity for studying the relationship between, on the one hand, multidimensional relatedness and, on the other, resource redeployment across innovation systems.

With this exercise we make three main contributions to the study of sustainability transitions and innovation systems.

First, empirically we give a rich account of how multidimensional relatedness between innovation systems may encourage or hinder redeployment of resources. Second, drawing on management studies and EEG we propose and qualify an integrated framework that accounts for multiple dimensions of relatedness between innovation systems. In particular, the interplay between technological and non-technological aspects of relatedness is highlighted. Third, this multidimensional framework also contributes to the TIS-context discussion, by making progress in understanding which conditions encourage or hinder the redeployment of resources from an established sector to a TIS.

We begin our paper in section two by reviewing the concepts of TIS and relatedness, and bridge these notions to develop our analytical framework. In section three, we present our case study and methods. Section four presents our analysis of relatedness between O&G and OWP in Norway. Section five discusses our results and section six concludes the paper.

2 Innovation systems and relatedness

2.1 Technological innovation systems and context

The technological innovation system (TIS) framework has evolved as a powerful tool to understand the emergence of novel technologies. In a TIS perspective, system dynamics and performance result from the interaction of *"a set of elements, including technologies, actors, networks and institutions, which actively contribute to the development of a particular technology field"* (Bergek et al., 2015, p. 52). The analysis is therefore centred on the assessment of key functions of a system to develop, diffuse and utilize a new technology, such as knowledge development and diffusion, market creation, and entrepreneurial experimentation within the TIS (Hekkert et al., 2007; Bergek et al., 2008).

Such system delineations usually exclude in-depth analysis of external influences, such as other technologies, sectors and politics. This has been argued to limit the usefulness of TIS to explain socio-technical transitions (Smith & Raven, 2012; Markard et al., 2015). This critique has sparked attempts to conceptualise and empirically analyse TIS context dimensions and patterns of interaction (Wirth & Markard, 2011; Bergek et al., 2015; Haley, 2015; Stephan et al., 2017).

Established industries have been identified as one important context dimension for the development of TISs, because interaction with established industries can enable the TIS to access numerous resources of sectors (Markard, 2018). Indeed, established industries can function as a platform for the development in an early phase of new TISs by providing structural elements, such as actors and networks, that later develop into TIS specific structures and enable the flow of resources from established industries to TIS (Hanson, 2018; Leitch et al., 2019). Such interactions between TISs and sectors have been conceptualized as structural couplings, which represent situations where a TIS and a sector share elements (such as actors, institutions, technology etc.) (Bergek et al., 2015). This is a useful starting point for analyzing interaction between innovation systems. However, structural couplings is limited to acknowledging the existence and the potential influence of such interactions on a TIS but does not explain *why* a specific established industry and a TIS interact. From the perspective of resource flows between innovation systems, it is important to understand why and how such interactions emerge, and which factors may hamper them from materializing. Further conceptual development is therefore needed.

2.2 Relatedness

Literature on management and EEG have argued that relatedness may explain why interaction between certain industries takes place. Relatedness refers to the degree of similarity between industries. Relatedness is likely to increase the interaction between industries as firms can form synergies and redeploy resources (e.g. knowledge regarding markets and technologies) between similar markets (Markides & Williamson, 1996; Helfat & Lieberman, 2002; Folta et al., 2016). Similar ideas on relatedness are employed in EEG where relatedness is considered an important underlying factor of diversification and resource flows within regions (Kogler, 2015; Boschma, 2017).

While the literature in EEG has often focused on studying relatedness in terms of technologies and products, it should be noted that relatedness between industries exists in several dimensions (Tanner, 2014; Binz et al., 2016). For instance the role of institutions has been highlighted (Boschma & Frenken, 2011). The literature in management studies has also discussed relatedness in terms of products

(Magnusson et al., 2005; Tanriverdi & Venkatraman, 2005), markets (Nayyar & Kazanjian, 1993), manufacturing and assembly (Carroll et al., 1996; Magnusson et al., 2005), strategic management (Prahalad & Bettis, 1986; Markides & Williamson, 1996) and marketing and retail (Carroll et al., 1996). Therefore, it is necessary to account for multidimensional relatedness as an underlying factor of diversification in order to understand why firms from established sectors would redeploy resources to certain kind of emerging technologies (Markides & Williamson, 1996; Piscitello, 2000; Bergek, 2014; Boschma, 2017). This is highly relevant in the context of sustainability transitions where the core markets of established sectors may face an eventual decline and the firms may therefore seek alternative uses for their existing resources (Anand & Singh, 1997; Anand et al., 2016).

2.3 Analytical framework: Innovation system relatedness and resource redeployment

Building on and integrating the reviewed literature, we outline a framework for analysing the relationship between multidimensional relatedness and resource redeployment across innovation systems.[2]

Figure 1 illustrates relatedness between two innovation systems, in our case between a sector and a TIS. We consider TISs and sectors as structurally similar socio-technical systems of different degree of structuration and maturity (Markard & Truffer, 2008). They consist of actors, networks, institutions and technology (i.e. the system components) whose properties and interactions influence innovation processes (e.g. knowledge development, resource mobilization and market formation) within the systems (Hekkert et al., 2007). Taking multidimensionality of relatedness into account, we suggest that relatedness can be seen according to the structural elements of innovation systems. We see resource redeployment as a process enacted by actors (e.g. firms), but contingent upon the relatedness between the innovation system elements (networks, institutions and technology) (Binz et al., 2016). In other words, we argue that relatedness in the structural dimensions of innovation systems enable firms and other actors from one innovation system to apply their capabilities in another innovation system, which consequently may lead to formation of structural couplings (i.e. shared structural components). It is important to note that this does not take place automatically, but high relatedness rather provides opportunities for actors to realize resource flows between innovation systems, while low relatedness hinders such interactions. We therefore see relatedness between networks, institutions and technology of two innovation systems to affect the likelihood and ease at which actors can engage in resource redeployment.

