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Report

Greener and smarter? Transformations in five Norwegian industrial sectors

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ABSTRACT

This report is an output from the INTRANSIT Research Centre on Innovation Policy for Industrial Transformation, Sustainability and Digitalisation. The report presents an analysis of green and digital transformations in five Norwegian industrial sectors: oil and gas, maritime, aquaculture, manufacturing and process industries. By drawing on perspectives from innovation and sustainability transition studies, we analyse how the industrial sectors respond to green and digital pressures as well as opportunities. Our results show that while a green transformation is gathering momentum in the maritime sector, little radical change has yet taken place in various other sectors. Meanwhile, the thrust driving digitalization is often connected to increasing cost-efficiency and competitiveness in global markets. However, in the aquaculture sector, digital technologies are often applied to solve environmental and fish health issues. Green and digital transformations in industrial sectors may thus have points of interaction, leading to complementary, but occasionally also conflicting, developments. Based on empirical findings we draw insights for green and digital transformation policy, and take note on how COVID-19 pandemic may affect such transformations.

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1 Executive summary

The pressure to move towards **greener modes of production and consumption**, particularly in terms of reducing carbon emissions, is increasingly challenging the Norwegian industrial sectors. Meanwhile, continued innovation in e.g. artificial intelligence, big data use, robotics and digital platforms are making **digital technologies** increasingly pervasive, potentially changing how the sectors operate and how their products are made, distributed and used. In this report, which is an outcome of ongoing research in the INTRANSIT research centre, we analyse how these two megatrends are affecting the key Norwegian industrial sectors, and how these sectors respond to these challenges. We analyse how the **value chains** of **oil and gas, maritime, aquaculture, manufacturing and processing** are **transforming towards greener and more digital directions**. Our analysis builds on theoretical perspectives from the **sustainability transitions** and **innovation studies** research traditions**.** We emphasise that **industry transformations must be seen as multilevel and broadscale phenomena** that are not only about development and deployment of new technologies**.** Rather, we need to understand transformations as **responses to societal and technological pressures,** leading to **systemic changes** involving changing compositions of **actors, institutions and core technologies** of sectors.

We identified that while the growing attention to environmental concerns, especially **climate change**, has impacted all industrial sectors, the **magnitude of this pressure**, and how it is experienced, **varies** across sectors. Moreover, while **digital technologies have not (yet) disrupted** the Norwegian industrial sectors in a significant degree, **digitalization** has been rather viewed as an **opportunity** for e.g. increased cost-efficiency.

In the **oil and gas sector**, climate change has been the most central environmental pressure, creating **high level of uncertainty** regarding the long-term perspectives of the sector, and already affecting e.g. the **availability of human resources and financing**. This has led the sector to **diversify** to alternative markets, reorient towards provision of energy rather than oil, and initiate efforts to **reduce emissions** in the extraction of oil and gas. Digitalization in the sector has been observed through e.g. increased use of **digital modelling and simulations**. The sector is, however, already rather digitalized and for instance a leading sector in the use of big data.

In the **maritime sector**, pollution reduction targets and export opportunities have led to a rapid **development** of e.g. **battery-electric and hydrogen innovations** especially in the ferry segment, while especially **autonomous vessels** are seen as a future technology enabling more cost-efficient operations and new modes of goods transport.

Aquaculture have multiple environmental and fish health problems such as **sea lice, escapees and pollution.** These challenges have been tackled for instance with the development of larger and **more controlled production units**. This has been partly enabled by the **increased use of digital tools** such as sensors and data analysis.

Manufacturing, using the carbon-free hydropower of Norway, has relatively low carbon emissions, but parts of the sector have begun to e.g. explore the production principles in **circular economy**. Advanced production, such as the increased use of **robotics**, is a promising area of development in Norway due to the high wage rates and competences among employees.

The process industry is energy intensive, and has lower emissions than in some other countries, thanks to the abundant and relatively cheap Norwegian hydropower. **Carbon capture and storage (CCS)** is nevertheless considered an important future technology, and has recently gained momentum through demonstration projects and a full-scale CCS project in the cement industry. Digitalization is currently following a gradual pattern in the process industry, with **few new radical technologies** entering the sector.

These trends have also been influenced by the **COVID-19 pandemic**. The global economic recession has hit hard particularly the oil and gas sector, due to the **plummeting oil price**, and the maritime sector, because of **lower demand** for vessels. Meanwhile, the process industry and aquaculture operate with longer investment cycles, and the consequences of the pandemic on these sectors have so far been more limited. The initial impression of the effect of the pandemic on digitalization is that it has increased the pace of **adoption of mature technologies**, such as in digital communication. However, during hard times sectors often **focus on their core business**, **slowing down** e.g. the uptake of radically new technologies. We nevertheless note that **targeted policy instruments can compensate for firms' lacking ability to prioritize e.g. environmental innovations**. However, the long-term effects of the COVID-19 pandemic on green and digital transformations remain uncertain.

In terms of policy for green transformation, we observe that while policy has been effective in promoting **incremental innovations** within the existing markets of sectors, it has been less so in **terms of radical innovation development**, including development of new products and markets. Policies have been mainly directed to R&D and pilot projects, and with the promising exception of the maritime sector, **the scale-up and deployment of radical new technologies has not yet taken place** to a large extent. We also observe that digitalization is yet to take its form in the capital-intensive industrial sectors in Norway. This opens an opportunity for policy to seek to **strengthen the competitive position** of these sectors, e.g. through public procurement and continued development of digital infrastructures.

We also observed that **green and digital transformations may interact**. For instance in the aquaculture sector, digital tools are often used in seeking to solve environmental and fish health problems. However, in the oil and gas sector, digital tools enable more cost-efficient production, strengthening the long-term competitiveness of the Norwegian sector, hence contributing to **a path extension in oil and gas extraction**. Meanwhile, green pressures drive the sector towards alternative markets, such as renewable energy. These examples show that **greening and digitalization may have synergies, but also conflicting features**, requiring increased attention to **the coherence across policies** in different domains.

2 Introduction

Digitalization and increased attention to sustainability are megatrends that will change the economic, organizational and institutional set-up of the Norwegian economy. Digitalization refers to the pervasive and rapid development and diffusion of digital technologies, such as digital platforms, artificial intelligence, big data and robotics. These technologies have the potential to transform the production and consumption patterns of different Norwegian sectors, as well as how companies operate. On the background of negative environmental effects of production and consumption (e.g. carbon emissions), environmental sustainability has recently gained more attention in Norway. Moving towards greener forms of production and consumption will impact and possibly disrupt most sectors of the economy. Hence, environmental issues and digitalization are set to cause fundamental changes in the Norwegian economy over the next years and decades. How Norway engages with these two big transformations will strongly influence the longer-term competitiveness and viability of the economy. To inform policymakers and business managers, this report presents an overview of how important Norwegian sectors are affected by digitalization and green opportunities and pressures, and how the sectors are transforming to respond to them.

This report is written by researchers at the research center "Innovation Policy for Industrial Transformation, Sustainability and Digitalization" (INTRANSIT, funded by the Research Council of Norway). It reviews the status of green and digital transformations in five key Norwegian industrial sectors: oil and gas (O&G), maritime, aquaculture, and process and manufacturing. It presents an overview of the most recent developments in these industrial sectors, paying attention to the green and digital pressures and opportunities they face, and the respective transformations that are taking place in the value chains of these sectors. We also take note on the effect of COVID-19 pandemic on industry transformation processes. To provide more detail, we take note of developments in different value chain segments of the sectors. Methodologically the report utilizes analytical perspectives from the innovation and sustainability transition studies, and uses semi-structured interviews, documents and available statistics as the main data sources. The results will be useful for policymakers, industry actors and researchers in their efforts to take stock of the current green and digital transformations in these sectors, and broaden perspectives on possible future transformation pathways.

The O&G sector, understood as both petroleum extraction and supply of services and technologies to oil and gas, continues to be the largest export sector in Norway. The sector is, however, increasingly challenged by climate change action, the on-going energy transition towards more renewable energy and electrification, and the low and volatile oil price. The maritime sector has centuries long traditions in Norway and has over the years developed into a full value chain of maritime organizations, ranging from ship design and building to classification and shipping operations. The sector has in recent years been hit hard by the decline in the O&G sector (a key market segment) and more recently by the COVID-19 pandemic. The aquaculture sector in Norway is associated with high growth expectations. These prospects are nevertheless challenged by e.g. the sea lice and pollution problems, to which organizations in the sector are addressing by development and deployment of new technological solutions. The process and manufacturing sectors consist of multiple segments providing materials and products to various consumer and industrial sectors. They are to varying degrees influenced by environmental challenges and digitalization, but also influenced by increased global competition.

The report is organized as follows. Section 3 presents briefly the analytical approach and methodology underlying this report. Section 4 presents a comparative summary of the green and digital transformations in

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the five Norwegian industrial sectors, as well an insight on how these two megatrends may link up in each sector. Moreover, we present a note on the COVID-19 pandemic in these transformations. Section 5 discusses the implications of our findings for policy. Section 6 presents the full analysis of all five sectors.

3 Analytical approach

3.1 Theoretical perspectives on sectoral transformations

Our analysis of sectoral transformations in Norway builds on theoretical insights from innovation studies. A key underlying idea is that economic transformation is an evolutionary process (Nelson, 1995). The approach emphasizes transformation and creation of new economic resources (i.e. economic dynamics) rather than optimal and cost-efficient allocation of existing resources. In contexts characterized by uncertainty and limited foresight, actors try to navigate in an evolving landscape with their limited resources. The principal engine of change in the economy is the introduction of new knowledge (e.g. innovation) which can transform or overthrow existing sectors (e.g. from horse carriages to automobiles). The actions and operating space of organizations are shaped by contextual elements such as markets, institutions, political system and geography as well as the actions of other organizations (Schumpeter, 1943, Nelson and Winter, 1982). At the same time, actors work to change markets, policies and institutions in their favor (Köhler et al., 2019). Above all, technological change and economic transformation are seen as socially embedded phenomena.

We further draw on the sustainability transition studies which builds on the above understanding of economic and industrial change. However, while innovation studies have been focused on sectoral change in the light of economic growth and technological development, sustainability transitions research focuses on sectoral change towards sustainability, e.g. towards United Nations' Sustainable Development Goals (Markard et al., 2012). Sectoral transformations are fundamentally understood in similar fashion as in innovation studies, as interlinked changes of technologies, markets, culture, user practices, infrastructures, supply and distribution chains etc. in the patterns of production and consumption (Köhler et al., 2019). However, the underlying logic of sustainability transition studies is to draw attention to desirable *directions* of sectoral transformation. This leads to increased attention to for instance politics, urgency of change, and legitimacy, compared to traditional innovation policy approaches.

Sectors are understood to be comprised of three main elements.

First, technologies, which include artefacts, devices, infrastructures and knowledge base (Malerba, 2002). Such technologies can be more or less mature and widely diffused. Mature and dominant technologies are denoted “incumbent technologies” while immature and emerging technologies are “niche technologies” in the sectoral context. Through innovation, niche technologies may over time substitute or overthrow the dominant technologies.

Second, actors and their decision-making create change. Actors include firms but also users, societal groups, public authorities and research organizations shape sector dynamics (Geels, 2004). These actors interact by communicating, exchanging, cooperating and competing.

