The industrial dynamics of technology phase-out in socio-technical transitions: Insights from the upstream oil technology value chain

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Abstract

The urgency of a socio-technical transition in the energy area has led numerous authors to argue that it can and should be accelerated through more active phase-out, disruption and destabilization of the undesirable established technologies. We argue that this may be a too narrow view and based on a biased perspective of Schumpeterian creative destruction. We propose that technologies often involve many different sectors, and that there is a great but underappreciated potential to speed up transitions through focusing on the opportunities for recombination and diversification by upstream firms. This may also dampen the possible negative effects of transitions such as loss of jobs and bankruptcy of firms. We therefore suggest that technology phase-out policy should include diversification support so as to provide exit routes for firms and associated resources. We develop a framework which we use to study diversification processes in firms that are suppliers to the Norwegian offshore oil technology value chain. We find that firms face a number of diversification challenges that are mostly unrelated to technological aspects. We use these findings to discuss how policies can better support diversification and how the theory of sociotechnical transitions can be expanded to take this perspective into account.

1 Introduction

Transition studies are concerned with fundamental, socio-technical transformations in sectors such as energy, transport, healthcare, forestry, and equipment manufacturing (Markard, Raven, & Truffer, 2012). A socio-technical transition is normally defined as a technology substitution cycle in a focal sector where a mature technology and the associated regime is disrupted and eventually replaced by an emergent technology. Transitions are typically depicted as a battle between the new and the old (Geels, 2005; Kemp et al., 1998). One of the classic examples is how steam ships (emergent)over time came to replace sailing ships (regime) (Geels, 2002).

In the pending transition in the energy sector, consecutive failures to significantly alter the world's emission path have led to calls for greatly accelerating the transition process (EC, 2016; IEA, 2016; Zindler & Locklin, 2016). Transition scholars have consequently considered how to accelerate socio-technical transitions. Following the Schumpeterian notion of 'creative destruction', it has been argued that transition policies need to pay attention not only to creation of novel sustainable technologies but also 'destruction' and phase-out of unsustainable established technologies and associated industries (Kivimaa & Kern, 2016). A new sub-field has emerged that includes studies of technology phase-out policies (Rogge & Johnstone, 2017), exnovation (David, 2017), regime destabilization (Turnheim & Geels, 2012), and discontinuation of socio-technical systems (Stegmaier et al., 2014).

Transition studies in general and technology phase-out studies in particular thus mainly focus on disruption and discontinuity aspects of socio-technical transitions rather than dimensions of continuity (Winskel, 2018). This is however problematic because it risks disregarding incremental and continuity-based change processes that, in an evolutionary perspective, may be equally important. The emphasis on disruption is often legitimized with reference to the evolutionary economics of Schumpeter. While Schumpeter certainly highlighted the importance of destruction and disruption of the status quo, he did so with a 'combinatory' understanding of innovation. Seeing innovation as recombinations of extant resources and knowledge opens up a space for distinguishing between products and technologies, on the one hand, and the firms and industries producing them, on the other. Hence, although certain technologies and products decline, it is not straightforward that the underlying resources and capabilities, and the firms embodying them, must also decline (Helfat & Peteraf, 2003). There is thus a need for considering continuity aspects in transitions related to a combinatory view on innovation and change.

The prospects of identifying and analyzing recombinations in transitions are however inhibited by the tendency in transition studies to focus on technology-using sectors such as electricity and transport. The string of technology-producing sectors that constitute the full technology value chain tend to be backgrounded (Steen & Weaver, 2017; Stephan et al., 2017). The emerging literature on technology phase-out suffers from the same bias in perspective. There is thus a related need for systematically considering entire technology value chains in transitions and technology phase-out.

With our study we address these two imbalances in transition studies by integrating insights from technology studies and evolutionary economics to articulate a framework that enables us to discuss transition processes that go beyond disruptions in single sectors. It gives us a perspective for considering the industrial dynamics of technology phase-out in socio-technical transitions and the role of firms' opportunities for redeploying capabilities and resources in such processes. We argue that by providing firms with diversification and exit opportunities, technology phase-out processes could be less contested, faster, and involve less negative labor and economic effects particular regions. The underlying mechanism is that firms' market opportunities and political strategies are related (Geels, 2014). Therefore, destabilization of actor networks (via diversification) associated with an established technology, reduces wider social legitimacy of and political support for that technology. Reduced legitimacy is, in turn, likely to hasten technology decline (Karltorp & Sandén, 2012; Kivimaa & Kern, 2016; Markard et al., 2016).

We apply this framework to study how firms engage with diversification in the upstream industries of an incumbent technology value chain in response to transformation pressure. Our focus on firms follows the logic that we can improve our understanding of transition dynamics by studying actors (Farla et al., 2012). We analyze firm behavior in the upstream industries of the offshore oil technology value chain in Norway. Our data consist of 15 interviews with firms that have engaged with diversification activities in response to decline signals.

We find that upstream firms can and do redeploy their capabilities across different industries, and that this mechanism is augmented in response to industry decline. We also see that firms are challenged by organizational rather than technological innovation. Lastly we find that simultaneous exit pressures and opportunity pulls are important, and that time and timing is essential for success.

Our main conclusion is that complementary forms of interplay between technology 'creation' and 'destruction' in transitions can happen at the level of capabilities and resources when firms manage to find novel combinations to fit a new situation. This points to an underappreciated type of continuity in transitions with important implications for technology phase-out policies.

The structure of the paper is as follows. In section two, we review the literature on socio-technical transitions to qualify our assessments and propose a framework of analysis. In section three, we describe our methods and data. Section four contains our analysis. In section five we discuss main insights and present conclusions.

2 Literature review and framework of analysis

2.1 Disruption, transitions, and technology phase-out

Transition studies have predominantly been preoccupied with disruption, discontinuity, and creative destruction aspects of socio-technical transitions rather than continuity (Winskel, 2018). There are many studies of how actors associated with the challenged technologies react antagonistically to potentially disruptive innovations (see e.g. Hess, 2013; Smink et al., 2015; Wesseling & Van der Vooren, 2017). Although studies of possible complementarity between established and emerging technologies in transitions do exist (see e.g. Berggren et al., 2015; Geels et al., 2016; Geels & Schot, 2007; Raven, 2007) they do not represent the mainstream.

This is problematic because preoccupation with discontinuation narratives risks marginalizing important incremental and continuity-based change processes in socio-technical transitions. It moreover leads to one-sided recommendations to policy makers to actively disrupt undesired technologies to pave the way for preferred niche technologies (Winskel, 2018).

In this regard, recent studies on active technology phase-out in socio-technical transitions (David, 2017; Kivimaa & Kern, 2016; Rogge & Johnstone, 2017; Stegmaier et al., 2014; Turnheim & Geels, 2012) are symptomatic for the focus on disruptions. They share the perspective that established technologies block growth of emerging sustainable technologies and suggest a conflicting relationship between new and old technologies. Hence, weakening the established technology is deemed necessary to create windows of opportunity for niche technology growth (Turnheim & Geels, 2013).

In this context the Schumpeterian notion of creative destruction is mobilized to argue that policies aiming at governing socio-technical transitions must address both creation and destruction. In fact, doing so can not only support but also accelerate transition processes (Kern & Rogge, 2016).