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[2] We acknowledge that relatedness is not the only determinant of such processes. For instance, prior literature has argued that environmental factors like market changes (Anand & Singh, 1997; Mäkitie et al., 2019), mindful deviation of firms (Garud & Karnøe, 2001), and spatial proximity may also explain such phenomena (Frenken & Boschma, 2007; Steen & Hansen, 2014).

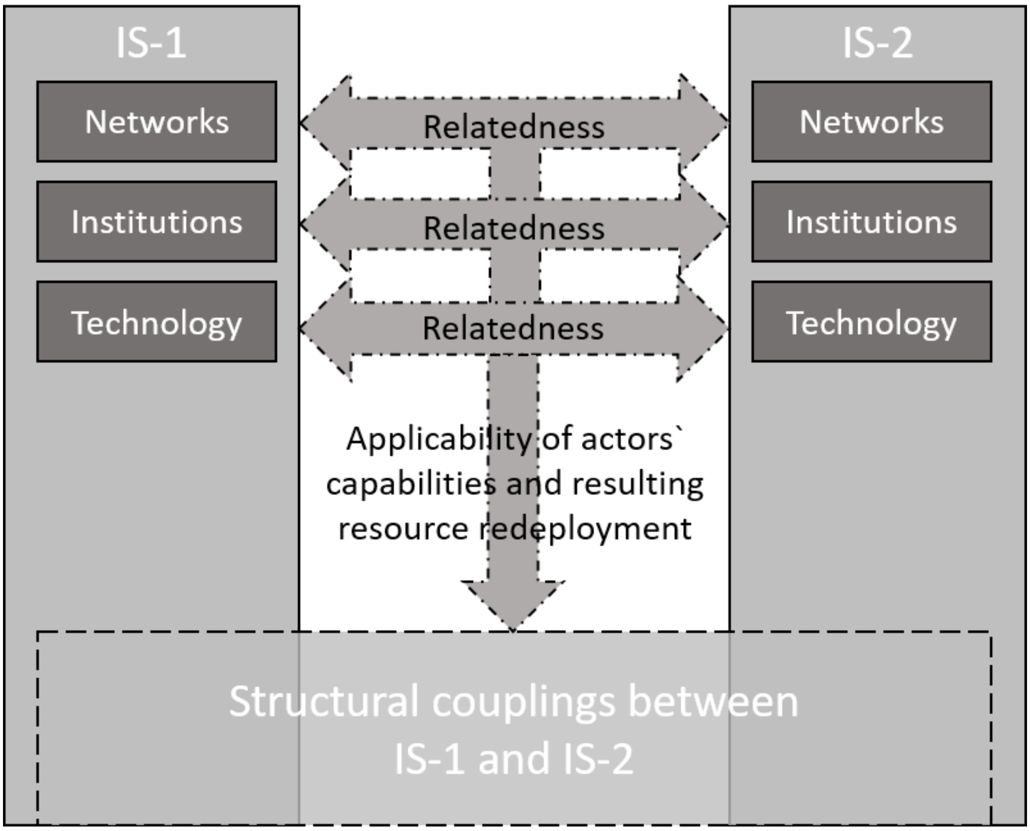

Figure 1: The analytical framework

This implies that our framework puts particular emphasis on the agency of actors in realizing the resource redeployment and the formation of structural couplings. Such a perspective is compatible with the understanding of innovation system performance (i.e. functions) resulting from the interaction between actors within a particular structural setting (Markard & Truffer, 2008). Our framework emphasizes firms as key actors in carrying out resource redeployment and establishing structural couplings, but it does not exclude other types of actors, such as public authorities, research organizations and individuals. We nevertheless apply the resource-based view of a firm, and see actors operating with a particular set of capabilities and resources (Penrose, 1959), which may help to explain why they enter in certain kind of innovation systems (Helfat & Lieberman, 2002; Benner & Tripsas, 2012). Actor resources refer to the resurces which are controlled by individual actors or firms, and include e.g. know-how, production facilities, patents and customer relations (Barney, 1991). The cost and ease of successfully moving from one innovation system to another is therefore strongly influenced by the applicability of the existing resources of actors, which then is facilitated by the relatedness between innovation systems (Helfat & Eisenhardt, 2004).[3] The resources form the base for the engagement of actors in an innovation system. Capabilities, on the other hand, refer to the strategic and organizational processes, such as product development and strategic decision-making, that coordinate the use of resources (Eisenhardt & Martin, 2000).

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[3] Obviously, firms' ability to change is also a relevant factor (Eisenhardt & Martin, 2000) but this is beyond the scope of this paper.

To sum up, innovation system relatedness can be seen as an important underlying factor for the actors to create resource flows and structural couplings between innovation systems. High degree of relatedness in multiple dimensions (technology, institutions and networks) is likely to enable more actors to engage across innovation systems, and vice versa (see Figure 1). However, high degree of relatedness only along one of the structure dimensions, with low relatedness in others, is likely to reduce the ease at which structural couplings can be formed. We expect that such a multidimensional perspective on relatedness enables a more fine-grained analysis of factors that either facilitate or hamper structural couplings and resource redeployment. Below we define the content of relatedness in terms of innovation system components.