Third, sectors also have formal and informal institutions that specify the “rules of the game” (Malerba, 2002, Geels, 2004). Informal institutions represent e.g. routines and expectations that are taken for granted. Formal institutions include agreed upon standards, formal processes, laws and regulations that shape what actors can do and the solutions they choose.

Technologies, actors and institutions of sectors co-evolve over time. For instance, technological innovation may change institutions, and the existing institutions may shape which kind of technologies are adopted and how fast. Moreover, innovations may also change the actor constellations of the sector by e.g. bringing in new kinds of firms with novel competences, or force existing actors to adapt to the introduction of new technologies (Malerba, 2002). The co-evolution of elements creates sector-specific modes of change; i.e. transformation patterns are expected to differ markedly across sectors. The transformations may also differ between value chain segments of a sector, affecting some segments more than others. The interdependencies between sector elements create stability, making it difficult for innovators to challenge the lock-ins in sectors, thus slowing down fundamental change (Unruh, 2000). For instance in the energy sector, technologies such as wind turbines and solar-PV have been developed for decades, but only recently they have begun to be price-competitive compared to fossil fuel technologies. This has led to a faster adoption rate and more pressure on the “hydrocarbon regime”.

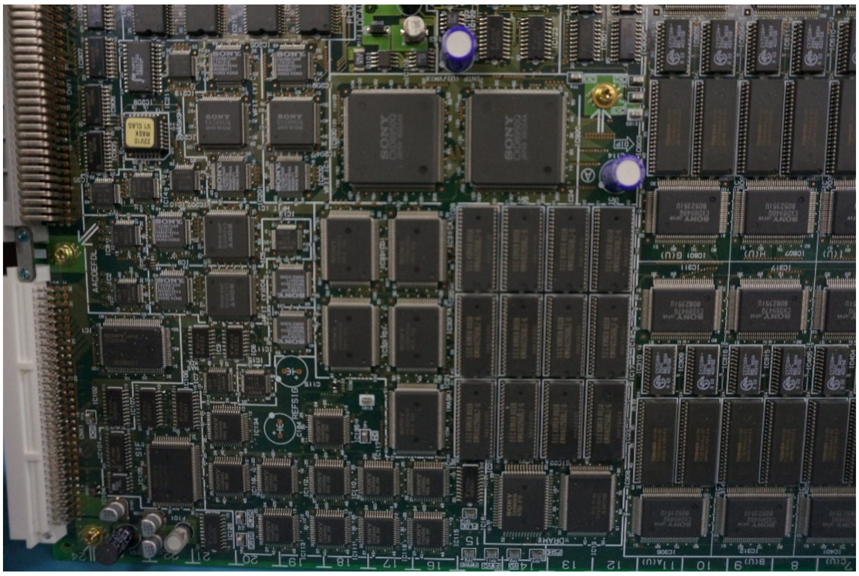
Picture: SINTEF, Geir Mogen

Transformations may take place over time through continued efforts of actors. However, favorable societal and economic conditions are typically needed for a breakthrough of radical niche innovations, caused by events that put pressures on the current patterns of production and consumption (Köhler et al., 2019, Geels, 2002). Such events can thus push forward transformations (Carlsson and Stankiewicz, 1991, Geels and Schot, 2007). Pressures and opportunities can emerge from a broad range of events such as politics (e.g. grassroots movements), environmental issues (e.g. climate change), macro-economic events (e.g. financial crises, COVID-19 pandemic), accidents (e.g. Fukushima), geopolitics, etc.

Sectoral transformations may affect each other in positive and negative ways. Such interactions between sector transformations typically become more and more obvious when they reach more advanced stages (Schot and Kanger, 2018, Andersen et al., 2020). This perspective is particularly relevant for understanding the role of Information and Communication Technologies (ICT) that may enable transformation in multiple sectors.

Digitalization is one such process. Digital technologies are "products or services that are either embodied in information and communication technologies or enabled by them" (Lyytinen et al., 2016: 49). They may be technologies such as advanced computing and modelling, Internet of Things (IoT), communication tools, digital platforms, and various digital artifacts such as sensors and robotics. Digital technologies may find applications and further development in various sectors, potentially leading to fundamental transformations in them. The effect on digitalization may however differ from one sector to another. Therefore, it is necessary to analyze the drivers of, and responses to, digitalization at the level of individual sectors and value chains.

Digitalization refers to the process of using digital technologies to change one or several socio-technical structures. *"By digitalization, we mean the transformation of socio-technical structures that were previously mediated by non-digital artifacts or relationships into ones that are mediated by digitized artifacts and relationships. Digitalization goes beyond a mere technical process of encoding diverse types of analogue information in digital format (i.e., "digitization") and involves organizing new socio-technical structures with digitized artifacts as well as the changes in artifacts themselves"* (Yoo et al., 2010: 6). Furthermore, when digitalization and digital innovation are used over time to change ways of working, leading to substantial changes in an organization or industry, it is called digital transformation (Osmundsen et al., 2018). Digital transformation is thus defined as "*the combined effects of several digital innovations bringing about novel actors (and actor constellations), structures, practices, values, and beliefs that change, threaten, replace or complement existing rules of the game within organizations, ecosystems, industries or fields*" (Hinings et al., 2018: 52). The definition highlights digital transformation processes as a socio-technical system transformation, where skills, practices and social structures are interrelated with the deployment of new, digital technologies.



Picture: Dave Jones

Digitalization has sometimes been considered to support sustainability goals. For instance, Perez (2015: 200) argues that digitalization *"has the capacity to facilitate wide-ranging sustainable innovations to radically reduce material and energy consumption while stimulating the economy"*. Moreover, digital technologies have enabled the development of smart grids, increased efficiency in the production and use of natural resources, and new mobility and consumption practices made possible through development of digital platforms, etc. However, such increased efficiency may also exert a negative influence on sustainability, for instance through rebound-effects (Røpke, 2012). Moreover, it has already been noted that e.g. the contribution of sharing economy, enabled by digital platforms, often makes only a limited contribution towards sustainability goals, if not outright leading to even more unsustainable production and consumption patterns (Frenken, 2017). Exactly how digitalization and green transformations interact is not obvious and will most likely differ across sectors. This is an important question, also for further research.

3.2 Analytical framework

Table 1 summarizes key insights from above. The analytical units in the table will guide our analysis of green and digital transformations in this report.

Table 1 The analytical units of the report

Analytical units	Explanation
Sectoral developments	Brief history of the sector, important recent developments, key technologies and institutions, etc.
Value chains	Mapping and description of the value chain segments in sectors, including central actors (firms) and regional characteristics
Pressures and opportunities	Green and digital pressures and opportunities that affect industrial sectors
Sectoral transformations	Responses of industrial sectors to the specific green and digital pressures and opportunities
Interaction between transformations	Identified linkages between green and digital transformations

First, to understand the starting point for such transformations, we take note of some of the key historical as well as more recent developments in the sectors, and their central technologies and institutions. Second, we describe the internal organization of the sectors by describing their value chains and key firms. This helps us to understand the different kinds of organizations, business models and geographies that the sectors entail in Norway.

Third, we analyze the specific green or digital pressures and opportunities that may lead to sectoral transformations. The distinction between pressures and opportunities implies that such external factors may have different kinds of implications. For instance, the COVID-19 pandemic represents an external shock that has put pressures on many established sectors, for instance resulting in necessary adaptation measures in transport, hospitality, education and more. However, the pandemic has also led to opportunities for digital solutions, e.g. in a form of improved digital communication and distributed work across multiple sectors. Such external events and developments may act as opening “windows of opportunities” for challenging the status quo in sectors, potentially driving fundamental transformations.

Fourth, we analyze the specific responses to green and digital pressures and opportunities across the value chains of sectors. To this end, we gather information on the key on-going green and digital innovations. Finally, we take note of how these green and digital transformations may interact in sectors, e.g. whether digital innovations may help green transformations.

We summarize our findings in these analytical categories in section 4. A more detailed analysis of each sector is presented in section 6.

3.3 Methodology

The data collection and analysis in this report has been carried out between August 2019-August 2020. The main data sources have been various industry reports as well as 37 semi-structured interviews with various industry experts (see Appendix for details regarding respondents). Moreover, the authors of this report drew upon their prior experience and knowledge regarding the studied sectors (Mäkitie, 2020, Mäkitie et al., 2019a, Mäkitie et al., 2019b, Hansen and Steen, 2015, Steen, 2019, Steen and Weaver, 2017, Andersen and Gulbrandsen, 2020, Thune et al., 2018, Steen et al., 2019, Lund and Steen, 2020), gained in research projects such as FME CenSES, SIVAC, RENEWGROWTH, GREENFLEET, TRAZEPO, POCOPLAST, CIRCULAR SEATING and SFI Manufacturing, that all received funding from the Research Council of Norway.

The empirical work utilized the presented analytical framing and was carried out in three stages. First, we mapped the key actors, institutions and technologies in the five industrial sectors in Norway. We also outlined some of the key earlier developments and events in these sectors. Moreover, we mapped the value chains of the sectors as well as the most important geographic characteristics of the sectors, e.g. clusters.

Second, we identified the most important external pressures and opportunities that the sectors have recently experienced. We focused especially on green and digital pressures and opportunities, and how they may have affected the sectors across their value chains. Moreover, we identified some of the most relevant green and digital innovations in the sectors. Consequently, considering the observed industry dynamics, as well as pressures and opportunities, we were able to outline some of the emerging green and digital transformations in the sectors.

Third, we analyzed whether the green and digital transformations had converged in the sectors. This way we could identify situations where the different transformations had led to either synergetic situations, for instance digital transformations contributing to green transformations. Finally, we could draw implications for policy and industry, and outline possible future research avenues for the INTRANSIT project and beyond.

4 Summary of results

The green and digital transformations in the Norwegian industrial sectors show some similarities but also remarkable differences. In a small country like Norway, there are multiple linkages between the different sectors (e.g. maritime and manufacturing sectors supplying products to the O&G sector) that are of relevance to understand sectoral transformations. However, while some sectors seem to face fundamental transformations in near future, others are as of yet less touched by environmental pressures and digitalization.

4.1 Green transformations

A common characteristic of the green transformations under study is that they have consisted of responses to public demands to limit the environmental externalities (e.g. pollution, waste, etc.) of sectors. Particularly the attention to climate change topics and the need to reduce greenhouse gas emissions has been a central challenge which may cause fundamental transformations. Environmental topics therefore have acted as external pressures to which the sectors need to adapt. These pressures, and the consequent attempts of sectors to respond to them, are summarized in Table 2.