The destruction process entails that "*resources, skills and knowledge held by incumbents become obsolete; in an industrial context, implying that, for example, the value of existing expertise and other factors of production reduces significantly*" (Kivimaa & Kern, 2016). The authors propose four key processes that policy can support to enable decline of undesirable technologies. These include control policies (e.g. carbon tax), changes in regime rules (e.g. feed in tariffs in electricity), reduced support for dominant regime technologies (e.g. discontinuation of educational and research activities related to undesirable technologies), and changes in social networks and replacement of key actors (e.g. limit influence of actors on policy). This last point refers to the importance of technology legitimacy for attracting resources and avoiding political opposition (Markard et al., 2016). Destabilization of actor networks (e.g. via exit and diversification) associated with an established technology, can be both an indication and driver of decreasing legitimacy (Geels et al., 2016; Karltorp & Sandén, 2012).

According to Andersen (2009, 2013) and Fagerberg (2003), viewing creative destruction as a process where newcomers via a single major innovation overthrow existing actors in a single-industry setting reflects a narrow interpretation of Schumpeter's work. Schumpeter saw innovation as new combinations of existing resources and knowledge, performed by either established firms (Mark II) or de novo entrants (Mark I).

This combinatorial perspective on innovation made Schumpeter skeptical to radical innovation jumps in terms of knowledge. His favorite example of creative destruction was the transition in mail services from horse carriage to railroads. Schumpeter was aware though that the railroads had already been built such that an upstream technology value chain already existed. Only minor recombinations of resources and knowledge were therefore needed to transition to railroad in mail services (Andersen, 2009). Indeed, Fagerberg (2003) argues that Schumpeter interchangeably used creative destruction and economic evolution which suggests that the use of Schumpeter in transition studies is based on selective reading of his writings.

In fact, a distinct research tradition based a combinatorial perspective on innovation exists (see e.g. Hidalgo, 2018; Weitzman, 1998). The central tenet underlying this perspective is that economic value comes from the complementarity of resources and knowledge. Technological diversification and emergence of associated industries will be related to current resources and knowledge. Actors develop mainly new combinations that build on or are closely related to those already available thereby making industrial and technological evolution path dependent (Cantwell & Vertova, 2004; David, 1985). In light of a combinatorial perspective on innovation, an over-emphasis on destruction and obsolescing of resources and knowledge risks overlooking important aspects of continuity and recombinations in a socio-technical transition.

2.2 Technology-using versus technology-producing sectors

Socio-technical transitions are conceptualized as a single-sector phenomenon (Markard et al., 2012). In addition, transition studies focus pay particular attention to downstream, technology-using sectors (Steen & Weaver, 2017; Stephan et al., 2017). This leaves sectors or industries that produce inputs to or use outputs from that focal sector in the background.

Geels et al. (2016), for example, focus almost exclusively on the technology-using sector (i.e. electricity) in their analysis of transition pathway dynamics. In terms of actors, the study considers new entrants solely as new entrants into power production. Likewise, identified incumbent actors reside in the power sector including utilities and regulators as well as relevant activities of ministries and government agencies (also see Raven, 2007).

Still, the importance of aligning related sectors for the success of transitions is widely acknowledged. Geels and Schot (2007), for example, highlight the upstream institutional innovation of mass-production by Ford as a decisive factor for the outcome of the technological competition involved in the transition from horse-carriage to the internal combustion engine in the (personal) transport sector in late 19th century. Also, Geels (2002) argues that the misaligned interaction between up- and downstream sectors was a major factor behind the slow diffusion of steamships. Next to innovation in sailing ship technology and political resistance from incumbents, slow and gradual learning and technology improvement in the upstream sectors including new fuel infrastructures (coal) and new production facilities to enable up-scaling were key barriers to overall performance of steamship technology.

Geels (2006) observes that the ability of upstream (construction and manufacturing) firms to use the competences the of old technology with only modest modifications to deliver the new technology, influences transition dynamics. He suggests that the ability of upstream sectors to diversify competences along with the transition may very well be a determinant factor for how established firm respond to technological change. Despite this acknowledgement, there is an absence of systematic treatment of how up- and down-stream sectors interact with the focal sector of analysis.

2.3 Decline signals and firm diversification

In a situation where a change in a firm's environment reduces the value of existing resources and capabilities (e.g. a transition), it can react in two ways. It can attempt to alter its environment or/and it can to adapt to changes. The former relates to 'corporate political strategy' which is often pursued collectively by industry actors in response to external threats. The latter refers to firm-internal learning processes (Geels, 2014). The two options are related. If a firm sees ways of adapting, it will be less incentivized to work against changes in its environment. We focus on adaptation strategy. It entails finding a fit between extant resources and capabilities, on the one hand, and the new situation, on the other (Geels, 2014; van Mossel et al., 2018). In the context of technology phase-out, diversification to new industries or technology value chains is a relevant option.

Innovation is required for firms to enter a new industry, which means that diversification can be viewed as an innovation process. We follow Helfat and Lieberman (2002) in understanding patterns of diversification primarily as a matter of matching a firm's resources and capabilities accumulated in the 'old' industry to the requirements of the new. Diversification cost is thus decided by a combination of the properties of resources and capabilities of the firm and demands from the environment. In this perspective, inter-industry differences largely define the challenges of diversification.

The 'distance' between what was required to succeed in the old industry versus what is needed in the new industry co-defines the size of the challenge (Leonard- Barton, 1992; van Mossel et al., 2018). The distinction between related and unrelated diversification has been suggested to discuss such distance (Rumelt, 1974). Relatedness between industries is defined as the extent to which they have common factors of production (Lemelin, 1982; Rumelt, 1982). Unrelated diversification is more challenging, and therefore rarer since firms need to acquire significant new resources and capabilities and integrate these with existing ones (Helfat & Peteraf, 2003; Kogut & Zander, 1992; Porter, 1990). The associated effort required by diversifying firms is thought to be high and equivalent to disruptive innovation. Related diversification requires less integration of new resources and capabilities and therefore only an incremental innovation efforts by firms. It is therefore the most commonly observed pattern of diversification, and perceived to be the most successful one (Helfat & Lieberman, 2002; Porter, 1990).

Relatedness between industries is multi-dimensional (Porter, 1990; Rumelt, 1974). It encompasses inter alia technological relatedness (Breschi et al., 2003), market properties as customer relationships (Lemelin, 1982; Tanriverdi & Venkatraman, 2005), capabilities for production (Magnusson et al., 2005), or capabilities for innovation management (Helfat & Lieberman, 2002). The diversification process must therefore take place in several dimensions. We conjecture that the more dimensions that require change, the more challenging diversification will be for a firm.

2.4 Sectors, technologies, and upstream firms

In this section we integrate insights from technology studies, evolutionary economics, and recent advances in transition studies to articulate a framework of analysis. The goal is to have a tool that allows us to systematically consider the industry dynamics of upstream parts of multiple technology value chains and how they interact. We combine this meso-level view with a firm-level perspective on diversification.

Our starting point is that every technology is a system because it is a combination of other technologies (interdependent subsystems and components) and is part of larger technological systems. Technologies are therefore both combinatorial and recursive which makes them highly reconfigurable (Arthur, 2009; Murmann & Frenken, 2006; Tushman & Murmann, 1998).

Considering a particular technology, the subsystems and components comprising it are applied in and produced by different sectors or industries that constitute the technology value chain (Stephan et al., 2017). Technology value chains connect several and heterogeneous sectors. A main distinction is between technology-using and technology-producing sectors along the value chain. We distinguish between two basic forms of technology interaction: competition or complementary interaction (Wirth & Markard, 2011).

Interdependencies among different parts of a technology value chain implies that change in one sector must often be accommodated by changes in other sectors (Arthur, 2009). For example, if extensive technological changes are required in a technology-using sector (e.g. decarbonizing electricity production), it will have repercussions for technology-producing sectors (e.g. good for wind turbine producers but bad for producers of coal power plants).