2.3.1 Institutions

We define institutional relatedness as the degree of similarities in institutions. Institutions govern interaction patterns between actors (Edquist & Johnson, 1997). Institutions can be formal and codified entities such as regulations and standards. Moreover, they can be informal and tacit practices in the industry or companies, such as routines and norms. Finally, they can consist of cultural-cognitive conceptions of reality which create meaning, examples being identities, symbols and beliefs (Scott, 2014). Established sectors, for long periods of time, can persist as stable, regulated and thus institutionally mature socio-technical systems (Dolata, 2009). Emerging TISs, on the other hand, rarely enjoy clear and stable supporting institutions, and therefore tend to require the development and alignment of new supporting institutions (Bergek et al., 2008; Fuenfschilling & Truffer, 2016). However, especially in the formative phase of innovation, TISs may also draw on the existing institutions of e.g. other technologies and sectors (Bergek et al., 2015).

2.3.2 Networks

We understand network relatedness as the degree of similarities in customer, collaboration and other networks between innovation systems. For instance, when separate technologies share a similar customer base, an actor can apply its existing networks and knowledge about them in the new system by offering new products to old customers (Nayyar & Kazanjian, 1993). Such benefits in customer needs, preferences and behaviour can encourage diversifiers to enter a new market (Tanriverdi & Venkatraman, 2005). Existing networks can also act as a tool for creating further strategic partnerships, as prior experiences with collaborators can be transferred to the new market (Gulati, 1999). Old networks can also be used for learning. For instance, when seeking to diversify to a technologically related TIS, actors can absorb knowledge through their networks in the established industry. However, such exploitation of similarities in networks can be limited to introducing incremental innovations (March, 1991; Burt, 1992). Moreover, geographic proximity between actors may lead to similarities in social networks (Boschma, 2005).

2.3.3 Technology

Technological relatedness describes the degree of similarities in technological knowledge and artefacts between innovation systems. Technological relatedness is often considered a key aspect of diversification (Granstrand, 1998), and firms often diversify into product-markets which are technologically related to their core market (Breschi et al., 2003). By entering a technologically related field, an actor from an established sector can leverage existing knowledge regarding technologies and production (Carroll et al., 1996; Klepper & Simons, 2000). For instance, diversified firms can seek to introduce technologies from one innovation system into a technologically related one (Tanriverdi & Venkatraman, 2005). While TISs can benefit from technology transfers from related established industries, such resource flows can also lead to rigidities as technologies from other innovation system can eventually prove to be sub-optimal for the demands of the emerging TIS (Leonard ‐ Barton, 1992).

3 Case study and methods

3.1 Case selection: the O&G sector and the OWP TIS in Norway

We chose to investigate the relatedness between OWP and O&G in Norway because it provides an illustrative case study of the relationship between multidimensional relatedness and resource redeployment across an established sector and a TIS (Andersen & Gulbrandsen, 2019). Several firms in the O&G sector have diversified to OWP with the help of e.g. their capabilities in offshore technologies (Hansen & Steen, 2015; Steen & Weaver, 2017). This has contributed to the formation of structural couplings between the two innovation systems, leading to e.g. knowledge development and resource mobilization in the OWP TIS (Steen & Hansen, 2014; Mäkitie et al., 2018). The resources and capabilities related to the design, fabrication and installation of offshore constructions and related technologies form the focus area of the empirical analysis (see Figure 2). The grey box in the centre of the figure points to the "related offshore knowledge" within the market segments of O&G and OWP.