Table 2 Green pressures and transformations in Norwegian industrial sectors

	Green pressures	**Green transformations**
Oil and gas	- Political threat of discontinuing O&G production in Norway - Increasingly difficult financing - Recruitment difficulties	- Carbon emission reduction in O&G extraction - Diversification to non-O&G markets
Maritime	- Carbon reduction targets: domestic (~50% by 2030) and international (50% by 2050) - Also NOx, SOx, etc. reduction targets	- Ambitious emission reduction targets - Active low-carbon technology development and deployment
Aquaculture	- Sea lice - Escapes of farmed salmon - Waste and pollution (organic and non-organic)	- Controlled production units to reduce pollution - Large-scale offshore farming
Manufacturing	- Carbon emissions - Waste and use of raw materials	- Renewable energy use - Recycling - Product as a service
Process industry	- Carbon emissions - Waste	- Renewable energy use - Planned CCS projects

For the O&G sector, climate change poses a pressure that is likely to lead to a fundamental transformation and a decline in the sector during the next years and decades. The sector has already faced a period of decline after the oil price plummeted in 2014 and 2020. The Paris Agreement, increasing deployment of renewable energy technologies and other low-carbon innovations (such as electric vehicles), are likely to reduce the demand for hydrocarbons permanently, and e.g. climate youth movements are making petroleum extraction increasingly controversial. Such developments make the possibility of an eventual political decision to discontinue O&G extraction in Norway a fundamental threat for the sector. For instance, while the mainstream political landscape in Norway has thus far been committed to O&G exploitation, there have been demands for limiting e.g. O&G exploration in the High North (Mäkitie and Normann, 2020). Moreover, the sector has recently experienced difficulties to secure financing for new projects, which has forced the sector to consider the "carbon-risk" of new installations. Meanwhile, the sector is reporting difficulties to hire new talent, particularly among young job seekers, who increasingly seem to prefer to direct their careers towards other sectors. The sector has sought to respond to these challenges in two main ways: by reducing emissions in the extraction phase of O&G (e.g. electrification of platforms) and by diversifying to technologically related markets (such as aquaculture and renewable energy). While the former strategy seeks to extend the path of O&G production by making Norwegian petroleum "greener", the latter strategy also responds to the overall decline in the sector caused by the low oil price, especially during 2015-2017 and again in 2020 during the COVID-19 pandemic.

Picture: SINTEF, Tyd

Carbon emission reduction is a key topic also in the maritime sector. While shipping has been slower than some other sectors in focusing on decarbonization, the recently announced domestic (Government's 50% reduction by 2030) and international (International Maritime Organization's 50% reduction by 2050) carbon reduction targets have increased the priority of the issue in the sector. Moreover, conventional fuels also produce other harmful pollutants such as NOx and SOx that are increasingly curbed via regulation. Emission reduction targets have been addressed through innovation, especially around battery-electric vessels. Particularly battery-electric ferries have entered the market quickly, driven especially by demands set in public tendering. In addition, deployment of the first hydrogen-powered vessels are expected during the next few years. Notably, the sector expects low-carbon vessels to be a growing export market, encouraging companies to take an early-mover position in such technologies.

Aquaculture is subject to high growth expectations but is also affected by environmental problems. While escapees and local pollution have been persistent issues, sea lice (a parasite affect fish health) has recently taken the stage as the key challenge. This has led to ambitious new technology development, seeking to help the sector to meet the double challenge of growing output while tackling environmental problems. Organizations are developing technological concepts that enable more controlled sea production units (with more command over inputs and outputs, which represent significant technological change from the conventional way, of using open plastic containers. Moreover, there is a tendency to seek to move towards larger production units in open-sea conditions, allowing more production capacity and somewhat lower local environmental impact.

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Picture: SINTEF, Geir Mogen

The manufacturing sector consist of diverse production segments with varying dynamics. Due to high labor cost in Norway, these segments compete fiercely in the international markets, where more environmentally friendly production could be a potential future competitive advantage. Norwegian manufacturing has relatively limited carbon emissions due to the hydropower dominated electricity mix, and focus has therefore been directed to the reduction of raw materials, waste, and increased lifetime of products. There is increasing interest in material recycling and circularity, but this has until now been hindered by a lack of demand and difficulties in organizing functional circular supply chains of materials. For instance, in the furniture branch, circular economy concepts utilizing resource flows from other industries like aquaculture are being developed.

The process industry is energy intensive, but due to the Norwegian renewable energy, it has lower CO2 emissions than some international competitors. Until now, the emissions of the process industry have so far attracted limited attention from the public. Nevertheless, the industry has set itself a target to become zero-emission by 2050. Carbon capture and storage (CCS) is a key technology in this ambition. There has also been some interest in circular economy concepts, including industrial symbiosis projects of utilizing waste streams as inputs in other production processes.

It is apparent that the green transformations take different forms and intensity across the sectors. On the one hand for the O&G sector, the global energy transition towards e.g. renewable energy ultimately poses a fundamental challenge to reorient from producing O&G for combustion to other business models. On the other hand, for the maritime sector, the challenge of climate change opens a market opportunity for innovative firms to provide low-carbon technologies and services. Meanwhile, sectors such as process industry and manufacturing have been less exposed to environmental pressures and demand for more environmentally friendly products. For aquaculture, sector-specific environmental problems have stood in the way of realizing its ambitions of rapid growth. The megatrend of green transformations thus has manifested differently across sectors, highlighting the need to understand the sector-specific drivers and conditions of green transformations.

4.2 Digital transformations

Differing from environmental pressures, digitalization has primarily been perceived as an opportunity. This has been caused by the continuing development of various digital technologies, which as general-purpose technologies are widely applicable. They have mainly been seen as tools to improve the cost-efficiency and competitiveness of Norwegian industrial sectors in a global market. Notably, our empirical studies include rather few observations of digital technologies disrupting the sectors, even though they have been associated with major disruptions in some other sectors (e.g. digital platforms in retail, music, and media sectors). Digital technologies were instead often observed as add-ons to the existing production patterns of sectors. There was, at least in the present times, much less attention to long-term, potentially disruptive transformations associated with digitalization, such as loss of jobs and need for reskilling, which are issues high on the agenda in many other countries. The key perspectives on digitalization in the sectors are summarized in Table 3.

Table 3 Digital opportunities and transformations in Norwegian industrial sectors

	Digital opportunities	Digital transformations
Oil and gas	- Cost-efficiency - Long-term competitiveness	- Simulations (e.g. digital twins) and modelling - Digital platforms and data clouds
Maritime	- Cost-efficiency - New modes of transportation (e.g. coastal cargo shipping)	- Autonomous vessels - Simulations
Aquaculture	- Mitigating environmental problems - Increased value creation - Cost-efficiency	- Sensors and (the use of) big data - Drones
Manufacturing	- Re-shoring (advanced manufacturing) - Data from the use of products	- Robotization
Process industry	Little impact until now	- Automation/robotization

In the O&G sector, digitalization is opening opportunities for more cost-efficient operations. Advanced digital technologies, such as improved modelling and simulations e.g. through digital twins, use of digital platforms and data clouds, sensors and better use of data in decision-making, seek to make the sector more competitive in the long-term, thus contributing to the long-term survival of the sector. To some extent, digital technologies may therefore be seen to guard the international position of the Norwegian O&G production against countries with cheaper production costs, enabling the sector to run operations cheaper, and identify new O&G fields.

Picture: SINTEF, Tyd

In the maritime sector, attention to digital technologies has especially been focused on automatization, sensors, and performance modelling. These technologies enable the development of concepts such as autonomous vessels and digital twins. The most ambitious of these projects, such as fully autonomous vessels, are still under development, but may nevertheless pose a future opportunity for more cost-efficient shipping, which increasingly may compete with land-based transport. Autonomous shipping has therefore been seen as a potential market opportunity for both Norwegian shipping companies and suppliers.

Aquaculture has increasingly made use of ICTs, e.g. sensors and data, to achieve better oversight and control over their production process. Importantly, digital technologies have been seen as opportunities to remedy the pressing environmental challenges, while also improving the efficiency of fish production. Automation may also improve safety. For these reasons it is expected that digital tools will be increasingly implemented. They are particularly relevant for operating modern, often large-scale, production units.

Picture: SINTEF, Tyd

In Norwegian manufacturing, digitalization has been seen to create opportunities by making it more competitive internationally. Digitalization could therefore help in e.g. reshoring manufacturing through robotization and advanced manufacturing. However, the sector lacks competences in digital technologies, and advanced use of new digital technologies is yet only emerging. This is even more so in the process industry, where digitalization has been slow to advance, for instance because of high sunk costs in existing equipment and facilities.

Overall, and similarly to green transformations, digitalization has affected industrial sectors in several ways and in different levels of magnitude. New digital technologies have particularly been adopted in the O&G and aquaculture sectors where they have been seen to solve some key challenges in the sectors (cost-efficiency and environmental problems, respectively). In other sectors, digitalization has been a matter of future potential, and concrete value propositions of digitalization have remained somewhat unclear. In maritime sector, advance of digital technologies in shipping has been seen as a future market opportunity, fitting with the already high level of marine competences in Norway. Digitalization could also help to strengthen the competitiveness of Norwegian manufacturing, but like in process industry, it has yet to make a significant impact. Remarkably, despite the broad public attention towards digitalization, little has yet changed in the key Norwegian industrial sectors. However, large potential for future transformation nevertheless remain, especially in maritime (e.g. autonomous vessels) and manufacturing (e.g. robotization and reshoring).

4.3 Convergence of green and digital transformations

While green and digital transformations are largely separate megatrends, each with their own driving forces (e.g. environmental externalities and development of general-purpose technologies, respectively) and conditioning factors (e.g. societal pressures and economic incentives), they still have points of interaction. These may lead to synergies between the green and digital transformations. The dynamics between green and digital transformations are summarized in Table 4.

Table 4 Interaction between green and digital transformations in Norwegian industrial sectors

	Convergence between transformations
Oil and gas	Digitalization connected to efficiency and electrification may reduce carbon emissions somewhat, but also extends the O&G extraction path in Norway
Maritime	Digital technologies enabling some emission reduction in e.g. route and performance optimization
Aquaculture	Digital technologies used to solve environmental problems
Manufacturing	Potential increase of resource efficiency from further digitalization
Process industry	Unclear

In the O&G sector, digitalization has mostly emerged as a separate trajectory from green transformations. We can nevertheless observe some linkages. While digitalization in the O&G industry may help to reduce emissions in the production phase, it also can be seen to extend the path of O&G production in Norway. Improved cost-efficiency through digitalization improves the international competitiveness of the Norwegian O&G sector, enhancing the preconditions for continued O&G production.

In the maritime sector, some digital technologies possess the opportunity to introduce (minor) emission reduction in the industry. One example is that more advanced routing simulations and optimized cruising speed in relation to the capacity of handling cargo in harbours (so-called virtual arrival) may enable shipping companies to save fuel, and thus reduce emissions.

Digital technologies are central in seeking to solve the vast environmental problems in the aquaculture sector. Digital technologies enable for example better oversight of fish health and growth as well as better control over the production process through automation and monitoring, and production in larger units with presumably smaller environmental impact. Green and digital transformations thus show notable convergence in the aquaculture sector.

Picture: SINTEF, Thor Nielsen

The effect of digitalization on sustainability goals was less apparent in manufacturing and process sectors. While business models related to circular economy concepts and servitization in the manufacturing may use e.g. digital platforms, potentially improving the efficiency of natural resource use, concrete evidence and examples of environmental benefits were still insufficient. For process industry, however, more significant digitalization is yet to be unfolded, thus leaving also the relation between these transformations unclear.

To summarize, digitalization has until now only had a limited effect on the greening of the studied Norwegian industrial sectors, with the clear exception of aquaculture. However, future potential is evident in the maritime and manufacturing sectors.

4.4 A note on COVID-19 pandemic[1]

This report focuses on two overarching trends: greening and digitalization. While such trends are pervasive, the changes that they create in sectors are slow. In 2020, the COVID-19 pandemic has dealt a hard blow on the global economy. How has the pandemic influenced the green and digital transformations in the sectors that we focus on in this report?