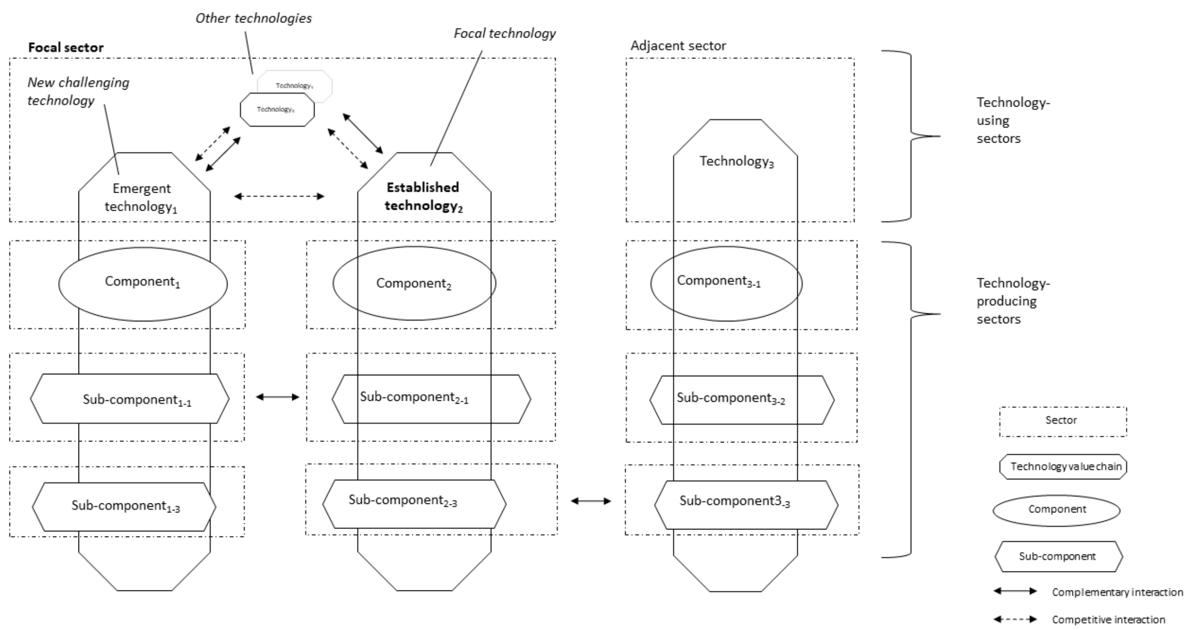
Also, innovation in technology-producing sectors can generate opportunities or pressure for change in technology-using sectors. There are thus mutual dependencies between the sectors of a technology value chain whose coordination and “interactive learning” influence the technology’s overall performance (Lundvall, 1985; Pasinetti, 1993; Robertson et al., 2002).

Each sector normally applies several different technologies to generate outputs, and these technologies can be both complementary or in competition regarding market shares and overall sector performance. Hence, progress in one technology can change the competitive balance and require innovative responses from other technologies, or induce change in complementary technologies (Dahmén, 1989; Markard & Hoffmann, 2016).

This implies that what happens in upstream sectors influences the performance of a focal technology in the technology-using sector. Improved performance will see it grow in the use-sector and vice versa. Our framework also suggests that each sector can have its own transition which will have varied consequences for linked sectors. We can thus envision that a rather disruptive transition in the technology-using sector will not necessarily imply disruptions in upstream sectors. Indeed, this line of thinking enables us to systematically consider how sector transitions in different segments of a focal technology value chain may influence its performance.

In principle, a technology phase-out implies disruption along the entire value chain. In cases where actors in the upstream sectors are highly dependent on the out-phasing technology segment, diversification to other technology value chains is necessary. This can be linked to the same technology-using sector (e.g. car manufacturer shifting to electric vehicle and hydrogen technology) or firms can move into adjacent sectors and value chains. The degree of disruption of or relatedness involved in these two types of diversification is not obvious a priori.

Figure 1: Industry and technology map



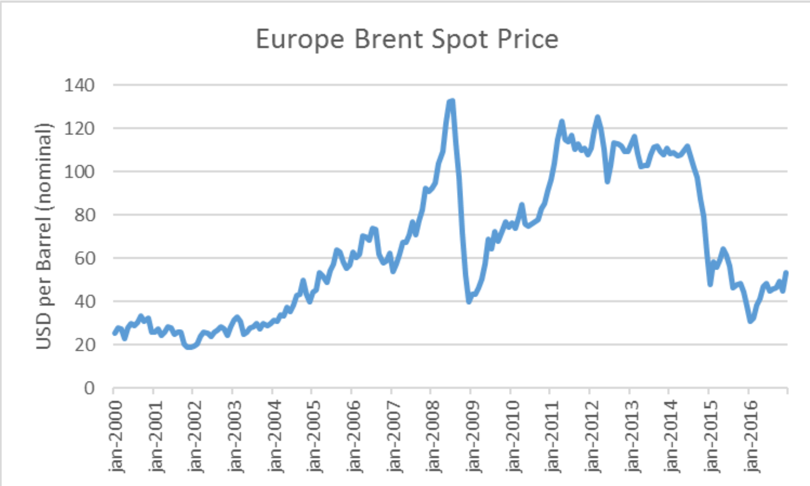
If firms can see credible diversification opportunities when faced by technology decline, it is likely they will pursue this market strategy rather than (only) investing in stopping phase-out processes. Provided that upstream firms play important roles for creating and maintaining technology legitimacy (Geels et al., 2016; Normann, 2017), firm diversification weakens legitimacy. This suggests that incentivizing firms along the technology value chain to diversify, would be one step in advancing the phase-out process. When considering a transition or a technology phase-out process in the perspective outlined here, it seems obvious that involved firms distributed across numerous sectors and technology value chains can move between areas.

3 Methods

3.1 Case description

Offshore oil activity was established in Norway in the late 1960s and has since evolved through an interplay of international oil firms, Norwegian suppliers, large R&D institutes and universities, and supportive policies (Engen, 2009; Saether et al., 2011). In 2015, 15 per cent of Norwegian GDP and 39 per cent of total exports originated from oil sales. Norway has moreover developed a full upstream technology value chain to serve production and sale of oil. The value chain sectors are major exporters of technological equipment and combined constitute the second largest industry in Norway in terms turnover. Most segments of the supply chain are technologically mature with established practices, standards, and dominant designs.

