Energy sector; an industrial perspective on energy transitions

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Abstract

An energy transition is needed to mitigate climate change. Put simply, the world's current reliance on fossil fuels must end through a process of decarbonization whereby the combustion of fossil fuels is replaced by low- and zero-carbon energy solutions. These changes will rely on substantial technological innovation and imply significant transformation processes in both energy-producing and energy-consuming sectors, as well as in e.g. grid systems. While significant changes are already underway, overall change is currently too slow and needs to be greatly accelerated for carbon emission reduction targets (such as outlined in Paris Agreement) to be met. Drawing on the sustainability transition literature, the aim of this chapter is to provide an overview of the socio-technical transformation dynamics and processes associated with this on-going energy transition. The chapter reviews two key frameworks in the sustainability transitions literature: the multi-level perspective and technological innovation systems. Moreover, it takes note of the recent elaborations outlining an industrial perspective on sustainability transitions. We illustrate energy transition processes and industry perspectives with examples from two empirical cases in Norway. We conclude by arguing that more attention to industrial perspectives in energy transitions is warranted to better understand crucial industrial upscaling processes necessary for the acceleration of energy transitions, and to explore policy perspectives that may aim to contribute to a sustainable industrial transformation and just transitions. Finally, we point to promising future research avenues in this yet emerging field of research.

1. Introduction

Fundamental changes in world's energy systems are needed to avoid catastrophic climate change. In brief, the energy production and consumption need to stop emitting fossil fuel-based greenhouse gases to the atmosphere and instead transition towards alternative solutions. This is a complex process that we in this chapter discuss through the perspective of socio-technical systems change (Markard et al., 2012), or the 'energy transition' in short (Markard, 2018). While incremental improvements such as increased energy-efficiency are also needed, at the core of this transition is the radical shift from fossil fuels to renewable energy sources. Moreover, development and deployment of negative carbon technologies such as carbon capture and storage (CCS) are needed to cut emissions in for instance cement production. Decarbonization needs to occur everywhere and in practically all sectors of our economies. However, the conditions for energy transitions differ immensely across sectors, regions and countries.

Curiously, emission reduction strategies and political commitments have by and large been developed "separately from economically-oriented industrial strategies" (Busch et al., 2018, 114). Energy transition research has also primarily focused on production technologies (e.g. wind power) and energy use 'downstream sectors' (e.g. transport). By contrast, industry dynamics and the many 'upstream sectors' involved in the provision, development and manufacturing of various raw materials, components and services have received far less attention (Andersen et al., 2020). There is thus a need to further explore the intersection between energy transitions and industrial development.

The aim of this chapter is to provide an socio-technical perspective on industrial development in the context of energy transitions, both in energy producing and using sectors. In order to do so, we draw on the sustainability transition literature (Markard et al., 2012). This field of research offers various perspectives to the phenomena of socio-technical systems change. Similar to them is that the various perspectives conceptualize and explain broad socio-technical change through the interplay between various social and technological factors, including agency, existing and emerging technologies, policies, institutions, infrastructure and social practices, taking place under sectoral, technological, geographical and societal contexts. The sustainability transition literature thus acknowledges the complex and systemic nature of energy transitions. Crucially, such transition processes also are dependent on, but also have major implications for, industrial development. We illustrates this 'industrial perspective on sustainability transitions' with insights from sustainability transitions literature and with empirical examples from two cases: transformations inn offshore energy extraction/production and maritime transport in Norway.

This chapter has five sections. In Section 2 we provide a brief background to the energy transition. In Section 3 we review two key frameworks in the sustainability transitions literature: the multi-level perspective and the technological innovation system. Moreover, we present recent elaborations regarding an industrial perspective on sustainability transitions. In Section 4 we provide two brief empirical illustrations of energy transition processes based on our own empirical work in Norway. Finally, in Section 5 we conclude by discussing promising future research avenues.