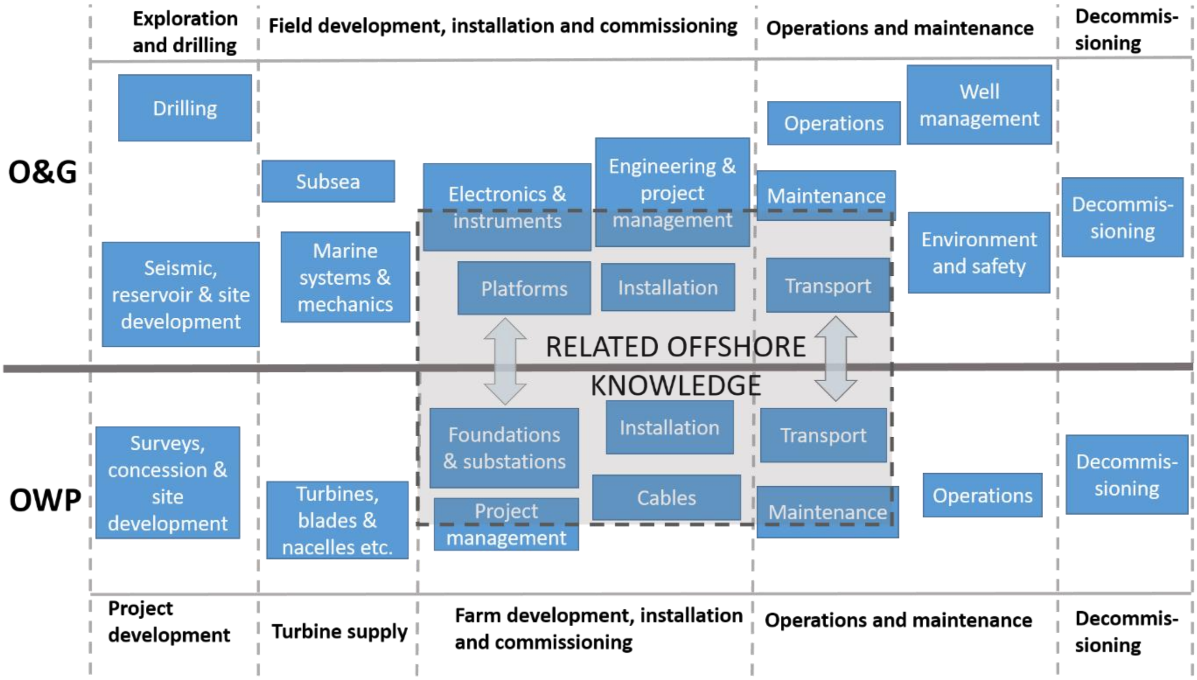

Figure 1: The market segments of oil and gas and offshore wind power (Olesen, 2015; NORWEP, 2017).

About two thirds (more than 100 firms) of OWP firms in Norway are diversifiers from the O&G industry, mostly supplier companies of different kinds (Normann & Hanson, 2015). However, considering the relatively large degree of similarities in the required knowledge related to offshore conditions, the vast size of the O&G supplier industry in Norway (according to Blomgren et al., 2015, about 3000 firms), and the rapid growth of the international OWP market (Wind Europe, 2018), the scale of diversification towards OWP is nevertheless relatively low. What is more, the degree of engagement in diversification has varied over time, with more engagement during the O&G downturns and less during the O&G booms (Mäkitie et al., 2019). This suggests that the O&G industry has sought to use OWP to compensate the fluctuations in demand in the O&G market (Hansen & Steen, 2015). Finally, in many of the companies, the OWP activities sum up to a very small share of the total activities of the firms. In sum, the engagement of O&G industry in OWP has remained small (Hanson & Normann, 2019). While the lack of domestic market of OWP in Norway is one hindrance for further overall engagement (Normann & Hanson, 2018), a key question is nevertheless why we are not witnessing larger resource redeployment between O&G and OWP (Steen & Hansen, 2014). We seek to shed more light in this empirical question by employing the framework developed in section 2.

3.2 Methods

We performed a single-country case study regarding the relatedness between an established sector (O&G) and a TIS (OWP). Our data material consists of 33 interviews with senior managers in O&G industry firms which had diversified to OWP, senior managers in OWP farm operator firms, and other industry experts (see Appendix for more information). We selected to interview diversified firms that (i) historically have lived off supplying the O&G industry, and (ii) that had (partly) succeeded in or were attempting to establish themselves in OWP. This way we could gather insights on the process of diversification, what have been the drivers and challenges, and how firms have managed these challenges. This way we operationalize the degree of relatedness in different dimensions between the two innovation systems, as perceived by the actors. We understand relatedness as a continuum rather as a binary concept. Therefore we use the terms low, medium and high relatedness rather than relatedness and unrelatedness.

We limited our scope to market segments where diversified companies' capabilities and resources were related to designing, fabricating and installing offshore constructions, or components and products used in such processes. Sampling segments where technological relatedness is high between OWP and O&G provides us a unique position to understand how other dimensions of relatedness supports or constrains how technology relatedness can induce resource redeployment. The act of diversification was therefore assumed to include processes of redeployment of "offshore knowledge" (see Figure 2).[4] The diversifiers were identified by (a) examining news items in the Norwegian press and (b) via "snowballing" (i.e. we asked interviewees about their knowledge of other diversifiers). The interviews with operator companies and industry experts were used to triangulate the insights of diversifiers.

The interviews were performed in two periods: during December 2016 - April 2017 and April - September 2018, and lasted on average around an hour. The interviews were conducted either in

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[4] Normann and Hanson (2015) report that more than 80% of diversified O&G industry firms in Norway could transfer their O&G experiences to OWP with no or some changes.

Norwegian or English, and were recorded and transcribed.[5] Further on, the data was coded in NVivo, where we categorized the different perceptions of related and unrelated elements between O&G and OWP. Finally, these codes were analysed in light of our analytical framework consisting of technological, network and institutional relatedness. The following section presents the results of this analysis.

4 The relatedness between oil and gas and offshore wind power

Our empirical analysis showed that high technological relatedness had encouraged firms from the O&G sector to redeploy resources in OWP, but lower relatedness in institutions and networks had limited this process. In Table 2, we summarize our findings of how the actors, and particularly the diversified firms, perceived the relatedness.

Table 1 Overview of empirical analysis ("-" low relatedness; "+" high relatedness)

Structural dimension	Oil and gas	Offshore wind power	Related-ness	Overall relatedness
Institutions	Interactive technology development	Independent technology development	-	**Low**
	R&D financing by operators	R&D self-financing by suppliers	-	
	Open to new technologies	Proven technologies	-	
	Quality over price	Price over quality	-	
	EPC-contracts	Multi-contracting	-	
	A few large and long contracts	Several small and short contracts	-	
	Higher profits	Lower profits	-	
Networks	Few customers and suppliers	Many customers and suppliers	-	**Medium**
	Partly the same networks		+	
	Strong customer offshore competences	Poor customer offshore competences	-	
	Domestic networks	International networks	-	
Technology	Marine engineering		+	**High**
	Power cabling		+	
	Mooring		+	
	Installation and marine operations		+	
	Small batch production of customized technologies	Mass production of standardized technologies	-	
	Broad and large constructions	Slim and tall constructions	-	

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[5] Our empirical analysis partly builds on the analysis made in a book chapter on diversification challenges for O&G supply firms (see Andersen & Gulbrandsen, 2019), using partly the same material (interviews 1-11, see Appendix). The present analysis however differs significantly e.g. in terms of the theoretical approach and the scope of analysis.