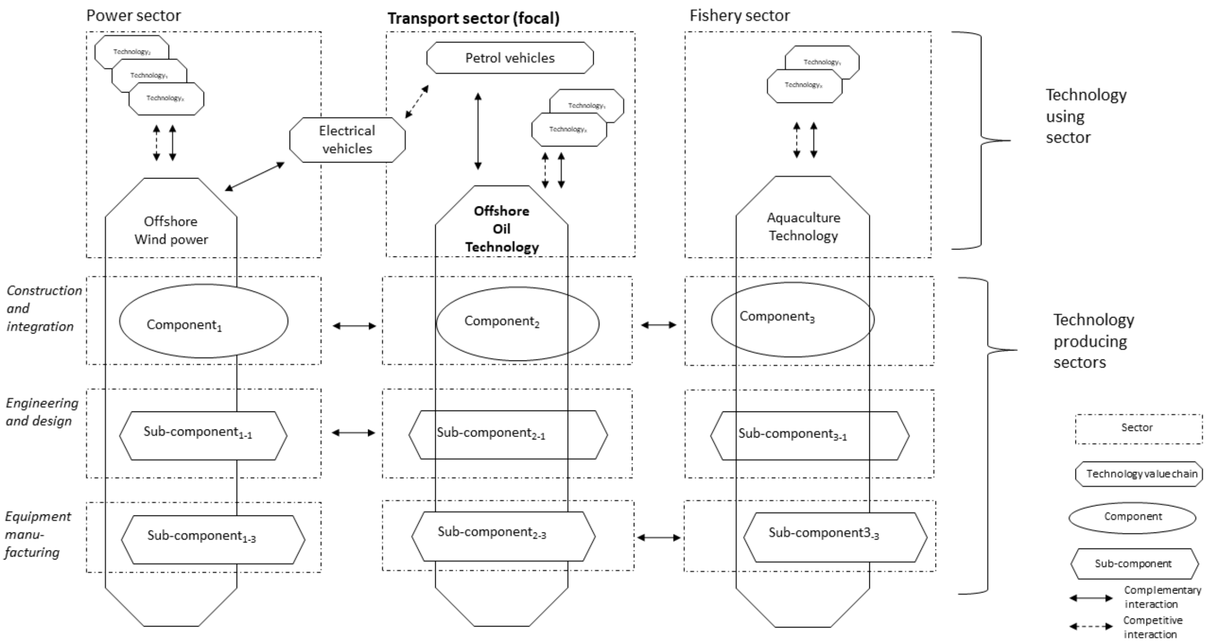
Figure 2: Oil price evolution



Source: The U.S. Energy Information Administration

The international oil market goes through boom and bust periods, cf. Figure 2. When price falls both oil companies and supplier firms in the upstream sectors come under pressure to adapt. Most notable were the price declines in 2008 and again in 2014. Firms typically respond by cutting cost and/or consider diversification (E24, 2016). In recent year's structural shifts in the global economy, however, augments uncertainty of oil's longer-term profitability. One shift is the entry of shale-oil which keeps prices down. Another is the rising pressure from the advancing energy transition which feeds the perception that oil is already in a long-term decline (Steen & Weaver, 2017). Although this may not necessarily imply an imminent economic risk for the upstream sectors, firms experience heightened uncertainty which, in turn, informs their decision making. Upstream firms have responded to such decline signals with diversification primarily towards offshore wind power (Mäkitie et al., 2018) but also offshore aquaculture, construction, and the defence sector, see Table 1. These activities constitute interesting examples of resource and capability redeployment across the upstream segments of different technology value chains, see Figure 3. The figure specifies the main sectors of relevant technology value chains. As most oil is consumed in transport we leave out the other sectors where it is used.

Figure 3: Approximate illustration of our case study dynamics



3.2 Method and Case selection

We perform a single case study in Norway limited to the period between 2008 and 2017. We operate both at the level of sectors related via a technology value chain and at the level of individual firms. Our primary interest is in phenomena at the level of sectors and value chains. We do a range of experiments (firm interviews) to improve our understanding of those phenomena. We seek analytical rather than statistical generalization from our study. This implies to sufficiently substantiate our propositions through a pattern-matching logic across experiments / interviews. The purpose is to convincingly establish that our phenomenon of interest is also valid for other—but by no means all other—cases (Robson, 2002; Yin, 2009).

We selected the upstream industries of the offshore oil technology value chain in Norway as our case for three main theoretical reasons. First, in our focal period the technology value chain was under transformation pressure partly caused by an ongoing (energy) transition which inhabitant firms interpreted as signals of decline. Second, the case is suitable for analyzing what takes place in the upstream segments of technology value chains. Third, due to firm diversification and resource transfers, the case is suitable for studying continuities in (perceived) technology decline processes. In the context of the pending energy transition, the case is further unique. As any energy transition would entail phasing out oil activities, it is crucial to understand how the actors operating in the technology value chain react to decline signals.

3.3 Analysis and data

In this paper we will explore the characteristics and challenges of diversification processes by use of a qualitative method.

Our main data material consists of 15 interviews of which 11 were with oil supply firms, two with client companies and two with industry experts. We selected supply firms based on three criteria: (a) they have recently attempted diversification, (b) had oil as the main market at time of diversification decision, (c) and diversification decision was motivated by a decline in the oil market. We identified firms through news items in the Norwegian press and asked first interviewees about other firms with similar experiences. In addition, we selected firms that have diversified into different types of industries – for example, offshore wind power, aquaculture and medical technologies – as well as firms that represent different segments of the oil technology value chain. In this manner we strived to find firms and interviewees that represent a variety of experiences and contexts.

Interviews were semi-structured, and carried out between December 2016 and April 2017, with an average duration of 50 minutes. The most frequent types of informants were Chief Executive Officers (CEOs) and Chief Technology Officers (CTOs). All interviews were taped, transcribed and loaded into NVivo. Table 1 provides an overview of interviews and various details of the firms. Each interview is ascribed a numeric code which we use in the text when referring to interviews as sources of information.[1]

[1] The empirical material has been used to also to write a book chapter about diversification challenges for oil supply firms (see Andersen & Gulbrandsen, 2018). Our analysis however differs in crucial aspects. Firstly, this current paper addresses and aims to contribute to thinking about socio-technical transitions in general and technology phase-out thinking in particular. Second, we here use an altered selection of firms and our empirical descriptions are much shorter.

Table 1: Overview of interviews and firm information

Interview	Value chain position	Income share from Oil prior	Diversification year	Motivation for diversification	Phase of diversification[2]	New market(s)
I-1	Construction and integration	«Very high»	2003	Expected decline in industry c combined with opportunity for using resources and capabilities in other industries	3	Offshore wind
I-2	Equipment manufacturing	60%	2010	Decline in industry combined with opportunity for using resources and capabilities in other industries	4	Offshore wind
I-3	Construction and integration	90%	2008	Decline in industry combined with opportunity for using resources and capabilities in other industries	3	Offshore wind
I-4	Construction and integration	100%	2015	Decline in industry	1	Aquaculture, offshore energy
I-7	Equipment manufacturing	90%	2012	Decline in industry	2	Organic waste management
I-8	Engineering and design	40%	2014	Decline in industry	2	Medical industry
I-9	Equipment manufacturing	100%	2015	Decline in industry	3	Defence & aquaculture
I-10	Equipment manufacturing	80%	2014	Decline in industry combined with opportunity for using resources and capabilities in other industries	3	Solar power, smart housing, Tunnels
I-11	Equipment manufacturing	55%	2013	Decline in industry combined with opportunity for using resources and capabilities in other industries	4	Aquaculture
I-12	Equipment manufacturing	60%	2014	Decline in industry combined with opportunity for using resources and capabilities in other industries	4	Aquaculture
I-13	Equipment manufacturing	60%	2013	Decline in industry combined with opportunity for using resources and capabilities in other industries	2	Aquaculture, defence, renewable energy
I-15	Renewable energy project operator	n.a.	n.a.	n.a.	n.a.	n.a.
I-16	Renewable energy project operator	n.a.	n.a.	n.a.	n.a.	n.a.
I-17	Subsea Industry association	n.a.	n.a.	n.a.	n.a.	n.a.
I-18	Energy consultancy firm	n.a.	n.a.	n.a.	n.a.	n.a.

[2] We define phases as follows. Phase (1): firm is scoping options for diversification but is yet to act on them. Phase (2): firm has commenced R&D search projects that could help penetrate new market. Phase (3): firm has made initial sales but still infrequent and small-scale contracts. Phase (4): firm is relatively established in new market with steady and significant activity.