2. The energy transition – entering a new phase?

The energy transition is a monumental task. In 1950, the direct primary energy consumption globally was 27,972 TWh, of which 20,139 TWh (roughly 67%) was provided by natural gas, oil and coal (fossil fuels). Traditional biomass (i.e. wood, agricultural bi-products and dung burned for cooking and heating purposes) accounted for 7,500 TWh, implying that a meagre 1% was provided by "modern" renewable energy, which in this context refers to all renewable energy except for traditional biomass-based energy. By 2019, global energy consumption has seen an almost six-fold increase to 158,839 TWh. Most of this growth is in fossil fuels, and only 8% (or 10,967 TWh) was provided by nuclear energy and modern renewables (e.g. solar PV) combined.[1] To meet the climate mitigation target of Paris Agreement, all sectors of the economy will be influenced directly or indirectly as fossil fuels need to be substituted with low- and zero-carbon energy solutions.

Apart from the shift from fossil fuels to renewables and the need for end-of-pipe solutions such as CCS, the energy transition implies significant changes in energy system architectures. More specifically, this concerns a change from largely centralized power production based on a few energy sources and large-scale solutions towards including also more decentralized (and off-grid) production based on many different energy sources, as well as the need for storage and (smart) grid management technologies. Obviously, this applies to those parts of the world where an energy (power) infrastructure already exists. Currently 13% of the world population does not have access to

[1] These figures are drawn from Our World in Data, see https://ourworldindata.org/charts#energy

'modern' energy resources, with that referring principally to electricity.[2] Therefore, and as mirrored in SDG7[3], an important objective for the world community moving forward is to "*ensure access to affordable, reliable, sustainable and modern energy for all*." By extension, the development of energy systems where those do not already exist needs to happen in sustainable ways. This having said, this chapter will focus on the energy transition and industrial transformation in the 'Global North'. Moreover, in addition to replacing fossil fuels with renewables, there is also need for massive energy efficiency improvements and most likely also for technologies that can contribute to removing carbon from the atmosphere.

As suggested in the introduction, the energy transition is a slow and challenging process. Fossil fuels (coal, oil, natural gas) remain dominant as the 'energy staple' of the global economy and will continue to do so for decades even with a sharp increase in the deployment of renewable energy. There are however strong indications that we are entering a new phase of accelerated change (Markard, 2018). This momentum is created by more progressive mitigation policies, and the co-evolution of technology development, policies, and the industrial capacity to produce and deliver new technologies at scale.

The increasing deployment of renewable energy technologies such as solar PV and wind power, as well as the ramp-up in the adoption of electric vehicles in certain markets can be regarded as both cause and effect of the development of economies of scale and significant learning effects. The costs of solar PV and wind energy have been drastically reduced over the last two decades, and is now price-competitive with established energy solutions in parts of the world. While a typical wind energy turbine in 1990 was 0.5MW, the largest wind turbines currently deployed (offshore) are now in the range of 9.5MW, whereas turbines in the 14-16MW range are expected in coming years. Offshore wind power farms developed in Europe, of which the Hornsea Two (1.4 GW) in the UK is the largest, now constitute some of the world's biggest infrastructure projects. Not only are these projects very large: they are also highly complex and involve a multitude of different specialized and multi-industry firms supplying various components and services throughout the different life-phases of these energy projects.

The upscaling of industrial capacity to provide raw materials, components and services to renewable energy will need to be significantly accelerated in coming years. Similarly, technological development and diffusion of solutions for alternative energy distribution and consumption in various energy end-use sectors needs to greatly accelerate. As energy is integral to all sectors of the economy, and many sectors are involved in energy value chains (e.g., forestry, agriculture, mining, metals, electronics, ICT), the energy transition will have pervasive if not paradigmatic effects.