4.1 Institutional relatedness

Diversified firms reported low institutional relatedness between the O&G and OWP, which had made their entry to OWP more cumbersome. In other words, the firms were challenged in their use of capabilities and resources in OWP as the norms, routines and practices were different.

4.1.1 Interaction with customers in technology development

One difference between O&G and OWP stemmed from that the business and R&D practices of operator companies, i.e. firms developing O&G reservoirs or OWP farms for production, differed. The key knowledge of O&G operators was related to finding and recovering petroleum resources. Such knowledge, e.g. reservoir management, was often considered as a company secret, while offshore technologies, such as platform technologies and offshore constructions, were areas where the operators preferred to collaborate closely with suppliers and even with competing operators (Interviews 12, 14, 19). In O&G, offshore technologies were often developed through a process of **interactive technology development** between suppliers and operators, characterized by responding to technological challenges in a specific project under a specified set of circumstances. This implied that the suppliers became “project-oriented” in technology development and focused on satisfying the pre-expressed demands of the customers. Moreover, this process was typically not only initiated but also financed by operators. For example, when developing a new oil field, the supply firms together with the operators went through a multi-stage process, where the project started with pre-studies and early conceptual decisions (e.g. between a bottom-fixed or a floating platform) towards more concrete plans of field development. Only in the last stage the cost-estimates were made and a contract was formulated. This process ensured a sound design concept for a new platform technology. Such **R&D financing by operators** had significant leeway in the use of resources (1, 3, 5) due to easy access to financing (11) (see also Andersen & Gulbrandsen, 2019).

For OWP operators and turbine manufacturers, in contrast to O&G operators, the details of cost-optimization of turbines, offshore operations and construction was central to their competitive advantage, which was said to reduce their willingness to share information (14, 19). Therefore, the technology search process was more challenging for the supplier firms as the customers would not be willing to share specific information regarding their technologies (15). This difference was clearly seen in a diversified operator company as well.

“*When [designing] marine structures [in O&G] you were always cooperating with others, and always tried to spread around your results to the supply industry. -- But when you entered the renewables and offshore wind, then the cost of building and operating a structure, its kind of the competitive edge you have. -- So suddenly the knowledge about the structure, about the construction and about the management and all this became the key company secret so to say.*” (19)

Moreover, OWP operators rarely initiated and drove technology development processes in offshore technologies. Again, it was rather the opposite. In OWP, suppliers were expected to engage in **independent technology development** that complied with the relevant standards, and only then would go look for buyers. This also implied that the firms had to **self-finance their technology development**, including prototype testing and certification, before coming into customer interaction. This could be particularly challenging for small and medium sized enterprises (SMEs) (3, 14).

This had to do with the typical financing of OWP farms, which follows the logic of "project financing"[6]. Project financing represented a low-risk source of finance from the perspective of the lender who was not required to own assets as a safety guarantee. Consequently, creditors demanded strong influence on the project planning and commissioning. This included often a meticulous and low-risk plan and a rigid framework for contracting, including risk allocation and time discipline to avoid unpleasant surprises. In such projects, the choice of technology tend to be conservative "**proven technology**" (11, see also below). Project financing contracts put pressure on the potential O&G diversifiers, first, because it made it very difficult to come into consideration without a proven technology and track record in OWP, and, second, because project developers sought to push financial[7] and technological risk (pre-qualification) onto suppliers, making it costly for them to participate in tenders.

In comparison, in the O&G the field developers accepted the cost and the risk of a thorough tender process to ensure high quality and safety. O&G operators were also described to be more **open to new technologies** and concepts, at least before the oil price experienced a significant drop in 2014 (2, 5, 11).

4.1.2 Quality and costs

The guiding principle in the O&G was that the best possible solution for a specific problem at hand was utilized, thus emphasising **quality over price**. This is because technological malfunctions can have serious consequences for safety in O&G platforms, potentially leading to loss of life and vast eco-system damage. Safety is thus highly institutionalized goal in O&G which has fuelled further customization, use of high-quality materials, extensive documentation and use of standards (Andersen & Gulbrandsen, 2019).

In comparison, OWP had an emphasis on **price over quality** (2, 5, 15, 17, 19, 20). This is for instance because the operational safety was not as a big concern in OWP because there was a categorical difference in the possible consequences of equipment failure (oil spill and explosion versus reduced electricity production).

"[The diversifiers from O&G] need to be [less] quality minded if you like. Yes quality minded, but 90% is good enough, because you don't need the same quality [in OWP] in terms of risk. -- So that's something some of these companies need to be aware of: doing good enough, at a good price." (20)

Hence, for firms diversifying from O&G to OWP, such differences entailed a shift from the best possible design ("gold-plating") and competition based on quality and durability, to "fit for purpose" design and competition primarily based on price.

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[6] Project finance is the financing of long-term infrastructure, industrial projects and public services based upon a non-recourse or limited recourse financial structure, in which project debt and equity used to finance the project are paid back from the cash flow generated by the project.