We used conceptual considerations on diversification and relatedness from the literature to design interview questions, but at the same time allowed new analytical dimensions to emerge from the data with open-ended questions that made room for probing and exploring respondents' own terms and understandings. We operationalised our theoretical considerations in two stages. First, we asked the firms about their main activities in oil in order to acquire an indication of the firm's core resources and capabilities. Secondly, we asked a set of nuanced questions regarding what the firm did or needed to do differently to enter the new industry, and what was experienced as the most difficult challenges. These questions highlighted resource and capability gaps. We assessed degree of relatedness between industries as the discrepancy between the resources and capabilities firms had accumulated in oil and those needed to succeed in new the industry. In turn, the extent of such discrepancy across dimensions of relatedness is indicated by what firms considered most challenging in the diversification process. For example, if firms did not mention technology when asked about the main challenges, we interpreted this as stating that technological relatedness is relatively high and not a major problem.

In our coding of interviews we developed an integrative synthesis between our main concepts and the data, resulting in five analytical categories. The theoretical concepts worked well as structuring devices and we categorized the data accordingly. These conceptual categories include innovation capabilities, production capabilities, market properties, and other issues. For each category, we considered differences between firms based on characteristics such as size, types of technology and position in the value chain.

4 Results

In this section present the main results from our analysis of firm diversification processes. Most firms have followed a logic of related diversification by modifying existing products for new markets, or by looking to redeploy existing capabilities – *'Our core competence is managing huge projects, really, not just in oil'* (I-3) as stated by an interviewee of an engineering firm.

4.1 Innovation capabilities

Oil technology is characterised by an advanced but predominantly responsive mode of technology development. Oil firms approach suppliers with specific problems that they want solved under a specific set of circumstances. Suppliers establish innovation projects focused on satisfying these pre-expressed demands. This process is typically not only initiated but also financed by the oil firms. For example, for new oilfield development, the supply firms and the client go through a four-stage process where only the last step implies cost estimates that can form the basis of a clear contract.

The earlier stages oriented towards selecting and improving overall design (e.g. platform or drilling ship) are financed by the oil companies, and several firms in our sample expressed that they have significant leeway in these design stages.

The described organisation of technology development was not found in any of the new markets that the firms aimed at. In other markets such as offshore wind power and aquaculture, suppliers are expected to develop a product internally that complies with relevant standards, and only then approach potential buyers. In other words, a higher 'technology readiness level' is required in these industries.

Overcoming this type of challenge implies a shift from what we may term a user-driven form of technology development to a more strategic and internally-driven form of development. Almost all interviewees described this as a huge problem. The renewable energy firms stated that supply firms which contacted them were often 'poorly prepared' in terms of products and ideas about value added (I-16), confirming the challenges that these firms have when approaching new markets.

Another and related difference in technology development relates to the notion of customisation. Search heuristics guiding technology development in oil often address problem-solving particular to the natural environment. Each reservoir provides a particular set of challenges related to, for example, going deeper and further and with unique safety requirements. The oil value chain has institutionalised a strong emphasis on safety because failure can mean oil spills, fatalities or ecosystem damage. This further drives customisation, use of high quality materials, high cost-levels, and places extensive demands on documentation. As expressed by a technology manager of an engineering firm (I-3), '*Everything is one of a kind [in oil]. We never make copies. This is because each oil reservoir is totally unique and therefore you never need the same [equipment]*'. The high degree of customisation implies that technology development is an integrated part of each project rather than an activity between projects and contracts.

Again, the contrast with most other industries was clear, where the logic in most cases was cost reduction through standardisation of technology components to facilitate economies of scale in production. In offshore wind power, for example, less emphasis was put on quality and safety, and much more on price. The interviewees stated that less severe consequences of equipment failure was a main reason.

4.2 Production capabilities

Related to the high degree of customisation, contracts in the oil industry most often involve small batches rather than a large volume. This has important implications for how firms organise production. To accommodate customisation in oil, firms must have a large degree of flexibility in production. Flexibility comes from many manual and engineering hours that raise costs. R&D is, in other words, typically integrated with production making it possible to experiment with product design so that a high quality output can be achieved. In the new markets, however, focus was on minimizing unit prices through mass-production of standardised components.

Firms articulated this as a change from engineering towards serial manufacturing. In the words of one manager (I-1): '[A] *major difference is that offshore wind is about serial production rather than small-batch production. For offshore wind, you often deliver 15–50 identical items while for oil it is normally 1–3 items per project. For offshore wind you therefore need more focus on planning the production steps and ensure that component stocks and logistics are in place*'.

An important aspect of such reorganisation is to separate engineering and production more clearly. For example, one firm (I-2) stated that it used to be '*50% engineering and 50% production*', but after moving into offshore wind it had become '*more like 20% engineering and 80% production*'. The firm said that '*this reduced labour input by 25% per output* unit'.

Large-batch production also has repercussions for innovation management. One manager explained, '*If you can change your component design such that production per unit is 10 minutes faster, then you can make money because these 10 minutes per unit are valuable when you produce thousands of units. In oil, engineering was more about tailoring solutions to each project*' (I-2). Many firms experienced the changes required in the organisation of production as very challenging and most indicated that this adaption is a long-term and ongoing process.

4.3 Market properties

4.3.1 From long-term coordinated to shorter-term multi-party contracts

The typical form of contracting between supply firms and their clients differs between oil and most other industries. We highlight four aspects: type of contracting, size and duration of contracts, culture of billing, and funding of project development.

In oil activities, so-called EPC (engineering, procurement and construction) contracts dominate. These imply that the client has 1-2 interfaces with turnkey supply firms – systems integrators – which manage a network of sub-suppliers. Many of the firms are therefore part of these coordinated networks and have close contractual relationships with only a few actors. By contrast, 'multi-contracting' is the most common form of contracting within offshore wind power. Here, the client manages many interfaces – up to 20 different partners – directly, which interviewees claim is because it allows them to have more control of the projects so as to reduce costs. For the supply firms this is unattractive because risks are higher and channels of communication more complex. Moreover, there are many more potential clients, and competition for their attention is fiercer.

Interviewees stated that the most attractive oil contracts last five years, much longer than for example wind park installation which typically is 6–9 months. A newcomer with a limited portfolio of orders can have costly, in-between-project periods of inactivity. In addition, diversifying firms need to operate in a more heterogeneous market with more frequent sales activities. This means that more organisational resources go into customer care, marketing and sales.

Furthermore, the culture of billing is different. The typical pattern described in oil is that cost overruns (concerning agreed price) are normally not problematic and firms are allowed to send an extra invoice. In other sectors, the price is fixed from the beginning of a contract and additional costs become the supplier's own problem. Moreover, timing and speed were described as more flexible in oil. If a supplier delivers a good quality product within 'reasonable time', a generous price can be asked. In sectors such as construction and offshore wind power, delays are penalised with day fines, requiring the firms to be much more disciplined.

Finally, in oil there is funding available for comprehensive 'pre-study' analyses and informal and interactive learning between suppliers and their clients. In other industries, funding is different. For example, offshore wind most often involves 'project financing' in which creditors demand strong influence on project planning and commissioning in the form of a meticulous and low-risk plan, and a framework for aspects such as risk allocation and time discipline that were seen as 'rigid'. Interviewees claimed that this led to 'very conservative' technology choices with only 'proven technology' being implemented rather than more innovative solutions.

4.3.2 Customer relations

As mentioned, the new markets were generally regarded as more competitive and with different types of business-to-business marketing and sales activities than responses to procurements. Oil was characterised by intense and long-term relationships partly based on trust with relatively few actors, while in other industries relationships were more arms-length. This type of industry difference suggests the need for a rather different approach to customer relationships which seems to be difficult to adopt. Indeed, several firms struggled to get into good working relationships with clients in other industries and to understand needs in the new market.