A pertinent question is thus, both from a policy and industry point of view, to what extent energy transition processes require that new solutions are developed from scratch, or whether decarbonization can be aided by the repurposing and reutilisation of existing infrastructures, knowledge, manufacturing capacity and other resources. From a value chain perspective, the need for transformation is contingent on the type of energy technology and (industry) characteristics of the sectors involved in the various parts of the value chain. For example, replacing fossil fuels with biofuels primarily demands changes in the production and distribution segments of the value chain,

[2] As of 2019, approx. 3 billion people relied on wood, coal, charcoal or animal waste (i.e. traditional biomass-based energy) for cooking and heating, which has highly detrimental health effects notably on women and children in developing countries. https://trackingsdg7.esmap.org/data/files/download-documents/2019-Tracking%20SDG7-Full%20Report.pdf

[3] Sustainable Development Goal 7 Affordable and Clean Energy. https://sdgs.un.org/goals/goal7

whereas the need for adaptation in end-user segments (e.g. transport) can be relatively minor. For other low- or zero-carbon solutions the reverse is the case. Provided that power generation and grid infrastructure is in place, the introduction of battery-electric energy solutions mainly requires significant changes in downstream value chain segments, charging infrastructure and other system interface technologies. And finally, for some of the energy solutions, such as hydrogen, significant innovation and investment is needed throughout the entire value chain.

While technologies such as wind power, solar PV and electrical vehicles are now maturing, progress has been slower in 'hard-to-abate' sectors such as deep-sea shipping, long-range aviation or the energy-intensive processing industries. This not only has to do with mere technical feasibility, but also factors such as long investment cycles in many sectors, no premiums on 'green operations' and the need for 'global' coordination to facilitate infrastructure development.

To summarize, energy transitions are complex long-term processes which not only offer a technical challenge, but a social one due to e.g. path dependence in old technologies, and the need for market creation, legitimation, and resource mobilization around new technologies. In the following we discuss key perspectives from the sustainability transitions literature to further conceptualize such transition and radical innovation processes.

3. Theoretical perspectives on energy transitions and industrial transformation

The research field of sustainability transitions has emerged over the last 15-20 years and made significant contributions to our understanding of the drivers and barriers for change processes in the socio-technical systems that deliver key societal services such as energy and transport (Markard et al., 2012). This interdisciplinary field emerged from innovation studies, evolutionary economics, science and technology studies, whereas it is increasingly also influenced by other fields such as sociology, political science and economic geography. This reflects how transitions fundamentally relate to how we organize the key sectors that deliver crucial services such as energy, heat, food and mobility that we all depend on.

As a point of departure, the sustainability transitions research field recognizes that established socio-technical systems of production and consumption have developed over long periods of time whereby technologies, markets, infrastructures, practices, institutions and cultural meanings have co-evolved into coherent functional systems. Transitions are thus multi-dimensional and difficult to achieve due to path dependencies and different types of lock-ins (Klitkou et al., 2015).

Transitions are furthermore open-ended, often with significant uncertainties with regards to for instance which new technologies that may prevail in the long run. They are therefore imbued with multiple and often competing expectations and visions, involving various types of actors. With this uncertainty also comes considerable risk, which may defer private actors from investing (sufficiently) into new technologies. There is therefore consensus within this research field that policy plays a key role in facilitating and enabling transitions by supporting niche technologies (from R&D to implementation) until they are competitive. On the other side of the coin there is an increasing recognition that policy also needs to contribute to the destabilization of existing socio-technical systems, however this is naturally associated with political problems and resistance from defenders (often industrial incumbents) of status quo (Kivimaa and Kern, 2016).

Needless to say, transition processes often involve power struggles. Most often this is articulated as a battle between the incumbent firms and actors associated with established technologies and sectors on the one side, and actors involved in for example the development of renewable energy technologies on the other (Hockerts and Wüstenhagen, 2010). However, power struggles in transitions involve also many other types of actors, including environmental NGOs and the general public, as witnessed in resistance towards renewable energy projects, or rising fossil fuel prices.

3.1. The multi-level perspective

The ways in which transitions unfold has most clearly been articulated in the so-called multi-level perspective (MLP), conceptualized by Geels (2002). According to the MLP, the specific dynamics through which transition processes unfold is contingent on the interplay between developments at landscape, regime and niche levels, with these levels being understood as representing different degrees of institutional structuration. Put simply, transitions require sufficient pressure on the 'regime' to change, and this pressure may be exerted by for example increasing public and political attention to environmental issues or rising fuel prices (i.e., 'landscape' factors), while there also needs to be technological alternatives ('niche' technologies) that can supplement or replace 'regime' technologies for a transition to occur.