[7] Another aspect is that suppliers will not enjoy payment guarantees. I.e. if the project for some reason fails, they have no guarantee for payment which makes any upfront investment in technology further risky.

4.1.3 Contract types

The typical forms of contracting between customers and supply firms differed between O&G and OWP projects.

First, in O&G, **EPC (engineering, procurement, and construction) contracts** were common, meaning that a project developer (the operator) usually had contact mainly with one or two turn-key supplier firms (so-called system integrators) that managed networks of sub-suppliers in a project. In OWP, **multi-contracting** had been more common, meaning that a project developer managed directly many contacts with up to 20 different partners (7, 8, 11). Developers said that this was because it allowed them to have more control of the projects in an attempt to reduce cost (8). Moreover, supplier firms indicated that the EPC segment in OWP was unattractive due to the imbalance between risk and benefits (see 4.1.1) (3) (Andersen & Gulbrandsen, 2019). However, this might be changing, as EPC-companies have recently become more active in OWP, and EPC-contracting has become more common in some market segments (14, 16).

Second, the size and duration of contracts differed, especially in terms of maritime operations. In general, typically only relatively short contracts were offered for shipping companies (for instance 6-9 months), while O&G contracts were generally longer (e.g. 5 years). This is because OWP contracts were commonly offered per project rather than over time which created inter-project gaps of inactivity. For some firms this was financially difficult to cope with (5). Hence, firms operating in the O&G typically had only **a few large and long contracts** while the OWP market was dominated by **several small and short contracts** (6) (Andersen & Gulbrandsen, 2019).

Moreover, the profits had usually been higher in O&G than in OWP. This made it more lucrative for firms to favour O&G contracts with **higher profits** over the ones available in the OWP with **lower profits** (18, 19, 22, 25). However, after the drop in oil price in 2014, OWP had produced better day rates than O&G for instance in the supply vessel market (20).

4.2 Networks

As already mentioned, the networks in O&G and OWP were somewhat different, while also some similarities could be observed.

4.2.1 Types of customer and supplier networks

Due to e.g. the multi-contracting model and the number of customer and supplier contacts (see 4.1.3), the business networks and sales channels in OWP were more demanding for the supplier firms coming from O&G. This required them to establish new customer contacts (1, 23, 26). The CEO of a large supply firm formulated the issue as follows:

"…customers (in OWP) are very different. They don't know us and we don't know them, and neither of us know the OWP market very well. This creates uncertainty and absence of trust; something that we have in O&G" (1).

The challenge was therefore not only of finding new customers, but was linked to how firms were used to win new contracts. In O&G, due to e.g. the above-discussed EPC-contracting model, firms had usually relatively **few customers and suppliers**. In OWP, due to multi-contracting, firms commonly had **many customers and suppliers**.

Partly because of these reasons, several supply firms struggled to get their first contract. They invested, over periods of up to four years, a lot of resources on understanding the supply chain, identifying, contacting, and convincing potential customers of their technology and to gain the trust of both the project developers and larger supplier firms established in the OWP (1, 2, 6). This was not the case for all respondents, though, as some of the customers and suppliers were active in both O&G and OWP, enabling firms to partly use their **existing networks.** In such cases prior O&G customers or suppliers had also moved to OWP (12, 14, 25). Moreover in one case, a company had tried to leverage their prior relationship and trust with a customer to get into the OWP market. But as the supply firm did not have a “proven technology” in OWP, the buyer preferred other suppliers with “inferior products” (2). In this case, then, the institutional differences trumped the potential positive network effect.

Moreover, the OWP operators were described to have **limited knowledge in offshore technologies**, as they had usually diversified to OWP from e.g. on-shore wind power, thus having their competences primarily in on-shore wind technologies. OWP customers were therefore described to be focused mostly on the price of the offshore technologies and operations (15, 20). Meanwhile, O&G operators usually possessed **strong in-house knowledge in offshore technologies**, which was described beneficial for supplier firms with high quality products, as the O&G operators were therefore better prepared to appreciate the qualities of the products beyond mere pricing (20, 28).

4.2.2 Geographic markets

Norwegian companies experienced significant difference in the geographic orientation of markets, given a strong domestic market in O&G while OWP markets so far have been international. This is because, until now, no OWP has been installed in Norway besides one demonstration project[8], while Norway is a significant producer of O&G. In O&G, the firms could therefore utilize their **domestic networks**, while a move to OWP often required establishing **international networks**. This was challenging especially for SMEs, which usually were not present outside of Norway, and therefore worked as sub-suppliers for large domestic companies who had engaged in international markets (14, 19, 22, Normann & Hanson, 2018). This form of entering international markets was nevertheless challenged by the common local content policies, which encouraged OWP operators to use mostly domestic suppliers (15, 23).

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[8] Norway`s electricity supply is dominated by renewable hydro power. Meanwhile, renewable energy deployment policies have traditionally been technology neutral. For these reasons no deployment of OWP has taken place this far (Hanson et al., 2011; Normann, 2015).

4.3 Technology

O&G and OWP required similar kinds of technological knowledge. However, some differences still remained. Seen overall, though, the high relatedness in offshore technologies was a key underlying factor encouraging further engagement and resource redeployment.

4.3.1 Offshore technologies

As also suggested by previous studies (Hansen & Steen, 2015; Normann & Hanson, 2015), the respondents reported significant similarities in terms of offshore technologies. Although most firms had to innovate to some extent to enter the OWP market, firms indicated that the new products were not radically different from O&G.