4.4 Other issues

In this section we summarize selected other findings that inform us of aspects of firms' diversification process beyond the three selected analytical dimensions.

4.4.1 Time and timing in diversification

A general finding is that firms tend to underestimate the time needed for diversification. A technology manager (I-13) emphasised that the biggest challenge '*is that things take time, and time is money'*. Although the process of learning about new clients and their needs, and adapting and marketing products and services to these needs, was not insurmountable, it took much more time and resources than anticipated. Indeed, most firms in our sample are still in the process of finding their feet in the new market, see Table 1. Hence, it is not yet certain that maintaining their activity in the new area will prove financially viable in the longer term.

For this reason alone, the issue of timing is important. In the view of one informant: '*If you decide to diversify only when you are in a crisis, it will be too late*' (I-11). The same informant observed that many oil suppliers have the ability and willingness to diversify but have been too busy with surviving the oil crisis to dedicate the necessary attention and resources. Struggling simultaneously in new and old markets is problematic for a more evolutionary process of organisational learning.

This issue is also visible in firms' assessment of the role of policy. Some firms used funding from the Research Council of Norway and R&D tax deduction schemes to support diversification. Still, they emphasised that the adequacy of these policy instruments depends on context. For example, if there is a need to diversify due to a crisis in the main market, traditional instruments work too slowly. In the words of one R&D manager: '*It is OK but takes too long and requires too much energy. You haven't even gotten a response on your application before you have passed the concept design phase (in a project)'* (I-7). Firms thus seem to miss dedicated support for diversification rather than more general support for various types of innovation, R&D and (re)training that do not fit their immediate problems.

4.4.2 Target industry maturity

Some informants also highlighted that low maturity of new industries is an advantage. One CEO argued that '*if you produce milk, you can't just start producing meat and expect to outcompete established slaughterhouses. There are more opportunities in emerging, niche markets*' (I-11). Another CEO remarked: '*Aquaculture is like a teenage industry: a bit Wild West with few rules but many opportunities*' (I-12). Hence, although often characterised by high uncertainty, diversification to emerging product markets may be easier due to less competition from established players.

5 Discussions and conclusions

In this paper we have proposed a framework for broadening our understanding transitions as something that involves multiple technologies and sectors. The main motivation was to better capture continuity aspects of transitions residing in the upstream industries of relevant technology value chains. Here we emphasized the potential of firms to diversify across industries and technologies in response to transition processes. We have used this framework to explore such activities among firms operating in the Norwegian offshore oil technology value chain. In this section we present main insights from our study and discuss their implications for research and policy.

5.1 Firm diversification insights

Firms that have tried to diversify to other technology value chains faced various challenges. Technology was not an obstacle which indicated high relatedness. This may be because firms choose target markets based on perceived relatedness in the product or technology dimensions. However, the 'softer' aspects linked to organisation of innovation, production, and market properties clearly exhibit lower relatedness than technology. Consequently, they constitute more disruptive challenges for firms.

The firms are accustomed to customized technology development and production processes, often oriented towards large-scale one-of-a-kind outcomes, generously supported by the oil clients and carried out in a system with few but intensive linkages. For most firms, the new markets operate differently. To diversify, the firms have to streamline production, increase in-house R&D and technology development, and maintain linkages to a much larger number of potential customers. The low relatedness in multiple dimensions implies that the transformation is very challenging for most firms. Since technology was not a major issue, firms reported that traditional innovation policy instruments such as support for R&D, innovation and retraining of personnel were not very helpful. Particularly if decline was already significant.

Our analysis shows that firms can and do diversify away from their main technology value chain in response to decline signals. It also shows that diversification decisions are partly motivated and guided by considerations of technology relatedness combined with an underestimation of associated organizational changes and the time needed adapt them.

5.2 Technology phase-out thinking

Our findings show that technology phase-out and associated industry decline is not only about disruption and obsolescing of resources and capabilities but also about diversification, redeployment, and continuity. Our analysis also demonstrates the relevance of explicitly considering upstream sectors of the focal technology value chain.

We saw that the decision to diversify was motivated both by decline signals and by visible opportunities to redeploy existing resources and capabilities (cf. Table 1). Further qualifying this insight, a recent survey (anno 2013) of

102 firms distributed across the oil technology value chain, found that uncertainty about future prospects and opportunity to redeploy resources and capabilities were major motivations for firm diversification (Steen & Weaver, 2017). It suggests that co-existence of exit pressure and identifiable diversification opportunities, is important for diversification to occur. This points to a demand-side or market-pull perspective on diversification policy rather than merely exit and push pressures. It suggests that phase-out policy should address both exit pressures as well as supporting opportunities for entry to new markets.

Combining technology phase-out with diversification may yield several benefits. Firstly, by providing firms that depend on the focal technology alternative options for value creation, they are less likely to actively resist phase-out policy. As a consequence, the phase-out process may be faster and less contested. Second, promoting continuity of firms in phase-out processes may reduce job and income losses in areas whose industrial specialization is deeply related to the focal technology.

Our study further points to some particular challenges related to realizing these continuities that are relevant for phase-out policy. Firms in our sample found traditional technology-oriented innovation policy instruments inappropriate. One reason is that their main challenges were related to organizational innovation. Also, firms that decided to diversify only after a period of decline, found that traditional innovation policy instruments were too slow and thus irrelevant for them. This suggests that a policy strategy aiming at integrating technology phase-out with diversification should consider non-technological aspects of diversification. It should also address the likely situation that firms wishing to exit and diversify already are under significant financial stress. In fact, both issues suggest that such a policy strategy can only commence too late. While phase-out and exit may be achieved with the stroke of a pen, diversification is a longer-term and much more demanding process.

Firms also emphasized the attractiveness of targeting emerging rather than mature technology value chains because the latter is often characterized by high entry barriers including strong competition. This points to another aspect of the demand-side of diversification policy. It suggests that technology phase-out strategy should include support for the creation of new industries and technologies that in some dimension(s) are related to the old technology value chain. This would provide an identifiable and attractive diversification opportunity for firms expected to suffer from the technology phase-out. It could involve support for network formation, infrastructure investments, and appropriate skill development. Indeed, this amounts to a strategy for related diversification at the level of a country's industrial structure which necessarily involves distributed agency to enable collective search and experimentation processes (Boschma & Frenken, 2011; Garud &

Karnøe, 2001; Van De Ven, 1993). The new industries need not be related directly to the goals of the socio-technical transition in question.

5.3 Implications for transition studies

At a more general level we have suggested to draw on existing technology studies and evolutionary economics to get a better grip on the multi-sector and multi-technology nature of socio-technical transitions. Despite its limitations, our analysis qualifies this approach and the need for considering entire technology value chains as well as influence on adjacent sectors in transition processes. It also illustrates the value of taking a combinatory view on innovation. Here we discuss three resulting implications for transition studies more broadly.

First, the argument presented above that 'creation' of new activities in adjacent sectors and technologies can facilitate 'destruction' of another technology without being in direct competition, adds another spin on the relationship between Schumpeterian destruction and creation processes. Indeed, it illustrates that the new combinations of resources and capabilities that underpin economic evolution and structural change cannot be confined to single-sector dynamics. As such it questions the relevance of the term 'creative destruction' to describe niche-regime competition.