The key concept in the MLP is the socio-technical *regime*. The regime is understood as an interrelated and stable structure made up of a heterogeneous network of actors, comprising established products and technologies, infrastructure, user practices, expectations, norms and regulations (Smith et al., 2005). The socio-technical regime concept extends Nelson and Winter's (1982) conceptualization of technological regimes[4] by adding various informal and formal rules that also serve to stabilize regimes. This reflects an important argument in the MLP, namely that many different types of actors and social networks are involved in reproducing, maintaining and transforming socio-technical systems, making transitions – the shift from one regime to another – complex and long-term processes (Geels, 2011).

Niches are the 'protected spaces' in which new technologies can emerge and develop until they are able to compete with existing technologies on performance or price. Niches are protected spaces in the sense that they are offer opportunities for technology development and implementation ‘free’ from the constraints of market selection, performance standards and the infrastructural rigidities of established systems. Given the systemic perspective inherent to the MLP, niche technologies most often require some (small or large) degree of change and adaptation in existing socio-technical systems for them to 'work'. For example, the upscaling of renewable energy production requires massive investments into grid infrastructure, new storage systems, and grid management technology (Andersen and Markard, 2020). New (niche) technologies have been shown to have lengthy emergence phases, normally spanning several decades (Bento and Wilson, 2016). This underscores the importance of long-term policy support, not least to provide actors involved in innovation with some certainty that there is reason to believe in life after (potentially) crossing the valley of death.

Based on the MLP, different types of *transition pathways* (e.g., substitution, reconfiguration, transformation) have been articulated (Geels et al., 2016). In relation to industrial development and transformation, these are important in that they point to different types and degrees of system change (disruption or stability), which have significant implications for the industries involved.

[4] Refers to shared cognitive routines or search heuristics that guide technological development within a community of engineers.

3.2. Technological innovation systems

Another prominent approach is the technological innovation system (TIS) framework. While MLP seeks to provide a holistic view of transition processes, TIS framework outlines a systemic view on the social structures related to the development of a specific technology, and the systemic processes and agency leading to technological innovation. The TIS framework thus supports the analysis of key innovation dynamics related to the emergence and development of (niche) technologies. While the TIS framework was not initially developed with decarbonization topics in mind, it has emerged as a key framework in the analysis of energy transitions (Bergek, 2019).

The TIS approach is particularly geared towards studying the development and deployment of new technologies as well as the institutional and organizational changes that run parallel to enable such activities (Hekkert et al., 2007, Bergek et al., 2008). A TIS is defined as *”network(s) of agents interacting in a specific technology area under a particular institutional infrastructure for the purpose of generating, diffusing and utilizing technology”* (Carlsson and Stankiewicz, 1991, 111). A TIS is thus defined around a specific focal technology or product, thus has two main analytical components. First, TIS constitutes of a structure of dynamic networks of actors and institutions related to the generation, diffusion and use of a given technology. Second, innovation in TIS is driven by key processes or innovation "functions" (Bergek et al., 2008, Hekkert et al., 2007). These are emergent "sub-processes" of the overall innovation process, and include for instance knowledge development and diffusion, formation, resource mobilization, legitimation, and entrepreneurial experimentation (Bergek, 2019). See a full overview of functions in Table 1. Functions evolve over time through the agency of actors. Moreover, feedback loops (both positive and negative) within and between functions may emerge, further driving (or hindering) the innovation process of a technology. For instance, knowledge development may lead to heightened expectations around a technology, which then may lead further resource mobilization (e.g. funding for R&D projects), which then again may further drive knowledge development (Suurs and Hekkert, 2009).

Table 1 Functions of technological innovation systems (Bergek et al., 2008)

TIS function	Description
Knowledge development and diffusion	Development and diffusion of knowledge regarding the technology over time. Considers both the depth and breadth of knowledge.
Influence on the guidance of search	Inducing and pressuring factors for actors to enter the TIS, and mechanisms influencing the direction of innovation in terms of competing technologies, applications, markets, etc.
Entrepreneurial experimentation	Reduction of uncertainty through experimentation with new technologies, applications and markets.
Market formation	Opening of (niche) markets, articulation and creation of demand.
Legitimation	Formation of social acceptance, and compliance to institutions.
Resource mobilization	Mobilization and creation of human and financial capital, and formation of infrastructure and other complementary assets.
Development of positive externalities	Development of free utilities, such as specialized component suppliers.