For most industries, the COVID-19 pandemic and its economic repercussions came as a shock. The long-term effects of this crisis naturally cannot be known. Short-term responses can however tell us something about both the resilience and adaptability of these sectors, and also how important for instance environmental issues are. Table 5 summarizes main trends. There is certainly substantial variation across sectors which is obscured by these crude generalisations. What is clear, nonetheless, is that for some industrial sectors, such as O&G and the maritime sector, COVID-19 resulted in an abrupt decline in demand, whereas other sectors have longer business cycles and the effects are expected e.g. 6-12 months after the "lock-down". Therefore, when we conclude that aquaculture and the process industries seem to have been least affected by the pandemic crisis, it is also possible that the effects will be noticed later.

[1] A separate report on the effects of the COVID-19 pandemic was published (in Norwegian) in June 2020. The report can be accessed by contacting the authors.

Table 5 Summary of COVID-19 impacts

Industry	COVID-19 short	COVID-19 long	COVID-19 sustainability	COVID-19 - digitalization
Oil and gas	Negative	Uncertain	Uncertain, negative	Uncertain, positive
Maritime	Negative	Uncertain	Negative	Uncertain, negative
Aquaculture	Modest	Modest	Modest, positive	Modest, positive
Process industry	Modest	Uncertain	Modest, positive	Uncertain
Manufacturing (NB large variation)	Negative	Uncertain	Uncertain	Uncertain, positive

Colour codes: red=negative, orange=negative/mixed/uncertain, yellow=uncertain, green=positive

A main impression is that the COVID-19 crisis has had a positive impact on digitalization, especially in terms of implementing mature solutions and tools for digital communication. Larger development projects linked to digitalization may however been postponed or cancelled. In a longer-term perspective, we can assume that experiences during the crisis will contribute to increasing digitalization.

There is a clear trend that attention to sustainability can be severely reduced in sectors that experience sharp downturns in turnover. In the short term, we therefore expect that COVID-19 will have a negative impact on sustainability transitions in these five Norwegian industries. However, we also note that targeted policies and policy instruments can compensate for firms' lacking ability to prioritize sustainability in times of crisis, and also contribute to acceleration of activities taking industries in 'green' directions.

According to classical innovation theory, the main response from firms to crisis is to focus on core activities and do incremental innovation that contributes to enhanced efficiency and cost reductions. This implies that a crisis – such as that caused by the COVID-19 pandemic – first and foremost results in conservation of status quo. To meet the goals set in the Paris agreement and other sustainability ambitions however demands substantial radical innovation. Many of the solutions that are seen as necessary in the Norwegian context – such as CCS (oil and gas, process industry), offshore wind (oil and gas, maritime), or hydrogen for transport (maritime, oil and gas, energy) are large-scale, capital-intensive projects that will require substantial public support to materialize. Without policy with clear targets and adequate support, green transformations in key Norwegian sectors are likely to be hampered by the current crisis. Therefore, to both help industry overcome the crisis and ensure that new developments have a clear direction, policy instruments oriented towards large-scale projects should have a clear green profile.

5 Insights on policy

5.1 Policy context regarding green transformations

To speed up green and digital transformations in industrial sectors, policies fostering such changes are needed. This is particularly relevant for green transformations that, rather than focusing on economic gains, has an explicit direction in terms of supporting change towards more sustainable modes of production and consumption (Alkemade et al., 2011). Because of strong lock-ins in sectors (Unruh, 2000), policies for green transformations have to support both the creation of new (greener) technologies and industries, and include measures that could influence the decline of unsustainable practices and technologies (Kivimaa and Kern, 2016). Green industrial policy includes more active involvement of public actors in supporting the industry development around green technologies, for instance through means of green R&D support and infrastructure development, as well as market formation through public procurement policies (Busch et al., 2018). Decline policies may include e.g. introducing stricter environmental regulation or higher taxation of unsustainable practices and technologies. As decline policies may conflict with vested interests in established industrial sectors and threaten e.g. employment in the short-term, policies for new industry creation are likely to be politically more feasible to implement than decline policies (Mäkitie and Normann, 2020).

In Norway, sustainability and digitalization have been significant policy issues the last years, in relation to increased attention to industrial policy both in the European and Norwegian context. In 2017, the Norwegian government issued a white paper on green and smart industry policy in Norway (St. Meld. 27, 2016-17)[2]. A national strategy for green growth was issued in 2018. This plan was developed based on advice from an expert committee and development of road maps for green transformation in a range of Norwegian industries (Ekspertutvalg for grønn konkurransekraft, 2016). More recently, a report commissioned by the Ministry of Climate and Environment addressed the pace of green transformations in the Norwegian industrial sectors, as part of the follow-up of Norwegian climate policy (St. Meld, 41; 2016-2017)[3]. Other initiatives, mainly from industry itself, include Industri Futurum, GreenIndustry 21 and establishment of the Shift network. Also, the Confederation of Norwegian Enterprise (NHO) recently issued a "road map" for industry transformation ("Industry for the future").

The backdrop of this wide interest in green transformations in industrial sectors is the strong reliance on O&G in the economy (directly and indirectly) and the acknowledged need to diversify the economy and transform existing industries in a smarter and greener direction. The basic principle in Norwegian policy has been the continued support to O&G operations. Policies targeting green transformations in industrial sectors have focused on the development and deployment of technologies connected to more environment-friendly production processes and reduction of CO2 emissions and pollutants to air and water, as well as better use of resources, including circular economy perspectives. The most important policy tools to achieve goals have been R&D and technology policies, regulation, quota trading and taxes. For instance, the National Transport Plan for 2018-2029 has put forward concrete emission reduction goals in e.g. coastal shipping. Carbon emissions from the extraction and use of O&G are subjected to a tax which has recently been increased. Support to industry collaboration, access to finance, public procurement and support to R&D, pilot and technology demonstration projects in environmental technologies have also been preferred policy tools.

However, despite this policy effort, a report tracking the progress of green transformations in central Norwegian industrial sectors (based on the targets the sectors have set down themselves in industry road maps), the progress made has been slow, and mainly consisting of relatively small pilot projects connected to reduced energy consumption and carbon emissions (EY, 2019b). Substantial investments in new projects, and development and deployment of new technologies and products are yet to be realized.

[2] https://www.regjeringen.no/no/dokumenter/meld.-st.-27-20162017/id2546209/
[3] https://www.regjeringen.no/no/dokumenter/meld.-st.-41-20162017/id2557401/

The results in our report also point in a similar direction. Pressures to respond to environmental issues are certainly visible in the industries we have investigated, but until now mainly in form of incremental improvements in limiting environmental externalities (carbon emissions in particular). Steps towards developing new activities and technologies in a radically greener direction are more limited, although we see new technological development in the maritime sector (electric and hydrogen ferries), and e.g. some efforts towards diversification in O&G (e.g. aquaculture and offshore wind), and circular economy concepts in manufacturing. Development of new technologies and products addressing new markets are mainly driven by market extension and are based on business considerations, whereas steps taken towards reducing negative environmental externalities are more driven by compliance to regulatory change and stakeholder pressures.

5.2 Implications for green transformation policy

We observe that existing policy instruments are effective when it comes to promoting incremental innovations within existing business segments, but less effective when it comes to more radical technology development. Policies have mainly been directed to R&D and pilot projects. Results are clearly seen in e.g. aquaculture, but these are still in an early stage and scale-up is still uncertain. The maritime sector is a more encouraging example, where e.g. public tendering processes, strict emission reduction targets, and development projects have been effective in speeding up low-carbon innovation, especially in battery-electric ferries. This showcases the strong role that public policy, using technology-push mechanism (e.g. R&D funding) and market-pull (e.g. public procurement), may have in accelerating green transformations in industrial sectors.

Moreover, while we could observe some policies supporting green technology and industry development, there were yet fewer signs of strong decline policies actively putting pressure on e.g. the phase-out of unsustainable technologies, with a notable exception of e.g. the rather high emission reduction targets set in publicly tendered shipping routes, such as ferries and the coastal express (Hurtigruten). The policy context therefore resembled yet more traditional innovation policy rather than a transformation policy seeking to accelerate change by combining both green innovation and decline policies (Kivimaa and Kern, 2016).

5.3 Policy context regarding digitalization in industry

Digitalization has also received attention in both policy and business communities. Policy developments include a white paper issued in 2016 (Digital agenda for Norway)[4], outlining important areas for policy intervention, such as the sharing economy, big data, data sharing, smart city developments, digital entrepreneurship and innovation, and digitalization and robotization of industry, in addition to a strong focus on digitalization of the public sector. This white paper has been followed up with several national strategies within specific parts of digitalization policy (such as AI policy, cyber security, data protection regulation etc.). Different policy areas have also developed domain-specific digitalization strategies.

The industry white paper (Industrimeldingen), as described above in the section of green transformation policies (St. Meld. 27, 2016-173), also addressed digitalization. One concrete policy action recommended in

[4] https://www.regjeringen.no/en/dokumenter/digital-agenda-for-norway-in-brief/id2499897/

this white paper was to create a high-level expert group on digitalization in the private sector in Norway (Digital 21 strategy)[5]. The strategy, submitted in 2018, includes several action points to make industries and firms across all sectors more digital.

The strategy is based on the perspective that digitalization is an overarching transformation process that occurs across sectors. The process is characterized by increasing convergence across industries and knowledge fields. This leads to a change in the overall innovation system, whereby new technologies, domains of knowledge, actors and institutions emerge and coevolve. This process will fundamentally transform the economy and give rise to new kinds of firms, modes of collaboration and jobs with different competence requirements. The main policy recommendation is to support digitalization in industry through the following measures:

- support to fundamental or generic research
- support to public and private R&D and innovation activities including technology demonstration and scale-up
- competence development
- strategic use of public procurement

Support to development of data infrastructures, data sharing and attention to cyber security are seen as other key areas where policy support is needed. As digitalization cuts across sectors, there are several policy domains that support digitalization, in addition to digitalization as part of education, research and innovation policy more generally. An overview of support to research on digitalization made for the Digital21 strategy shows that sector specific research programs support considerable R&D&I activities in specific domains (e.g. oil and gas, aquaculture etc.), but less support is offered to more generic research on digital tools. The report also shows that R&D expenses connected to digitalization has grown substantially over the last years, but this growth is only in business R&D and not in the public research sector.

Data sharing and use is particularly topical, and in 2020, the government is preparing a white paper on data driven economy and innovation. Data-driven enterprises are expected to have the potential of becoming a significant export and growth opportunity for the Norwegian economy. The realization of this potential, however, is still hindered by e.g. limited specialist competences and education within ICT-technologies, as well as an unclear and complex regulatory framework (Gjørv et al., 2020, Waterhouse et al., 2013). Meanwhile, for instance the implications of sharing economy through digital platforms are only seen in a limited number of service sectors so far, such as personal mobility (e.g. Uber) and accommodation (e.g. Airbnb) (Gabrielsen et al., 2017), and have not yet featured as a policy focus in many Norwegian industrial sectors.

5.4 Implications for digitalization policy

Even though all see digitalization as an important driver for industry transformation and expect that digital tools will enable cost-efficiency and improved competitiveness vis-à-vis a global market, most of the studied sectors have taken few steps towards realizing these ambitions. There are examples of R&D activities and advanced use of digital tools, but perhaps fewer than expected. It is, however, important to note that the key

[5] https://digital21.no/

Norwegian industrial sectors studied in this report), being largely capital-intensive, natural-resource based, and parts of complex production systems, are very different from the service sectors (e.g. retail and mobility) where digitalization has until now had most impact (Gjørv et al., 2020). Digitalization in these sectors is yet unfolding. This means that policy may yet seek to support the Norwegian industrial sectors in strengthening their digital leadership in this emerging development. Some concrete policy measures are e.g. the increase of specialist education, support to R&D and innovation, as well as clarifying regulations e.g. in regards to data use and sharing (Gjørv et al., 2020). Moreover, there is yet a need for better guidelines and standards in governing access to data, which is relevant e.g. in industry projects with sensitive information (e.g. data from IoT that are driving competition) requiring collaboration from multiple organizations. These are measures that the recent Digital21 strategy also recommend.