"The first generation of our product was fundamentally the same as for O&G but with some additional smart features. [The diversification was about] using existing resources and competence in a new and better way… we are succeeding in OWP because the market wants the same core technology as in O&G" (2).

Both OWP and O&G required knowledge in **marine engineering** for instance in terms of the foundations of constructions, necessary to ensure the survival and performance of platforms and turbines in harsh open sea conditions (12-15, 18). Such technological knowledge would extend from design to fabrication of such technologies, and could use e.g. the same design tools and materials (14, 15, 19). Both types of constructions also needed different types of **power cabling,** which had enabled firms to use capabilities in e.g. production of cables and design of power systems (18, 19). Moreover, floating wind power technologies, similarly to floating O&G platforms, required **moorings**, i.e. the anchorage and chains that keep a floating device stationary (15, 19). Finally, **installation and marine operations** had similarities, as there was e.g. the same need to transport personnel to offshore devices. This had allowed e.g. use of O&G vessels and related competences in OWP (12, 18-20).

4.3.2 Design and production principles

Despite such similarities, some technological differences nevertheless were observed. Perhaps most importantly, most technologies in O&G were customized. This was because the 'natural idiosyncrasies' of each oil reservoir mean that most O&G constructions (besides e.g. drilling vessels) are normally custom-made for each project (Andersen & Wicken, 2016) . This meant that each O&G project typically required **small batch production of customized technologies**.

In comparison, OWP parks consisted of several dozens of turbines, making **mass production of standardized products** the central guideline in the design and production of OWP technologies. This required adaptations in firms in how the technologies were designed to allow easier production of a high number of units in comparison to one-off production (17, 19, 20). The firms therefore needed to transform themselves from being primarily project-based organizations thriving in complex product system industries towards being more traditional manufacturing firms (cf. Magnusson et al., 2005). In one interviewed engineering firm, on the other hand, the diversification also required a change in the business model, i.e. moving from one-off billing towards licensing agreements, providing income when the same design was used in multiple units (14).

Finally, the complexity and magnitude of offshore technologies differed. While O&G platforms were usually relatively **broad and large** constructions, OWP turbines were **slim and tall**. This required somewhat differing design approaches, as the constructions reacted differently to wave, wind and current conditions, causing different physical fatigue on them (15).

5 Discussion

5.1 Empirical insights on established sectors in sustainability transitions

From previous studies we know that the Norwegian O&G sector has provided resources (e.g. technological knowledge) in building a domestic OWP industry (Hansen & Steen, 2015; Normann, 2015; Steen & Weaver, 2017), and that the two innovation systems have structural couplings which have influenced the innovation processes (functions) of the OWP TIS in Norway (Mäkitie et al., 2018). However, it has also been noted that despite the obvious similarities in offshore technologies and the large size of the O&G industry in Norway, only a relatively few O&G industry firms have engaged in OWP (Normann & Hanson, 2015). To examine this further, then, we studied the underlying foundations for this relationship between the two innovation systems. By using the concept of relatedness (Helfat & Lieberman, 2002; Boschma, 2017), our findings suggest that despite the high technological relatedness, OWP and O&G were less related in terms of institutions and networks. Multidimensional relatedness may thus help to explain why relatively few O&G industry companies had engaged in OWP and redeployed their capabilities and resources to larger extents. That is, while the redeployment of technologies was less challenging, firms were more challenged by the low institutional relatedness, and thus struggled to redeploy resources.

These findings provide relevant insights for policy-makers. The relatedness perspective can be useful in identifying possible industrial transformation pathways, where a good understanding of the current resource base of established sectors can help to recognize in which kind of low-carbon technologies they can be redeploy existing resources and capabilities. Boschma and colleagues (2017) call these as exaptation pathways, where the local capabilities and resources are reutilized in developing new-to-the-world low-carbon technologies. The relatedness perspective can therefore be instrumental in assessing why and how firms from an established industry may or may not redeploy their resources in a new low-carbon technology. Such an analysis allows to identify drivers and barriers for utilizing existing industries as repositories of resources and capabilities when attempting a sustainability transition in a given country or region. However, more research regarding policy instruments supporting such processes is needed. For instance, policies supporting resource redeployment across related innovation systems could be combined with sector phase-out policies. Firms are then incentivized to diversify to new sustainable technologies while simultaneously being discouraged to continue activities in the existing unsustainable industries.

5.2 Multidimensional relatedness

Empirical analyses of relatedness in innovation studies have thus far often been limited to a single type of relatedness (Boschma, 2017). For instance, analyses are often limited to the study of e.g. technological (Neffke et al., 2011; Stephan et al., 2017) or skill (Neffke & Henning, 2013) relatedness.

Similarly to Tanner (2014) as well as Binz and colleagues (2016), we suggest that limiting the analysis of relatedness to only one dimension may give an incomplete and simplified picture of interactions between innovation systems. This is because innovation systems might be highly related in one dimension but not in another. One-dimensional perspective on relatedness could thus lead to biased conclusions regarding the potential resource redeployment between innovation systems. Our empirical findings support this view. For instance, if assessed only through technological relatedness, it would have been reasonable to expect strong involvement in OWP from O&G sector firms, while our multidimensional perspective shows that this engagement is discouraged by low institutional relatedness.