A typical TIS analysis would assess the performance of the TIS through an analysis of the above-mentioned structure and functions, and identify the inducement and blocking mechanisms for innovation (Bergek et al., 2008). Although new technologies may have many benefits (lower operational costs, less pollution etc.), they often struggle to develop beyond a nascent phase. Not only actors and markets but also institutions and networks can obstruct TIS formation. Emerging TISs often face challenges which can be identified as system weaknesses. TIS analysis may thus identify such bottlenecks and inform policymaking regarding action which may help to foster further innovation in the technology.

TISs are also influenced by their wider context (Bergek et al., 2015). First, TISs have geographic underpinnings, typically with a special anchoring to certain locations in world (for instance wind power in Denmark), but the TIS structure and functions also have international and multi-scalar features (Binz and Truffer, 2017). Second, TISs are embedded in political contexts, which is particularly relevant for politically contested technologies such as zero-emission technologies (Kern, 2015). The priorities and changes in political context of a novel technology may thus have importance for the innovation (Normann, 2015). For instance various stakeholders may seek to lobby for or against more conducive policies for a specific technology (Jacobsson and Lauber, 2006). Third, a TIS may be affected by other TISs through e.g. synergetic and competitive relationships (Sandén and Hillman, 2011). For instance, deployment of intermittent renewable energy technologies such as solar PV and wind energy may benefit from energy storage technologies such as batteries, while electric vehicles may compete against each other types of alternative fuel vehicles e.g. in terms of resources and investments in infrastructure (Markard and Hoffmann, 2016).

Fourth, a TIS may be affected by its sectoral context either in focal sector of transition (e.g. the transport sector) or in the upstream sectors of a technology (e.g. raw materials and components). We elaborate on such topics in the next section.

3.3. The industrial perspective on sustainability transitions

The above discussed frameworks on sustainability transitions are focused on socio-technical reconfigurations (transitions) and radical innovations in a specific socio-technical system, such as energy, mobility and food. Consequently, these perspectives typically have had less explicit attention to the upstream value chains of technologies (such as of renewable energy technologies) central to transitions (Andersen et al., 2020). Accounting for the changes and developments across technology value chains is however not only important for understanding transitions themselves, but also for gaining insights on the economic opportunities that transitions offer. In other words, transitions affect the different sectors that provide inputs (e.g. raw materials, components and services related to energy technologies) and outputs (e.g. energy production and use) for novel technologies. While the upscaling capability of value chains to meet the growing demand for novel technologies is crucial for transitions, the value chains of old technologies may face decline and collapse in demand. Indeed, while phasing out unsustainable technologies may lead to destruction of jobs (e.g. in fossil fuel production), new technologies create economic opportunities and work. Hence, to understand the industrial underpinnings of transitions, and account for the political acceptability and feasibility of transition-related policymaking and the "justness" of transitions, it is therefore necessary to account for what we call 'the industrial perspective on sustainability transitions'.

Especially in relation to energy transitions, the recent literature has started to focus on such topics in a greater detail. Andersen and Markard (2020) proposed to view technology value chains as a set of interacting technologies consisting of components and sub-components, provided by various industrial sectors, thus highlighting the inter-industrial nature of radical innovation. For instance Stephan and colleagues (2017) showed how the TIS around lithium-ion batteries was impacted by innovative activities in various sectors, such as chemical and electronics sectors. An additional example is the findings of Malhotra and colleagues (2019) who argue that learning-by-interacting across the sectors in a technology value chain can be highly important for innovation in complex energy technologies. Hence, these contributions show that a holistic view on the industrial features of radical energy innovation can help to identify enabling factors for the development and upscaling of new energy technologies.