Moreover, while several public digital infrastructures are already in place in Norway (e.g. encompassing broadband connections and digital public services), policy measures may be needed to further develop digital infrastructures, such as 5G networks, and adapt the regulatory frameworks to enable e.g. new data-driven business models. Existing polices have focused on the R&D side. However, just as in the case of green industry transformation, measures directed towards market opportunities and business model development are needed to facilitate upscaling and development towards the stated goals. Due to this, the Digital21 strategy suggests collaborative pilot and demonstration projects as new policy measures for supporting digitalization across industries. Public procurement and cross-industry collaboration are also likely to be effective policy measures, as recommended by the current policy and strategy frameworks.

Specifically, automation and remotely operated industrial assets (e.g. O&G platforms, vessels and aquaculture facilities) may have disruptive effects on the types of employment and competences needed in sectors. Digital technologies enable moving staff from offshore conditions to onshore offices to operate the assets, which is usually cheaper and safer, but also leads to new types of requirements for staff competences, which may or may not be aligned with the current competences of the employees.

In relation to this, but as part of a larger trend noted in the Digital21 strategy, new kinds of firms are likely to enter established industries and value chains. This is likely to disrupt the composition of value chains and the position of customers, supply and service firms. Established value chains are developing into ecosystems where several firms collaborate in creating, delivering and capturing value. For instance, in oil and gas, digital infrastructure and service firms are likely to get a more central role in value chains and future business ecosystems. Overall changes in firm and value chain composition and the kinds of jobs and competences needed may also influence the institutional set-up that regulates industries. This can for instance influence the established institutional set-up between trade unions, employers and the government. This organization (referred to as the “tripartite collaboration") is central in regulating industry development in Norway. One impact of changes in actor composition might be increased pressures on the central role of labor unions in Norwegian working life. Changes to the kinds of employment and competences needed may also have political significance. These issues span digitalization policy and R&D and innovation policy, requiring integrated policy responses across multiple policy domains.

5.5 Interactions between green and digitalization policies

The connection between digitalization and green industry transformation is rarely discussed in policy documents. The two ongoing transformations are not viewed in an integrated manner, and the responsibility for the two issues is also separated in different ministries. Digital tools (as general-purpose technologies) are occasionally seen to have the potential to support green transformations, but clear examples and policy action are limited thus far.

Our analysis has suggested that green transformations and digitalization may interact. This has implications for innovation policy, as the policy instruments that support digitalization may either drive or impede (the needed) transformations towards greener modes of production and consumption. This highlights the role of coordination and coherence between various policies towards achieving sustainability goals (Rogge and Reichardt, 2016). Rather than implicitly assuming synergies between policies directing green and digital transformations in sectors, their relationship has to be critically evaluated. The interactions between green and digital transformations differ from one sector to another. Policy consideration should thus pay attention to sectoral differences and complement more general policies (e.g. in terms of regulation and infrastructures) with sensitiveness to specific green and digital challenges in sectors.

6 Outlooks for further research in INTRANSIT

Our analysis has revealed several research questions regarding green and digital transformations in Norwegian industrial sectors. These open opportunities for further research activities in INTRANSIT.

We have until now found large differences in green and digital transformations across the studied sectors. The reasons for such variation nevertheless remain yet somewhat unclear. Why do the transformation pressures and opportunities affect sectors so differently? Why are certain segments advancing digital and green transformations while others are lagging?

Further variation may be found at the organization level. Analysis of different organizational responses to green and digital topics may provide fruitful research opportunities to better understand how such encompassing transformations unfold. For instance, how and why do the existing organizations in the different sectors transform over time? How do the green and digital pressures and opportunities translate into organizational behavior and decision-making?

Another central issue in green and digital transformations is time. ICT technologies are known for their rapid development, while e.g. climate change requires urgent cuts in emissions. How fast do the sectoral transformations in Norwegian industry unfold? How does the pace of transformation differ from a sector to another, and why? Can the pace of transformation be accelerated, and if so, how?

We identified several green and digital niche innovations, in sectors of varying degree of maturity. While many of these niches are unlikely to become mainstream practices or technologies, some of them may be of high importance for the future of the respective sectors. What are the conditions for further development and diffusion of these niche technologies? How can the innovation around the niche technologies be accelerated? Which organizations lead the innovation development?

Moreover, because of the growing political importance of climate change and continuing development and diffusion of various low-carbon technologies, the O&G sector in Norway is likely to sooner or later face a permanent decline. As this sector continues to be of key importance for the Norwegian economy, the eventual decline of O&G sector is a key challenge for the Norwegian economy in future. How can the Norwegian economy prepare for it, and be resilient against a possible economic decline that may result from it? To what extent can the organizations in the O&G sector move to other sectors? Can growth in other sectors ensure continued employment and level of welfare in Norway?

Finally, all of the above questions and topics are of crucial relevance for policy. A central element in the work in INTRANSIT is to provide relevant input for policy addressing green and digital transformations. How do the policy needs differ from one sector to another? What are the opportunities in different sectors to combine green and digital topics into a more holistic policy approach? How may policy contribute to diversifying the industrial structure of Norway, thus preparing for the decline of the O&G sector? What sets of policies, addressing both new innovations and decline in unsustainable technologies, may foster green and digital transformations in the Norwegian economy?

7 Full analysis of green and digital transformations in Norwegian industrial sectors

7.1 The oil and gas sector

In this section we briefly describe the main characteristics of the O&G sector and the on-going sustainability and digital transformations it faces. We begin by briefly reviewing the history of the sector, and then proceed to discussing the recent key market developments, as well as the main actors, institutions, technological issues and geographical clusters along the value chain of Norwegian O&G production. We then discuss the sustainability and the digitalization transformations within the sector.

When oil was struck in the Ekofisk field in December 1969, there were few petroleum competences and no mentionable O&G sector in Norway. However, there was a strong political will to change this situation and use the opportunity of the petroleum discovery to work for the economic development of Norway. Industrial policy measures were implemented which were of key importance in building a national value chain around O&G extraction. Strong national organizations, such as the national oil company Statoil (today Equinor) and the Norwegian Petroleum Directorate were established and used to facilitate the building of national competences of operators and supplier companies. Moreover, supplier companies with already existing knowledge in mechanical engineering and maritime technologies were able to use their experience in providing components and services in the O&G production, and thus transform themselves to suppliers also in the O&G sector. Additionally, the support for R&D organizations such as SINTEF and Christian Michelsens Research enabled the development of cutting-edge technological competences, today exemplified by world-leading knowledge in subsea technologies (Engen, 2009, Engen et al., 2019). Moreover, increased O&G activities in Norway have been encouraged by national policy instruments, such as regular opening of new exploration areas, reimbursement (up to 78%) of companies' exploration costs, tax deduction of R&D (50%) and investment costs (20,8%). All in all, since the discovery of Ekofisk, a world-class value chain in the extraction of O&G has been established in Norway.

The success of the O&G sector is reflected in its current significance in the Norwegian economy. According to Statistics Norway, in 2019 the crude petroleum and natural gas amounted to 46% of the export value of Norway, while in 2018 the industry as a whole provided employment for 54 000 people in the extraction of O&G and related service activities. The O&G industry also has strong links to some other industries. For instance, about 55% of the value creation in the maritime industry is linked to O&G (Regjeringen, 2019a). In other words, the O&G sector today has a completely central position in the nation's economy.

Nevertheless, the industry has recently been challenged, especially by the relatively low oil price. While the Brent oil price amounted to over USD 100 per barrel during 2011-2014, the price has varied between USD 30-70 in 2015-2019. After this period of somewhat recovering oil price, in March 2020 the Brent oil price crashed again to less than USD 30 per barrel. As offshore extraction of O&G in Norwegian conditions is relatively expensive, lower oil price has led to lower profits and fewer investments in the Norwegian Continental Shelf (NCS), and consequently to fewer and smaller contracts for Norwegian suppliers (see Figure 2). Therefore, since 2015, the whole industry has faced an urgent need to reduce cost, which has resulted in a strong pressure for more cost-efficient products, services and operations (KONKRAFT, 2018, Interviews 4, 11).

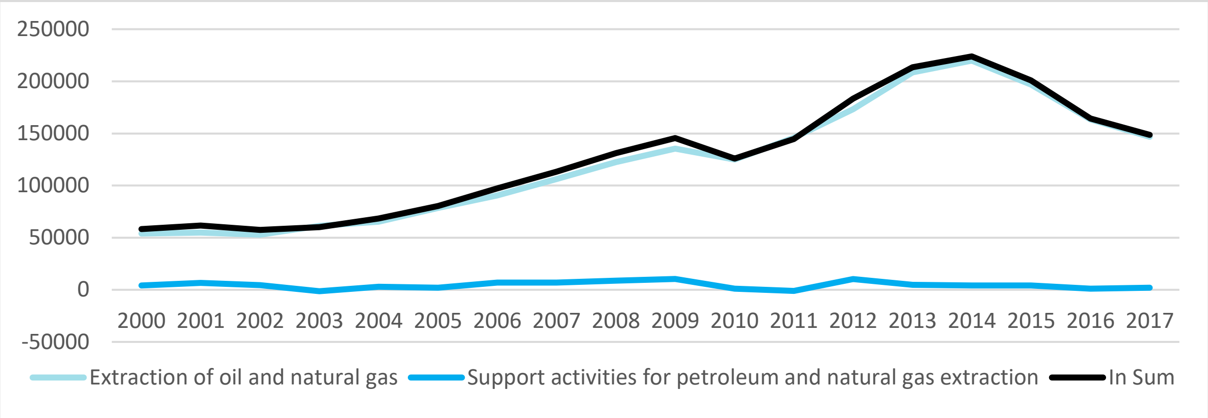

Figure 1 Investments in the Norwegian Continental Shelf in Millions of NOKs (Statistics Norway)

Moreover, except for the discovery of Johan Sverdrup and Johan Castberg fields in 2010-2011, there have been few recent petroleum findings, despite the all-time record high of 43 exploration wells in Norway in 2019, of significant size in the NCS (see Figure 3), decreasing the long-term prospects of the industry. For this reason, it has been estimated that the activity level across the value chain may turn to decline already in the latter half of the year 2020 in Norway (Interview 2). Also worries, regarding the availability of work force has been raised, as the staff is getting older and fewer young people choose to educate themselves in petroleum-related topics. This again may lead to inflation and growing costs (DNV GL, 2019b). Meanwhile, the NCS has increasingly become a natural gas bearing shelf. The production of oil has halved since 2001, but the increase of gas production has largely offset this reduction. Moreover, investors in O&G have reportedly increasingly sought faster return to their investments, preferring e.g. simpler projects and standard technological solutions over complex mega-projects, thus seeking to fast-track new projects (Interview 8).