In our study, particularly institutional relatedness was low between O&G and OWP, which had made diversification of O&G actors in OWP more difficult. However, in the study of relatedness, institutional factors have often been overlooked (Boschma & Frenken, 2011; Boschma, 2017). Hence, more research is needed regarding institutional relatedness between innovation systems.

Moreover, in much of the previous literature, relatedness is typically used as a binary concept of related or unrelated elements (Content & Frenken, 2016; Boschma, 2017). Our analysis, however, showed that the O&G and OWP were not perfectly either related or unrelated in the different structural dimensions (see Table 2). We therefore suggest that considering relatedness as a continuum of similarities and differences may provide a more accurate picture of industry interactions, rather than simply differentiating between related or unrelated industries.

5.3 TIS-sector couplings

Our paper contributed to the research regarding how TISs interact with established sectors in their contexts (Bergek et al., 2015). While this topic has been discussed through the notion of structural couplings (Haley, 2015; Mäkitie et al., 2018; Leitch et al., 2019), it has not yet been elaborated why and how such structural couplings between sectors and TISs are established. Our paper shows that relatedness between sectors and TISs can be an important encouraging factor for actors to enter in another innovation system. Relatedness influences the opportunities of actors to utilize their existing capabilities and resources in another innovation system, thus making them more likely to engage in it and realize structural couplings. Therefore, in the TIS perspective, structural couplings can be seen as the realized and shared structural elements (e.g. same technologies, actors and institutions) present in both innovation systems. Relatedness, then, refers to the degree of underlying similarities between the innovation systems in terms of their structural elements. Actors may identify and utilize such similarities by redeploying existing resources and capabilities and thus enter the other innovation system. Drawing on literature in economic geography (Boschma & Frenken, 2011; Kogler, 2015; Boschma et al., 2017) and management studies (Helfat & Lieberman, 2002; Folta et al., 2016), we therefore argue that relatedness can help to explain why structural couplings may or may not emerge between established industries and TISs.

6 Conclusion

It has recently been argued that the vast resources employed in established sectors can help to accelerate socio-technical transitions towards sustainability (Fagerberg, 2018; Geels, 2018). However, there is limited research on the underlying factors of such resource redeployment. In this paper we have explored the role of relatedness between innovation systems in such phenomena. We argue that high relatedness enables actors to apply their resources and capabilities in another innovation system, which then may lead to structural couplings. Low relatedness, on the contrary, discourages such engagement due to limited opportunities for redeployment. As a novelty, we further argue that relatedness between innovation systems should be understood in multiple dimensions, differentiating between similarities in institutions, networks and technologies which affect the opportunities of actors to utilize such similarities. We demonstrate the importance of multidimensional relatedness for resource redeployment through an empirical analysis of the engagement of Norwegian O&G sector actors in OWP.

Our paper has a number of limitations which open opportunities for further research. First, our analysis has lacked a clear temporal dimension. While some of our results referred to possible changes in relatedness between O&G and OWP over time, such dynamic analysis has been out of the scope of this paper. Future studies should therefore seek to elaborate on how the multidimensional relatedness between established industries and TISs evolves over time (cf. Bergek, 2014; Markard, 2018). Second, our study has been limited to a single established industry and a TIS in one country. Future studies should explore the role of relatedness also in other industrial and national contexts, as well as in international settings. Third, while in this paper we have focused on system-level factors of resource redeployment between innovation systems, this interaction is obviously embedded in a wider context. For instance in the case of Norwegian O&G and OWP, external market pressures, local conditions and politics have facilitated the engagement of O&G actors in OWP (Steen & Karlsen, 2014; Hansen & Steen, 2015; Normann, 2015; Mäkitie et al., 2019). Future studies could therefore seek to analyze the interplay of different underlying factors of resource redeployment between innovation systems, and their potential for accelerating sustainability transitions.

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Appendix (interviews)

Number	Actor type	Position
1.	Diversified supplier firm 1	Chief executive officer (CEO)
2	Diversified supplier firm 2	CEO and founder
3.	Diversified supplier firm 3	Technology Manager
4	Diversified supplier firm 4	Technology Manager
5	Diversified supplier firm 5	Vice President (VP)
6.	Diversified supplier firm 6	General manager
7	Industry association 1	Business Development Manager
8	Diversified operator firm 1	Manager Technology and supply chain development
9	Operator firm 1	Managing director
10	Standardization firm	Manager Offshore Renewables
11	Legal consultancy firm	Senior advisor
12	Diversified operator firm 1	VP
13	Diversified operator firm 1	Research Manager
14	Diversified supplier firm 7	VP (a) + Deputy Technology Manager (b)
15	Diversified supplier firm 7	Deputy Technology Manager
16	Diversified supplier firm 8	Head of Business Development (a) + Finance analyst (b)
17	Diversified supplier firm 8	Engineering Manager (a) + VP, supply chains (b)
18	University 1	Former Research Director
19	University 1	Professor
20	Industry association 2	Director
21	Commercial bank	Senior Advisor
22	Public financing institution	Senior Manager
23	Diversified supplier firm 3	Manager
24	Diversified supplier firm 9	Managing director
25	Diversified supplier firm 10	CEO
26	Diversified supplier firm 11	Managing director
27	Diversified supplier firm 12	Business director
28	Diversified supplier firm 13	CEO
29	Diversified supplier firm 14	Sales director
30	Diversified supplier firm 5	Senior VP
31	Diversified supplier firm 15	Director
32	Diversified supplier firm 16	VP
33	Diversified supplier firm 17	CEO

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