Second, considering entire technology value chains in socio-technical transitions asks new questions about how to define a socio-technical regime. In practice, researchers focus on technology-using sectors and associated actors. But sectors along the value chain are interdependent and their interaction patterns influence how transitions unfold. There may therefore be a case for arguing that the regime notion could be extended to cover the entire value chain. Indeed, Geels (2002) seems to suggest this. Still, given the heterogeneity of the actors and sectors linked along a technology value chain including suppliers, sub-suppliers, and raw material producers, it may be equally valid to consider a string of regimes interlinked along the value chain of a focal technology. Regarding actors, it seems likely that upstream manufacturers of components are more flexible than downstream oil companies. The reason is that value creation by oil companies is directly connected to the natural resource while upstream firms create value on the basis of their productive and innovative capabilities. Whether upstream firms in general are better equipped to adapt and diversify than downstream firms, is a question for future research. An upstream perspective also draws attention to new kinds of actors such as labor unions and local and regional public actors that are likely to orchestrate resistance to change that endangers jobs and income. Indeed, enrolling such actors in a technology phase-out strategy is probably crucial for its success.

Third, economies have different industrial and technological specializations that in aggregate terms change in an incremental and path-dependent manner. A combinatory view on innovation suggests that your specialization today to great extent will define what you can do tomorrow such that there are limits to the possible diversification space of both economies and firms. This implies that the upstream repercussions of a transition in e.g. the energy sector will vary across economies. Indeed, following up on the above, you would expect that economies with strong manufacturing industries or/and high complex (the more diverse and complex resources and knowledge you have, the more new combinations you can generate), will be able to redeploy resources in response to a changing energy technology landscape (Hidalgo & Hausmann, 2009). Similarly, economies that are less complex and/or are specialized in production of fossil-energy, are more exposed to such changes. An economy's prospects of combining any socio-technical transition with job creation and new industry formation, will depend on depth and diversity of extant knowledge and resources. Therefore economies follow rather different transition pathways. Looking beyond technology phase-out, it makes sense that transition analysts and policy makers consider more explicitly how related diversification of the industrial structure can be combined with a socio-technical transition. Indeed, it is one way of pursuing a transition pathway with minimized political resistance and maximized redeployment to support jobs and income in the process.

6 References

Andersen, A. D., & Gulbrandsen, M. (2018). Diversification into new markets: challenges and opportunities for petroleum supply firms. In T. M. Thune, O. A. Engen, & O. Wicken (Eds.), *Transformations in the Petroleum Innovation System: Lessons from Norway and Beyond*: Routledge.

Andersen, E. S. (2009). *Schumpeter's Evolutionary Economics: A Theoretical, Historical and Statistical Analysis of the Engine of Capitalism*. London: Anthem Press.

Andersen, E. S. (2013). Schumpeter's Core Works Revisited. In A. Pyka & E. S. Andersen (Eds.), *Long Term Economic Development. Economic Complexity and Evolution*. Berlin, Heidelberg: Springer.

Arthur, W. B. (2009). *The Nature of Technology: What It Is and How It Evolves*: Free Press.

Berggren, C., Magnusson, T., & Sushandoyo, D. (2015). Transition pathways revisited: Established firms as multi-level actors in the heavy vehicle industry. *Research Policy, 44*, 1017-1028. doi:10.1016/j.respol.2014.11.009

Boschma, R., & Frenken, K. (2011). Technological relatedness, related variety and economic geography. In P. Cooke, B. T. Asheim, R. Martin, D. Schwartz, & F. Tödling (Eds.), *Handbook of regional innovation and growth*: Edward Elgar.

Breschi, S., Lissoni, F., & Malerba, F. (2003). Knowledge-relatedness in firm technological diversification. *Research Policy, 32*(1), 69-87.

Cantwell, J., & Vertova, G. (2004). Historical evolution of technological diversification. *Research Policy, 33*, 511-529.

Dahmén, E. (1989). "Development Blocks" in Industrial Economics. In B. Carlsson & R. G. H. Henriksson (Eds.), *Developments blocks and industrial transformation : the Dahménian*

approach to economic development. Stockholm: The Industrial Institute for Economic and Social Research.
David, M. (2017). Moving beyond the heuristic of creative destruction: Targeting exnovation with policy mixes for energy transitions. *Energy Research & Social Science, 33*, 138-146. doi:https://doi.org/10.1016/j.erss.2017.09.023
David, P. A. (1985). Clio and the Economics of QWERTY. *The American Economic Review, 75*(2), 332-337.
E24. (2016, 2 September 2016). Oljeleverandører søker fiskelykken. Retrieved from http://e24.no/naeringsliv/ons-oljemessen/oljeleverandoerer-soeker-fiskelykken-satser-stort-paa-oppdrett-offshore/23780982
EC. (2016). *Accelerating Clean Energy Innovation*. Brussels: European Commission.
Engen, O. A. (2009). The development of the Norwegian petroleum innovation system : a historical overview. In J. Fagerberg, D. C. Mowery, & B. Verspagen (Eds.), *Innovation, Path Dependency and Policy. The Norwegian Case* (pp. 387). Oxford: Oxford University Press, 2009.
Fagerberg, J. (2003). Schumpeter and the revival of evolutionary economics: an appraisal of the literature. *Journal of Evolutionary Economics, 13*(2), 125-159. doi:DOI 10.1007/s00191-003-0144-1
Farla, J., Markard, J., Raven, R., & Coenen, L. (2012). Sustainability transitions in the making: A closer look at actors, strategies and resources. *Technological Forecasting and Social Change, 79*, 991-998.
Path creation as a process of mindful deviation 440 (Psychology Press 2001).
Geels, F. W. (2002). Technological transitions as evolutionary reconfiguration processes: a multi-level perspective and a case-study. *Research Policy, 31*, 1257-1274.
Geels, F. W. (2005). Processes and patterns in transitions and system innovations: Refining the co-evolutionary multi-level perspective. *Technological Forecasting and Social Change, 72*, 681-696.
Geels, F. W. (2006). The hygienic transition from cesspools to sewer systems (1840–1930): The dynamics of regime transformation. *Research Policy, 35*(7), 1069-1082. doi:https://doi.org/10.1016/j.respol.2006.06.001
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*(2), 261-277. doi:10.1016/j.respol.2013.10.006
Geels, F. W., Kern, F., Fuchs, G., Hinderer, N., Kungl, G., Mylan, J., . . . Wassermann, S. (2016). The enactment of socio-technical transition pathways: A reformulated typology and a comparative multi-level analysis of the German and UK low-carbon electricity transitions (1990-2014). *Research Policy, 45*(4), 896-913. doi:http://dx.doi.org/10.1016/j.respol.2016.01.015
Geels, F. W., & Schot, J. (2007). Typology of sociotechnical transition pathways. *Research Policy, 36*(3), 399-417.
Helfat, C. E., & Lieberman, M. B. (2002). The birth of capabilities: market entry and the importance of pre-history. *Industrial and Corporate Change, 11*(4), 725-760. doi:10.1093/icc/11.4.725
Helfat, C. E., & Peteraf, M. A. (2003). The dynamic resource-based view: capability lifecycles. *Strategic Management Journal, 24*(10), 997-1010. doi:10.1002/smj.332

Hess, D. J. (2013). Industrial fields and countervailing power: The transformation of distributed solar energy in the United States. *Global Environmental Change, 23*(5), 847-855. doi:http://dx.doi.org/10.1016/j.gloenvcha.2013.01.002

Hidalgo, C., & Hausmann, R. (2009). The building blocks of economic complexity. *Proceedings of the National Academy of Sciences of the United States of America, 106*, 10570-10575.