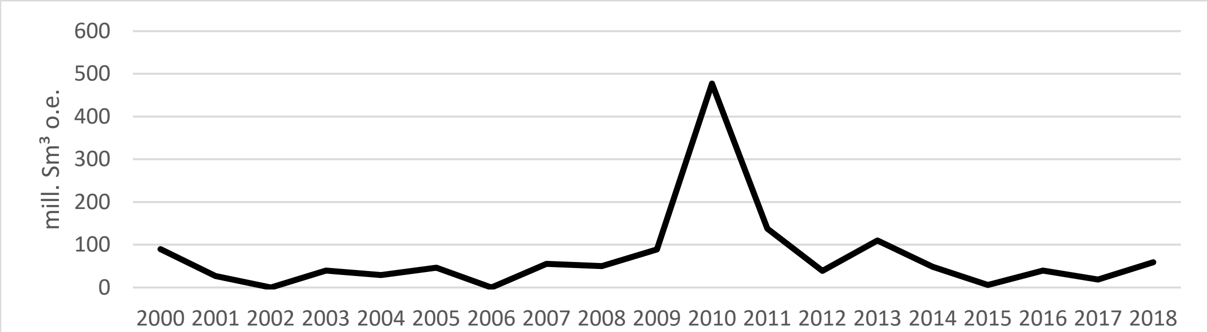

Figure 2 Petroleum findings in Norway in millions of standard cubic meters of oil equivalent (source: norskpetroleum.no)

While the above-mentioned indicators point to declining industrial activities, there are a few factors that provide reasons for some optimism for companies operating in the NCS. For instance the International Energy Agency expects continued demand for offshore O&G products, especially natural gas (IEA, 2018). Also, the market for the maintenance and modifications of existing O&G extraction facilities in NCS is expected to last for decades (Interview 2). DNV GL expects global oil demand to peak in 2022, and natural gas in 2033 (DNV GL, 2018a), painting a picture of relatively stable market environment for the O&G industry over the next decade or two. Aligned with this, the policy of the Norwegian government has been to continue supporting the extraction of O&G, and “enable the potential for further sustainable job and value creation” (Regjeringen, 2019a). Indeed, in 2018, 76% of global O&G professionals were confident about the O&G sector’s growth prospects, up from 63% in 2017. However, this confidence seems to highly correlate with the development of the global oil price (DNV GL, 2019b).

7.1.1 The O&G value chain

Despite its humble beginnings, Norway nowadays has a complete domestic value chain in offshore O&G production (Blomgren et al., 2015, EY, 2018). Many of these companies are international: either Norwegian-based multinationals, or foreign-based companies present also in Norway. See Figure 3 for an overview.

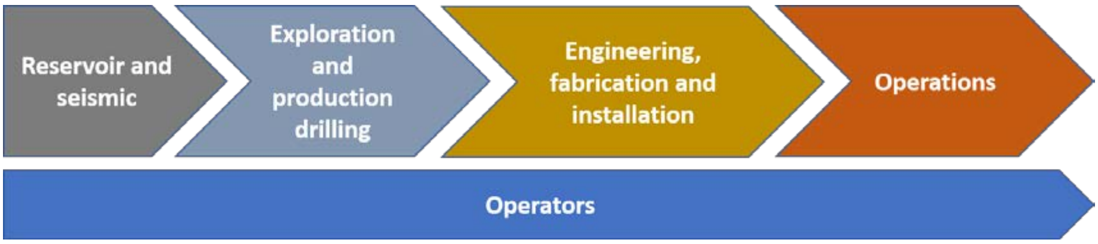

Figure 3 The upstream oil and gas value chain

In terms of *operators*, foreign oil companies such as Phillips (today ConocoPhillips), Elf Aquitane (today Total), and Shell played an important role in the early years of the Norwegian O&G sector. However, by today the Norwegian Equinor (former Statoil) has established a dominant position as the leading operator in the NCS. Moreover, a number of smaller and specialized operators, such as Lundin and Aker BP, have emerged in the market, having smaller organizational structures and specializing in certain niche markets such as exploiting mature fields. In comparison to large multinationals, smaller companies often have e.g. few technological competences in-house, relying more strongly on their suppliers (Interviews 5, 8). Meanwhile, increasingly many of the large multinational oil companies, such as Chevron, Total and ExxonMobil have begun to withdraw from NCS e.g. to focus on other O&G bearing countries with higher profit margins (Interviews 2, 5).

In the *reservoirs and seismic* value chain segment, key companies are for instance PGS Geophysical and TGS NOPEC Geophysical, located in the Oslo area. In *exploration and production drilling*, companies such as the multinationals Schlumberger, Halliburton and Baker Hughes are central in providing well services. Meanwhile, multinationals such as Seadrill and National Oilwell Varco provide rig equipment and services, located often in Rogaland and Agder.

Engineering, fabrication and installation of O&G constructions is a broad segment which features many Norwegian suppliers. For instance DNV GL is an important certification and classification entity, while Cognizant provides IT services. Aker Solutions and TechnipFMC are particularly known for their subsea engineering and products. Many of the engineering firms are based in the Oslo region. Norway also has a few important engineering, procurement and construction (EPC) companies such as Aibel and Kværner. Offshore yards, such as Coast Center Base and Westcon Yards, provide the necessary facilities for the construction and maintenance of offshore platforms. As mentioned above, the strong maritime sector, much of it in Møre & Romsdal region in Western-Norway, has also provided the necessary knowledge regarding O&G vessels. These companies are exemplified by shipyards like Vard and Kleven, and Kongsberg Maritime providing maritime technologies. Trondheim, on the other hand, has a strong R&D cluster around the technical university NTNU, with e.g. SINTEF and Marintek as prominent organizations.

Operations in and around O&G installations also offer opportunities for suppliers. Companies such as shipping firms Solstad Offshore and Siem Offshore, and helicopter firm Bristow, provide supply and logistics services. Moreover, Beerenberg, Kaefer Energy, Bilfinger Industries and others provide various platform services e.g. in maintenance and modifications. Operation services usually have to be provided physically at the O&G installations, for which reason such companies are often located in e.g. Rogaland and Hordaland.

7.1.2 Environmental topics and the transformation in the oil and gas sector

7.1.2.1 Pressures and opportunities

NCS is known to have relatively strict health, safety and environmental regulations (Interviews 2, 4). For instance, internationally operating companies sometimes may have to upgrade their rigs and other equipment when moving them from abroad markets to Norway. Because of this, for instance major oil spills are considered relatively unlikely in Norway (Interview 2). For this reason, instead of focusing on possible oil spills and other environmental accidents, the public pressure around environmental issues has usually culminated mostly around the issue of climate change.

As the combustion of O&G products is the key contributor to the global greenhouse gas emissions, the climate change issue has put increasing pressure on the O&G sector (IEA, 2020). The international O&G sector has faced climate change concerns for decades already, responding at worst with outright promotion of climate change denial, and at best with clean technology development (Levy and Kolk, 2002). However, our data suggest a recent change within the Norwegian O&G sector in how seriously it takes the issue of climate change (Interviews 3, 5, 8). The industry has begun to recognize the global need to cut emissions, and argues that it can be part of the climate solution (KONKRAFT, 2016, Interviews 3, 6), e.g. through e.g. use of natural gas, development of renewable energy and carbon capture and storage (CCS) technologies. However, the investments of O&G operators in renewable and CCS technologies have been tiny in comparison to the investments in continuing O&G activities (Interview 8), and the business case for CCS remains uncertain. Some scale is given by IEA, which declares that the investments in RETs and CCS have until now amount to about 1% of the overall investments of large multinational O&G companies (IEA, 2020). However, large Norwegian operators and suppliers have had somewhat higher engagement in such technologies than e.g. their USA-based counterparts (Interview 2). For instance Equinor has pledged to use 15-20% of their investments in carbon-free energy production by 2030.

The climate change pressures in the Norwegian O&G sector manifests in at least three ways.

First, typically the most important pressure arise from the potential future changes to the most relevant regulations and policies affecting the sector (Interviews 2, 8). The increasing political discussion regarding whether Norway should continue extracting O&G presents worrying signs for the sector, because discontinuing the opening of new exploration areas or the reimbursement of exploration costs would have major implications for the sector (Interview 3). While the largest political parties yet support continued O&G extraction, limitation of exploration particularly in the Lofoten, Vesterålen and Senja areas, as well as in the Arctic Sea, have gained support in several (particularly smaller) political parties. Moreover, parties have proposed the reorientation of the O&G industry towards other markets, such as renewable energy (Mäkitie and Normann, 2020).

Second, it has been reported that fewer people wish to educate themselves in petroleum related disciplines, which threatens the availability of future workforce in the sector (Interview 2). This was said that more young people seem to want to work with “greener” topics, making it difficult for O&G focused companies to recruit young talent with specialized O&G competences (DNV GL, 2019b, Interviews 12, 13). One interviewed large company was reportedly even denied a visit to a prestigious Swedish university because of their status as an “unsustainable” company (Interview 12).

Third, the financing sector has begun to consider the climate risk of carbon intensive petroleum production. This has recently led to a situation where some offshore O&G projects with high carbon footprint have had difficulties to secure financing from banks and investment funds, forcing operators to reconsider their planned projects (Interview 8). A main reason for the concern among financiers has been the expectation that carbon-intensive projects may involve an increasing climate risk in future, threatening the viability of such investments (Interview 5). Such financing issues have so far been limited to projects in Northern Europe (Interviews 4, 5), but the recent decisions of some of the world’s largest asset managers, such as BlackRock, and sovereign wealth funds, such as the Norwegian oil fund, to decarbonize their portfolios suggest a broader future trend.

7.1.2.2 Environmental transformation along the value chain

The O&G sector has responded to the climate change issue in a number of ways. One strategy has been to seek to diversify to other markets in order to reduce their reliance on the O&G market (Interview 3). Some firms, especially firms in *engineering, fabrication and installation* as well as *operations* segments have diversified e.g. to offshore wind and aquaculture (Hansen and Steen, 2015, Steen and Weaver, 2017, Interviews 4, 6). For instance turbine foundations such as floating platforms (Mäkitie, 2020), technical consultancy, cabling, surveying and installations capabilities from O&G have been used in OWP (Normann and Hanson, 2015). Moreover, O&G firms with offshore structural design competences have been able to enter the aquaculture market (Interview 10). In terms of *operators*, Equinor has made significant investments in renewable energy, especially offshore wind, in both technology development and electricity production, thus providing contract opportunities also for other Norwegian firms diversifying from the O&G sector (Afewerki et al., 2019).

The industry became more engaged in diversification after the oil price collapsed in late 2014 (Mäkitie et al., 2019b). In contrast, the period of high oil price in 2011-2013 marked with high level of investments offered plentiful opportunities for both operators and suppliers, and firms were reported to have little interest and time to explore other markets (Hansen and Steen, 2015, Interview 4). However, after the declined activities and subsequent growing opportunities in e.g. the OWP and aquaculture markets, more companies have diversified now to alternative markets, showing a trend of more integrated "ocean market" with overlaps in e.g. supplier companies and technological solutions across O&G, offshore wind and aquaculture (Mäkitie et al., 2018, Interviews 4, 6). Moreover, the earlier need to cut cost in the O&G market after 2014 have also made some suppliers more competitive in other markets (Interview 4). However, for suppliers the O&G market still often produces better profits (Interview 10). Moreover, especially firms in highly O&G specific value chain segments such as the *reservoirs and seismic* and *exploration and production drilling* few opportunities for diversification have emerged, making these segments vulnerable for market decline in the O&G sector (Interviews 3, 4, 8).