The availability of raw materials, capabilities in manufacturing, and the build-up of necessary infrastructure for novel energy technologies and alternative fuels are naturally key to achieving an energy transition, and also in realizing the economic opportunities of energy transitions. For instance the scalability of biofuel production and the conflicts between other uses and values related to biomass (e.g. food production, biodiversity issues) have often hindered biofuel technologies (Sutherland et al., 2015). Meanwhile, the availability of critical materials and related industries have affected the development of solar PV production in Germany and Norway (Quitzow, 2015, Hanson, 2018). Meanwhile in China, the high emphasis on price and limited attention to quality and maintenance of wind turbines haves hindered the exports of Chinese wind power turbine producers (Gosens and Lu, 2014). Finally, the vast upscaling of intermittent renewable energy technologies is interdependent with the build-up of power transmission and storage capacity (Andersen, 2014). In other words, the diffusion of energy technologies is closely dependent on the features and performance of the different sectors in its value chain (Mäkitie et al., 2020a).

At the firm-level, early transitions literature highlighted the role of new-comer actors in pushing forward transitions and radical innovations, while established firms and other incumbents have been portrayed as passive or hindering transitions (Turnheim and Sovacool, 2020). This view is however incomplete. For instance Swedish scholars have shown how established firms in automotive and gas turbine industries have been in a key role in developing radical innovations (Bergek et al., 2013, Berggren et al., 2015), while in Norway, established energy companies have been early entrants in various novel energy technologies (Steen and Weaver, 2017). The engagement and diversification of established industrial players may thus provide various types of resources (such as knowledge, human and financial capital) to the development of novel technologies (Mäkitie et al., 2018). Such reorientation strategies may indeed become necessary for established firms who may face a decline in their old (unsustainable) markets (Penna and Geels, 2015).

Such industrial perspectives are highly relevant for policy. A better understanding of how energy transitions impact, and are impacted by, various industrial sectors provide insights regarding how policy may foster energy transitions and the formation of green jobs. Green industrial policy may seek to capitalize on the industrial opportunities created by e.g. novel energy technologies but also advance the decarbonization of the energy system (Busch et al., 2018). However, facilitating transitions may also require the destabilization of the hegemony of unsustainable technologies through e.g. taxes and reduction of public support (Kivimaa and Kern, 2016). Such instruments explicitly addressing a decline in non-desirable technologies have adverse effects for industries in the value chains of such technologies, making them often politically challenging to implement. Questions related to how the gains and losses related to energy transitions and how the competences and capabilities around unsustainable technologies can be 'redeployed' into more sustainable technologies and practices thus become of high relevance for the political feasibility and justice topics related to transition policy (Healy and Barry, 2017, Skjølsvold and Coenen, 2021).

In sum, the industrial perspective on sustainability transitions provides insights on the role and implications of various industrial sectors on the development of radical energy innovations, and consequently on energy transitions. In the next section we provide two brief empirical examples on this topic.

4. Empirical illustrations

4.1. From fossils to renewable energy generation: offshore energy in Norway

Since striking oil in late 1960s, a strong and technologically advanced offshore oil and gas (O&G) industry has developed in Norway. In 2021 this industry is still economically the most important one in the country, providing plenty of well-paying jobs across the value chain of production, and vast state revenue through taxation of O&G income. However, due to fluctuations in the O&G market, limited recent oil discoveries, and growing uncertainty regarding the future of oil extraction in Norway (due to climate change concerns), firms in the O&G industry have increasingly explored diversification to new markets (Normann, 2015, Steen and Weaver, 2017, Mäkitie et al., 2020b). One technology which has attracted much attention among these firms is offshore wind power (OWP).

In MLP terms, O&G as one of the dominant energy sources in the world are at the core of current energy system *regime*. However, over the recent decades the climate change concerns have created *landscape* pressure on the current energy system regime, opening a window of opportunity for *niche* energy technologies such as OWP. A typical MLP interpretation would thus often provide a dichotomous view between incumbent and emerging energy production (Geels, 2014, Hess, 2016), or in our case, O&G and OWP respectively.