Hidalgo, C. A. (2018). From useless to keystone. *Nature Physics, 14*, 9. doi:10.1038/nphys4337

IEA. (2016). *Energy Technology Perspectives 2016. Towards Sustainable Urban Energy Systems*. Retrieved from http://www.iea.org/bookshop/719-Energy_Technology_Perspectives_2016

Karltorp, K., & Sandén, B. A. (2012). Explaining regime destabilisation in the pulp and paper industry. *Environmental Innovation and Societal Transitions, 2*, 66-81. doi:https://doi.org/10.1016/j.eist.2011.12.001

Kemp, R., Schot, J., & Hoogma, R. (1998). Regime shifts to sustainability through processes of niche formation: The approach of strategic niche management. *Technology Analysis & Strategic Management, 10*, 175-198.

Kern, F., & Rogge, K. S. (2016). The pace of governed energy transitions: Agency, international dynamics and the global Paris agreement accelerating decarbonisation processes? *Energy Research & Social Science, 22*(Supplement C), 13-17. doi:https://doi.org/10.1016/j.erss.2016.08.016

Kivimaa, P., & Kern, F. (2016). Creative destruction or mere niche support? Innovation policy mixes for sustainability transitions. *Research Policy, 45*, 205-217. doi:10.1016/j.respol.2015.09.008

Kogut, B., & Zander, U. (1992). Knowledge of the Firm, Combinative Capabilities, and the Replication of Technology. *Organization Science, 3*(3), 383-397.

Lemelin, A. (1982). Relatedness in the Patterns of Interindustry Diversification. *The Review of Economics and Statistics, 64*(4), 646-657. doi:10.2307/1923949

Leonard-Barton, D. (1992). Core capabilities and core rigidities: A paradox in managing new product development. *Strategic Management Journal, 13*(S1), 111-125. doi:doi:10.1002/smj.4250131009

Lundvall, B.-Å. (1985). Product Innovation and User-Producer Interaction. *Industrial Development Research Series, Aalborg University Press*.

Markard, J., & Hoffmann, V. H. (2016). Analysis of complementarities: Framework and examples from the energy transition. *Technological Forecasting and Social Change, 111*, 63-75. doi:http://dx.doi.org/10.1016/j.techfore.2016.06.008

Markard, J., Raven, R., & Truffer, B. (2012). Sustainability transitions: An emerging field of research and its prospects. *Research Policy, 41*, 955-967.

Markard, J., Wirth, S., & Truffer, B. (2016). Institutional dynamics and technology legitimacy: A framework and a case study on biogas technology. *Research Policy, 45*, 330-344.

Murmann, J. P., & Frenken, K. (2006). Toward a systematic framework for research on dominant designs, technological innovations, and industrial change. *Research Policy, 35*(7), 925-952. doi:http://doi.org/10.1016/j.respol.2006.04.011

Mäkitie, T., Andersen, A. D., Hanson, J., Normann, H. E., & Thune, T. M. (2018). Established sectors expediting clean technology industries? The Norwegian oil and gas sector's influence on offshore wind power. *Journal of Cleaner Production, 177*, 813-823.

Normann, H. E. (2017). Policy networks in energy transitions: The cases of carbon capture and storage and offshore wind in Norway. *Technological Forecasting and Social Change, 118*, 80-93. doi:https://doi.org/10.1016/j.techfore.2017.02.004
Pasinetti, L. (1993). *Structural economic dynamics: a theory of the economic consequences of human learning*: Cambridge University Press.
Porter, M. (1990). The Competitive Advantage of Nations. *Harvard business review*.
Raven, R. (2007). Niche accumulation and hybridisation strategies in transition processes towards a sustainable energy system: An assessment of differences and pitfalls. *Energy Policy, 35*(4), 2390-2400. doi:https://doi.org/10.1016/j.enpol.2006.09.003
Robertson, P. L., Pol, E., & Carroll, P. (2002). A new typology for economic sectors with a view to policy implications. *Economics of Innovation and New Technology, 11*(1).
Rogge, K. S., & Johnstone, P. (2017). Exploring the role of phase-out policies for low-carbon energy transitions: The case of the German Energiewende. *Energy Research & Social Science, 33*(Supplement C), 128-137. doi:https://doi.org/10.1016/j.erss.2017.10.004
Rumelt, R. P. (1974). *Strategy, structure, and economic performance*. Boston, Mass.
Rumelt, R. P. (1982). Diversification strategy and profitability. *Strategic Management Journal, 3*(4), 359-369. doi:doi:10.1002/smj.4250030407
Saether, B., Isaksen, A., & Karlsen, A. (2011). Innovation by co-evolution in natural resource industries: The Norwegian experience. *Geoforum, 42*(3), 373-381. doi:10.1016/j.geoforum.2011.01.008
Smink, M. M., Hekkert, M. P., & Negro, S. O. (2015). Keeping sustainable innovation on a leash? Exploring incumbents' institutional strategies. *Business Strategy and the Environment, 24*(2), 86-101. doi:10.1002/bse.1808
Steen, M., & Weaver, T. (2017). Incumbents' diversification and cross-sectorial energy industry dynamics. *Research Policy, 46*(6), 1071-1086. doi:https://doi.org/10.1016/j.respol.2017.04.001
Stegmaier, P., Kuhlmann, S., & Visser, V. (2014). The discontinuation of socio-technical systems as a governance problem. In S. Borrás & J. Edler (Eds.), *The Governance of Socio-Technical Systems* (pp. 111-128): Edward Elgar.
Stephan, A., Schmidt, T. S., Bening, C. R., & Hoffmann, V. H. (2017). The sectoral configuration of technological innovation systems: Patterns of knowledge development and diffusion in the lithium-ion battery technology in Japan. *Research Policy, 46*(4), 709-723. doi:https://doi.org/10.1016/j.respol.2017.01.009
Tanriverdi, H., & Venkatraman, N. (2005). Knowledge relatedness and the performance of multibusiness firms. *Strategic Management Journal, 26*(2), 97-119. doi:10.1002/smj.435
Turnheim, B., & Geels, F. W. (2012). Regime destabilisation as the flipside of energy transitions: Lessons from the history of the British coal industry (1913–1997). *Energy Policy, 50*, 35-49.
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). *Research Policy, 42*(10), 1749-1767. doi:https://doi.org/10.1016/j.respol.2013.04.009
Tushman, M. L., & Murmann, J. P. (1998). Dominant designs, technology cycles and organizational outcomes. *Research in Organizational Behavior, 20*, 231–266.

Van De Ven, H. (1993). The development of an infrastructure for entrepreneurship. *Journal of Business Venturing, 8*(3), 211-230. doi:http://dx.doi.org/10.1016/0883-9026(93)90028-4
van Mossel, A., van Rijnsoever, F. J., & Hekkert, M. P. (2018). Navigators through the storm: A review of organization theories and the behavior of incumbent firms during transitions. *Environmental Innovation and Societal Transitions, 26*, 44-63. doi:https://doi.org/10.1016/j.eist.2017.07.001
Weitzman, M. L. (1998). Recombinant growth. *Quarterly Journal of Economics, 113*(2), 331-360. doi:Doi 10.1162/003355398555595
Wesseling, J. H., & Van der Vooren, A. (2017). Lock-in of mature innovation systems: the transformation toward clean concrete in the Netherlands. *Journal of Cleaner Production, 155*, 114-124. doi:http://dx.doi.org/10.1016/j.jclepro.2016.08.115
Winskel, M. (2018). Beyond the disruption narrative: Varieties and ambiguities of energy system change. *Energy Research & Social Science, 37*, 232-237. doi:https://doi.org/10.1016/j.erss.2017.10.046
Wirth, S., & Markard, J. (2011). Context matters: How existing sectors and competing technologies affect the prospects of the Swiss Bio-SNG innovation system. *Technological Forecasting and Social Change, 78*, 635-649.
Zindler, E., & Locklin, K. (2016). Mapping the gap: The Road from Paris. Finance Paths for a 2-Degree Future.