Particularly the *operators* have also sought to respond to the climate change pressure by announcing to reduce the emissions in the extraction process of fossil fuels (KONKRAFT, 2016, Norsk Industri, 2018). This is sought to be done by e.g. electrifying the extraction of O&G by pulling power cables to offshore installations from on-shore. This way the installations avoid using natural gas generators, causing emissions. For instance the new Johan Sverdrup field, Equinor's giant O&G field opened for production in 2019, is using on-shore electricity. Such decarbonization of the production of O&G has gained political support, exemplified by for instance allocating funds to the opening of the LowEmission Research Center hosted by SINTEF, aiming to support the Norwegian O&G sector in challenges related to energy-efficiency and electrification. Moreover, in 2019 publicly funded ENOVA granted NOK 2,3 Billion to Hywind Tampen project, a 88MW floating wind power park planned to power Gullfaks and Snorre O&G fields. However, as noted by DNV GL in their Energy Transition Outlook: *"the production of oil and gas accounts for a relatively small proportion of greenhouse gas emissions along the value chain. It is during the consumption of oil and gas products where most emissions occur"* (DNV GL, 2019a).

Moreover, the sector has explored emission-free ways of using O&G, such as through carbon capture and storage (CCS). CCS has been proposed to be used e.g. in the production of hydrogen from natural gas (so-called blue hydrogen) where CO2 emission are permanently stored to an underground reservoir e.g. in the NCS (DNV GL, 2019a, Interviews 5, 6). However, such projects are yet to be implemented. Equinor, Shell and

Total are also partnering in developing the Northern Lights project, which considers transporting the CO2 from a cement production plant and a waste treatment plant around Oslofjord, and store it in the NCS. This project is facing investment decision from private and public partners in 2020/2021.

7.1.3 Digitalization and the transformation in the oil and gas sector

7.1.3.1 Pressures and opportunities

Digital technologies are not new in the O&G sector, and many such technologies have already been implemented several decades ago (Gressgård et al., 2018). For instance, seismic and well log data applications in e.g. modelling, analytics and visualization have historically been at the fore-front of developing digital tools (DNV GL, 2018b). What is new, however, is the pace of acceleration in data handling capacity and the emergence of online platforms which have increased the opportunities given by digital tools (Interviews 2, 10). Digitalization is currently considered the highest R&D priority by the O&G sector (DNV GL, 2019b).

Digitalization in the O&G sector is driven particularly by its potential for increased cost-efficiency: to operate cheaper with the same or better safety (NORWEP, 2016, Interview 5). This may increase the competitiveness of the Norwegian sector in the long-term. For instance, better modelling in an early phase of O&G projects may enable better planning of engineering work, decreasing cost throughout the development phase. This is crucial, especially in smaller fields (common in NCS) which have to be produced and managed as cost-efficiently as possible to be profitable (Interview 2). Moreover, there is much interest in building autonomous offshore installations to reduce e.g. staff-related cost (Interviews 4, 8, 10). This issue is nevertheless not without its controversies, as this inevitably affects the job opportunities in the sector, raising concerns in labor unions (Interview 6). However, it has been acknowledged that the digitalization in the O&G sector also may create new jobs specialized in ICT technologies (Interview 8). The concern regarding availability of workforce nevertheless remains, as e.g. data scientists are often drawn to technology firms and other digitally-driven companies rather than the O&G sector, increasing the difficulty to attract these skills (DNV GL, 2019b).

Digital technologies, including the use of big data, have been visioned to improve decision-making (NORWEP, 2016) and thus also the safety in O&G operations. This is because further inclusion of digital tools may reduce the risk of human error in managing the process of O&G extraction (DNV GL, 2018b, Interviews 1, 5). However, other risks may emerge, such as the threat of malicious hacking. Digital technologies may therefore improve the flow of information in process management, but this information has to be appropriately protected from intruders. Therefore many systems have been closed, but further utilization of new digital technologies and ways of collaboration between e.g. operators and suppliers may require more open systems (Gressgård et al., 2018). Such security concerns open a dilemma for the O&G sector which may hinder the development and application of digital tools (Interviews 1, 3).

It is yet unclear if and how the current digitalization will change the main patterns of behavior in the sector, for instance how operators and suppliers interact. One important issue is data sharing which could in principle help to further cut costs (Interview 8). For instance, digital technologies may enable more efficient data sharing and collaboration, but it is yet unclear if this will happen, as there may be reluctance to share valuable data (Interview 2). Some data is shared e.g. between suppliers and operators, but this is rather limited. Moreover, there may be limited incentives for sharing as data is currently handled and stored in a number of different formats and qualities. There are however exceptions, and for instance operators collaborate in joint industry partnership where data sharing takes place. However, to summarize new digital technologies such as digital platforms have not fundamentally changed the behavior of the sector, at least until now (Interview 5).

7.1.3.2 Digital transformation along the value chain

Digital technologies have been seen to change operations in all value chain segments of the O&G sector. They also open opportunities for new players and brings in new sub-suppliers specialized in ICT technologies (Interview 12). However, also established firms, especially incumbent *operators*, have also sought to position themselves in digitalization. Firms differ in being leaders and laggards, and for instance Equinor has been at the fore-front of adopting and developing new digital technologies (Interview 1, 5). In comparison to new-comers, incumbent companies like Equinor have the advantage of strong in-house subsea and offshore competences which can be coupled with the development of digital tools (Interview 4). Nevertheless, operators like AkerBP have also been ambitious in pushing the boundaries of digitalization (Interviews 2, 5, 8).

Clouds and digital platforms are becoming a central part of the digital transformation. Clouds are important as they are cheap and improve the accessibility to data and applications. There are a large number of digital platforms in the sector, and both operator and supplier firms commonly use multiple ones. It is yet unclear whether this situation will remain, or whether consolidation around a few platforms will take place (Interviews 5, 8). There are currently roughly three kinds of digital platforms in the sector. First, there are the several public providers such as Microsoft, Amazon and Google, which O&G sector uses for e.g. data storage and computing (Interviews 5, 12). Different companies have chosen different public providers. However, and secondly, there has been a tendency that large O&G operators build their own private clouds. ENI, the Italian multinational, has even built a large data storage and computing unit on their own company premises, securing full control over their data. Moreover, several O&G operators, like Equinor and Total, demand that their suppliers work on the operator's own cloud platform. For a supplier this may be challenging as operators' platforms function differently from one another. In contrast, the smaller operators rarely invest in their own platforms but use public clouds, and are therefore able to run leaner (Interview 5). Third, firms in the sector also use several more specialized industry platforms, such as Cognite, Cognizant and Veracity, used both internally and in collaboration with customers (interview 5). Rather than acting as generic data and computing hubs, such platforms enable working with more specific tasks around the development, design and operation of O&G technologies.

From specific value chain segments, digital technologies have especially had an impact on the *reservoirs and seismic* segment. For instance, improvements in artificial intelligence, big data and better modelling have recently enabled the discovery of new fields, and for instance new rather marginal fields have been able to connected with existing larger fields. In other words, such new digital technologies have helped to discover more O&G fields which can be commercially exploited (Interviews 1, 2). Among large players, for instance Schlumberger has made large investments in artificial intelligence and machine learning technologies (Interview 12).

In the *engineering, fabrication and installation* segment, integrating different phases of project development through digital tools may potentially increase efficiency (Interview 2). However, until now there has been no disruptive technologies e.g. in the design of offshore installations. Instead, the implementation of digital technologies has taken place in a step-wise and an evolutionary way, with some additional technologies becoming more common such as better 3D design. Moreover, for instance better computing and machine learning opportunities offer opportunities to explore optimal designs for installations. However, experienced companies already possess plenty of knowledge regarding what kind of designs work in which kind of conditions, which reduces the novelty that better artificial intelligence and machine learning can provide (Interview 10).

More potential in this value chain segment has been seen in the so-called digital twins, which link the modelling of an O&G installation with the actual data from the physical O&G installations. Digital twins can be used for instance to simulate and predict operations on an O&G installation before it is deployed, potentially enabling operators to reduce risk and operating costs. Many operator companies are known to be interested in this concept, but actual applications have until now been rather rudimentary. In practice, most digital twins today are dashboards enabling access to different sources of data, and have not yet used in advance functions such as automated decision-making, etc. (Interview 5). For instance, the recently opened Johan Sverdrup field has such an early version of a digital twin, essentially enabling an overview of the processes taking place in the field (Interview 6). There is also increasing interest in more autonomous offshore installations which can be controlled from on-shore. A key issue is however to see how this can be managed safely (Interview 3).

More advanced and applied digital sensoring and monitoring are seen to make an impact especially on the *operations* segment. They may for instance make the maintenance of O&G installations easier to plan and monitor automatically (Interviews 2, 4, 5). However, data acquisition and interpretation remain big issues, and data analysis technologies are needed to make sense of the vast amount of data (NORWEP, 2016, DNV GL, 2018b). Hence, albeit foreseen opportunities for improving the cost-efficiency of operations, operators and suppliers remain challenged with how to best utilize the potential of big data and other possibilities created by the digital tools (DNV GL, 2018b, Interview 5).

7.2 The maritime industry in Norway

As a country with scattered settlements divided by high mountains and deep fjords across the vast coastline, seafaring has always characterized Norway.

Since the emergence of modern Norwegian economy in the 19th century, sea-borne transport of goods (shipping) has played a central part in it. After the Second World War, the Norwegian fleet was increasing in rapid pace, but the great shipping crises in the 1970s and 1980s led to a collapse of up to 75% decline in tonnage from 1977 to 1987 (Tenold, 2019a). However, in the 1990s the sector began to modernize and transformed towards advanced niche markets, such as passenger ships and ferries, but especially the offshore O&G market (Jenssen, 2003, Tenold, 2019b). Since then, particularly the O&G market has led the development of Norwegian competences in designing, building and operating advanced vessels, specialized in technically challenging tasks like anchor and cable handling, subsea, surveying, and offshore construction.

According to the Norwegian Shipowner's Association, the total maritime sector employed around 85 000 people[6] in 2018. The turnover in the sector in 2018 was a bit more than NOK 140 Billion, from which more

[6] Note that a significant part of these employees work primarily with services and goods used in the O&G sector.

than NOK 80 Billion belonged to the shipping segment, and the rest to the ship industry: mostly in services, and then equipment and yards. This turnover is down from the peak years before the financial crisis in 2008 and then again prior to oil price crash in 2014, but some growth in recent years (Norges Rederiforbund, 2019), see Figure 4. However, the most recent economic downturn in March 2020 is likely to dim the short-term economic prospects.

Figure 4 Turnover in manufacturing of ships, boats and oil platforms in Norway, NOK Million (Statistics Norway)

Exports promoting public organizations, such as Norwegian export Credit Guarantee Agency (GIEK) and Export Credit Norway, have had a role to play in keeping the Norwegian maritime sector internationally competitive despite its high cost levels (Regjeringen, 2019a). Meanwhile, the formation of the Norwegian International Ship Register (NIS) has managed to reduce the amount of ships moving under flags of convenience (Benito et al., 2003). As shown by the recent Blue Ocean strategy of the Norwegian government, the maritime sector is considered to remain a key area of future economic activity and job creation in the country (Regjeringen, 2019a). Indeed, the maritime sector is currently the second largest export sector after O&G sector.