However, when studied from an industrial perspective, a more diverse picture becomes prevalent. In Norway, various O&G industry companies have diversified to this new technology, leading to e.g. strengthened knowledge base in OWP technology (Steen and Weaver, 2017). This has especially been the case in floating wind power, where O&G companies have been key entrepreneurial agents in developing this yet emerging technology (Mäkitie, 2020). From TIS perspective, the O&G industry firms have thus supported the OWP innovation in Norway in terms of e.g. *knowledge development* in form of offshore technologies along the OWP value chain (subsea, cabling, offshore operations), *entrepreneurial experimentation* through exploration of floating wind technologies and *resource mobilization* of financial and human capital as well as infrastructure such as offshore bases (Mäkitie et al., 2018). However, these positive effects have been limited by the lukewarm commitment of these actors to OWP. Many of the O&G industry firms engaged in OWP only when the core oil and gas market entered a decline period, and subsequently diminished their engagement as the demand in the O&G market picked up again, leaving the OWP only in a status of an auxiliary market for such firms (Mäkitie et al., 2019).

OWP thus offers novel opportunities for firms and workforce in the O&G industry in Norway if firms are willing to pursue them. As the O&G market can be expected to eventually decline, such opportunities may become particularly important for regions where O&G has been a key employer over the last decades. Indeed, OWP may offer new development opportunities for regions with related industrial resources (Steen and Karlsen, 2014), which may become important in seeking to achieve just energy transitions (Afewerki and Karlsen, 2021). However, O&G industry firms with general-purpose and "fungible" technological knowledge (e.g. engineering competences) are more likely to diversify to new markets than those with market-specific and specialized knowledge (e.g. related to oil exploration) (Mäkitie et al., 2020b). Related diversification does not thus act as a panacea for all regions and also other ways to achieve just energy transitions must be explored.

Seen overall, the Norwegian O&G and OWP case illustrates the relevance of an industrial perspective on energy transitions as they not only allow to better understand how innovation processes in novel technologies may be affected by local industrial contexts, but also opens perspectives for policymaking in seeking to improve the acceptability of transition policies through novel economic opportunities and job creation.

4.2. From fossils to renewable energy consumption: maritime transport in Norway

The shipping industry is also an important industry in Norway. Maritime transport along the coast is part of the key infrastructure that allows for movement of goods and people, whereas several of Norway's most important sectors are ocean-related (O&G, fishing, aquaculture). Norwegian shipowners also have large positions in certain deep-sea shipping segments, and the Norwegian maritime supplier industry is furthermore highly advanced and export-oriented (Mellbye et al., 2018).

Maritime transport is generally considered a ‘hard-to-abate’ sector, alongside energy-intensive processing industries and heavy-duty road transport. The transition challenges faced by such sectors follows from high capital-intensity, low profit margins, and international competition (Dewald and Achternbosch, 2016, Hansen and Coenen, 2017). Indeed, shipping has in general been slow in introducing low-carbon fuels (Bows-Larkin, 2015), also as a result of its global functional integration, its commercial and operational characteristics, and lacking global environmental governance (Lister et al., 2015). Regardless, change towards the use of more sustainable energy solutions is underway in certain parts of the global shipping industry (Poulsen et al., 2018), but even more so in certain parts of short-sea and coastal shipping, especially in Norway.

In MLP terms, maritime transport constitutes a socio-technical system that provides crucial societal services. Most ships run on fossil fuels as they have for more than a century (Pettit et al., 2018). While the *regime* of maritime transport has been slow to start decarbonizing, mounting *landscape* pressure to reduce carbon emissions in this sector are slowly beginning to have an impact. As a result, various *niche* technologies that can improve the environmental footprint in maritime transport are being explored. This is highly visible in Norway, which is a frontrunner globally in sustainable energy solutions for shipping (Jakobsen and Helseth, 2021). Experimentation with niche technologies has mainly occurred in specific market segments, such as in in ferries that operate along the coast and for supply vessels to the offshore O&G industry (Bergek et al., 2018). Here, battery-electric energy solutions have been adopted at remarkable speed over the last few years (since 2015), resulting from both public and private procurement strategies that emphasized emissions, but also because these segments were appropriate for this technology which can be implemented in both hybrid and pure form (Bach et al., 2020). Other low- and zero-carbon energy solutions, such as biofuels and hydrogen, are struggling with value chain and legitimacy issues (Steen et al., 2019), whereas also shipowners' perceptions of adopting these technologies is imbued with uncertainties (Mäkitie et al., 2021).

From an industry perspective, an interesting observation is that many pioneering firms in developing 'green solutions' for shipping are established maritime equipment suppliers that also develop and sell marine combustion engines, such as Wärtsilä. Depending on type of low- or zero-carbon energy solution, however, the involvement of different types of actors differs considerably, not least because of the differences between a value chain based on for instance liquefied biogas versus a value chain for battery-electric solutions. It follows that also TIS function dynamics (see Table 2) differ considerably for niche technologies, depending to large extent on the engagement of different types of actors. A striking feature with this analysis is that that biofuel innovation systems are found to have weak performance. This is remarkable because biofuels are interchangeable with fossil fuels (i.e., marine diesel and liquefied natural gas) and thus potentially benefits from existing technology on vessels and also infrastructure for storage and distribution (Bach et al., 2021). Put differently, from the maritime socio-technical system point of view, biofuels would be far less disruptive than hydrogen, yet is challenged by low legitimacy levels among maritime industry actors in part due to uncertainties regarding actual emission benefits as well as competition with food production.

Table 2 Comparison of TIS functions for biodiesel, liquefied biogas (LBG), hydrogen, and battery electric in the context of Norwegian coastal shipping. Black = weak, grey = intermediate, white = strong. Adapted from Steen et al., 2019.

	Knowledge development and diffusion	Direction of search	Entrepreneurial experimentation	Market formation	Legitimation	Resource mobilisation	Positive externalities
Biodiesel	Black	Black	Black	Black	Black	Black	Black
LBG	Black	Grey	Black	Black	Black	Black	Black
Battery-electric	Grey	White	White	White	White	White	Grey
Hydrogen	Grey	Grey	Grey	Black	Grey	Grey	Black

While there is certainly some contestation among maritime industry actors over the need for decarbonization in general (as well as for particular technology options to achieve that) in the context of coastal shipping, there is generally an agreement that carbon emissions need to be reduced. This is particularly the case among technology suppliers eyeing new market opportunities, but also among some shipowners expecting that being early movers in 'going green' will improve their market positions onwards, given that national and international environmental regulations will strengthen in the years to come.

5. Conclusion

This chapter has provided an overview of socio-technical perspectives on energy transitions which help to conceptualize and understand the complex social and technological processes underlying large-scale and radical transformations in world's energy systems, such as the one from fossil fuels to renewable energy. This chapter has particularly focused on an industrial perspective on sustainability transitions which has recently emerged in this literature (Andersen et al., 2020). We have provided empirical illustrations of this through two empirical cases from Norway.

We argue that an industrial perspective on transitions is useful for researchers, policymakers and other practitioners in at least three ways. First, it allows for better understanding of the industrial development necessary for (rapid) upscaling of radically new energy technologies crucial in the struggle to amend global carbon emissions. Second, it provides more explicit insights on how policy may be able identify and target crucial bottlenecks in the industrial development around novel energy technologies, and thus induce both decarbonization and novel industrial development. Third, an industrial perspective on sustainability transitions combines perspectives on the creation of novel economic opportunities and jobs and on the declining opportunities and employment in unsustainable industries, and thus offering insights regarding possible means to foster 'just transitions'.

Research on the industrial side of energy transitions are still emerging. More research is therefore needed. Overall, there are yet limited number of studies elaborating on the inter-industrial features of energy transitions. For instance, we know yet little of the possible complementary developments within and across the value chains of different technologies, which can be important for achieving an accelerated diffusion of novel energy technologies. Moreover, to contribute to just transitions, further research should explore policy approaches that may contribute to the sustainable reorientation of industrial structures at national and regional level, combining purposeful phase out of unsustainable technologies and the industrial development around new technologies. Finally, most literature has focused on industrial development around energy technologies in developed countries. Further research should elaborate on industrial perspectives in the context of Global South, including how energy transitions may contribute to the economic development in such contexts, but may also on the possible adverse effects through negative social and environmental impacts e.g. in the extraction of rare earth minerals and other natural resources.

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