Located along the western and southern coasts of the country and around the capital Oslo, the Norwegian maritime sector has a number of key supporting factors. For instance, it has good harbor infrastructure across the country, and the rough natural conditions at the North Sea and Northern Atlantic have always pushed the sector towards high quality of products. Moreover, the level of R&D capabilities is high among the suppliers, supported also by the competences in research organizations such as NTNUand SINTEF, and classification organizations such as DNV GL. Thanks to the long traditions of shipping in Norway, there are also a number of maritime and shipping financing organizations in the country, and traditionally a high level of human capital (Benito et al., 2003). Moreover, the sector is organized in a number of industry clusters and organizations, such as the Norwegian Shipowners´ Association (Rederiforbundet), GCE Node in Agder region, GCE Blue Maritime in Møre and Romsdal region, and NCE Maritime Cleantech in Hordaland and Rogaland.

More detailed presentation of the existing value chain of the Norwegian maritime sector is presented next.

7.2.1 Value chain

The maritime sector can be divided into six main value chain parts: providing 1) mechanical equipment, 2) electric and electronic equipment, and 3) design of vessels and 4) shipbuilding (yards), as well as 5) shipping and 6) support mechanisms for shipping (e.g. classification, financing, insurance). Norway presents a full value chain, with a strong knowledge base and several organizations in each of these value chain segments, consisting of both firms with long traditions, as well as newer companies. Thepresence of a full value chain in a small country enables close interaction within the sector, especially between the different organizations within the ship building segments (segments 1-4), and between shipping companies and companies providing support services for shipping (segments 5&6) (Benito et al., 2003, Tenold, 2019b, Norges Rederiforbund, 2019). See Figure 5 for an overview.

Figure 5 The maritime value chain.

The *Mechanical equipment* segment consists of companies which supply the various machinery needed in vessels, such as cranes, winches, propellers and engines (Helseth et al., 2018). The drilling machinery providers, such as National Oilwell Varco and MHWirth around the town of Kristiansand, were particularly hardly hit after the oil price crash in 2014. Other prominent companies in this segment include e.g. Framo providing cargo pumping equipment, IP Huse (winches), and MacGregor (mooring and cargo systems). Norway also has several notable engine, propulsion and thrusting companies, such as Rolls-Royce Marine (acquired by Kongsberg Maritime in 2019), Siemens and Brunvoll. Moreover, Jotun has approximately 20% world market share in paints used in vessels and offshore constructions (Helseth et al., 2019).

Vessels are becoming more technologically advanced, and therefore the e*lectrical and electronic equipment* providers are becoming increasingly important. Key products are for instance different software and electronic hardware required on-board, as well as bridge equipment and sensors (Helseth et al., 2018). Kongsberg Maritime is perhaps the most notable company in this segment, providing various advanced products in e.g. communication, automation, robotics and dynamic positioning. Other companies include e.g. ABB offering various electronic equipment, and Furuno providing navigational communication and fishfinding equipment.

Norway has high competences and long traditions in vessel *design* (Helseth et al., 2018). Prominent companies include e.g. Moss Maritime, which has specialized in the design of floating offshore structures, such as semi-submersible drilling platforms, and liquified natural gas (LNG) vessels, and recently has moved into aquaculture and offshore renewables segments. Ulstein and Vard are known for their innovative vessel designs.

Shipbuilding has traditionally provided plenty of jobs in Norway, but since the 1970s, the importance of this segment has reduced due to the competition from cheaper countries like South Korea (Benito et al., 2003). However, many mostly small- and medium-sized shipyards remain in Norway, focused especially in the offshore O&G market niche (80-90% of orders). However, after the oil price crash of 2014, the O&G vessel orders have dropped to almost zero over the last few years. The yards have nevertheless been able to enter new market niches especially in cruise ships, ferries and fishing vessels which, however, provide lower revenues and profit margins than O&G (Helseth et al., 2018, 2019, Interview 7). The somewhat larger yards in Norway are Kleven, Vard, Havyard and Ulstein, all located in the Møre and Romsdal region in Western Norway. Yards like Fjellstrand and Brødrene Aa have been focused especially in the ferry market.

The *shipping* segment, such as those operating in deep seas, is centered around Oslo and Bergen, while the e.g. the more O&G focused companies are usually located along the Western Coast (Tenold, 2019b). Shipping segment includes about 200 companies and about 60% of the revenue in the sector, and employs most people: about 34 000 people either on land or at sea. It is also important for the rest of the maritime sector, creating a demand for products and services which has driven technological innovation in the sector (Helseth et al., 2019). Norwegian shipping companies, such as Wilh. Wilhelmsen, are specialized in ro-ro vessels, while they also operate particularly chemical and gas transport vessels. Many O&G supplier ship companies, such as Solstad and DOF, were catastrophically hit by the crash of the O&G sector after 2014. A more stable situation prevails in the rest of the near-shore shipping, consisting of e.g. ferry and cruise ship companies like Color Line, Torghatten, and Hurtigruten.

Norway also has a broad *shipping support* segment, where many of the actors are world-leading in their respective markets. As a capital based and volatile market, financing and insurance are highly important in shipping, and where Norwegian companies have hundreds of years of traditions (Tenold, 2019a, Benito et al., 2003, Jenssen, 2003). For instance, DNB and Nordea in Oslo are key facilitators of shipping financing, while Gard and Skuld are leading providers of shipping insurance. Nordisk Skipsrederforening and Wikborg Rein provide maritime law services, while Fearnley and Clarkson Platou are notable ship brokers. Moreover, technological service providers such as DNV GL classifies every fifth vessel in the world, while e.g. SINTEF Ocean provide advanced R&D services. Moreover, Norway is scattered with harbors which provide important logistical and maintenance services (Helseth et al., 2019).

7.2.2 Environmental topics and the transformation in the maritime sector

7.2.2.1 Pressures and opportunities

The carbon emissions of shipping are about 3% of the total emissions in the world (IMO, 2014). However, the global shipping is expected increase with 60% by 2050, leading to increasing emissions without radical low-carbon innovations in the sector (DNV GL, 2017). Current (heavy) fuel oil powered vessels also produce a number of other (locally harmful) air pollutants, such as Sulphur oxides (SOx), Nitrogen oxides (NOx), and volatile organic compounds (VOC). Moreover, water pollutants, such as ballast, sewage water and oil spills can be harmful for flora and fauna in oceans and coastal areas (Sjøfartsdirektoratet, 2015).

Concerns around environmental pollutants therefore pose both pressures and opportunities for the Norwegian maritime sector. Higher environmental concerns may affect the sector through e.g. environmental regulations, environmental innovation in environmental technologies, changes in demand for energy carrier (e.g. crude oil, LNG, hydrogen) transport, and higher focus on environmental topics from stakeholders (DNV GL, 2017).

Various environmental regulations affect the Norwegian maritime sector. Vessels operating in Norway such as passenger vessels, ferries and fishing boats fall under the national legislation, and are affected by e.g. the

Norwegian government´s aim to cut carbon emissions by 50-55% by 2030 in comparison to the 1990s level. The sector is strongly influenced by the international agreements made in the International Maritime Organization (IMO). As the key governing body in international shipping, IMO's climate strategy outlines that greenhouse gas emissions from shipping must be reduced by 50% by 2050 from 2008 level (IMO, 2020a). Moreover, IMO also has a new regulation, taking effect from 2020, to limit Sulphur emissions from fuel from 3,5% to 0,50%, forcing ship-owners to use lower-Sulphur fuels and install scrubbers (IMO, 2020b, UNCTAD, 2019). Norway is also committed to diminish SOx, NOx and VOC emission under the Gothenburg protocol, for instance in the case of NOx with 23% by 2020. Also, stricter regulations to cut such emission may be expected in future (Maritim21, 2016, Sjøfartsdirektoratet, 2015).

The on-going global energy transition from fossil fuels to renewable energy also has other implications for the maritime sector. Reduced trade in fossil energy commodities is expected. In the short term, this is especially the case for coal, but later on the trade in oil, and finally the trade in natural gas, will also likely be affected. Due to this development, reduced demand for fossil fuel transportation is expected towards 2030. This reduction in transport demand, however, may to some extent be offset by increased demand in hydrogen and LNG transport (DNV GL, 2017).

Environmental concerns are also creating demand for more environmental-friendly shipping which creates opportunities for sustainable innovation in the sector. DNV GL expects that carbon emission reductions in maritime sector will likely be a combination of implementation of alternative fuels, more optimized logistics and speed, and energy-efficiency (DNV GL, 2017). It is therefore expected that carbon efficiency may become a source of competitive advantage in future. It should also be noted that the adoption of alternative fuels not only reduces carbon emission, but also other harmful air pollutants, as described above.

Technologies such as battery-electric, hydrogen and biofuel powered vessels have gained traction in Norway over the last years, some more than others. Battery-electric vessels have been especially successful in the ferry segment with several new ferries operating fully electric in Norway, and as hybrid vessels in cruise ships and offshore vessels with installed battery packs on board alongside conventional power sources. Battery-electric vessels have therefore shown strong innovation activities in Norway (Steen et al., 2019, Bjerkan et al., 2018). However, battery-electric technologies are only viable in short distance shipping, and are not viable for deep-sea, which produces most of the carbon emissions in the global maritime sector. Hydrogen-based fuels, such as ammonium, may have somewhat better qualities for that (Interviews 9, 27). There have been emerging innovation activities in hydrogen fuel cells, and there are currently some demonstration projects in hydrogen fast-speed ferries in the pipeline in Norway (Steen et al., 2019).

While hydrogen and battery-electric technologies are moving forward, the situation is different with biofuels. There is little to no traction with the use of biodiesel vessels in Norway, and no innovative activities. There are some limited activities in liquified biogas (LBG) vessels: the new Coastal Route passenger vessels (Hurtigruten) intends to use LBG as an energy source (Steen et al., 2019), and also biodiesel. LBG can be used together with LNG, which is more mature as a power source, but still in rather early phase as an innovation. LNG is a fossil fuel, but has lower emissions than conventional fuel oil powered vessels, and is therefore expected to grow as a power source in international shipping (Helseth et al., 2018). A key obstacle for the alternative fuels is currently that there is little infrastructure e.g. to supply vessels with alternative fuels in different ports, and little production capacity (Interviews 9, 27). While this applies also to LNG, this is particularly challenging for hydrogen-based fuels, which currently lack the whole value chain in production and distribution (Interview 27). Meanwhile, a recent Norwegian carbon tax has made LNG more expensive.

To summarize, the Norwegian maritime sector has been at the forefront of developing above-mentioned low-carbon technologies for maritime use, with the exception of biofuels. This early-mover position in low-carbon technologies therefore presents a market opportunity for the Norwegian sector across the value chain (Interview 7).

7.2.2.2 Environmental transformation along the value chain

The environmental transformation in the maritime sector is most visible in two dimensions: in terms of technologies that the sector produces (value chain segments 1-4) or uses (segments 5-6), and in terms of product-markets in which they operate in (e.g. offshore O&G, fishing, cargo transport etc.).

In terms of technologies, the environmental technologies in the maritime sector have until recently focused on improving energy-efficiency e.g. through incremental improvements in ship *design* and *mechanical equipment*, such as engines and propulsion systems. However, since the recent announcement of IMO to cut the total emissions of shipping with 50% by 2050, more attention has been directed to radical innovations such as alternative fuels. However, it is yet uncertain how this target can be achieved as there are currently no mature alternatives to fuel oil in deep-sea shipping. Even LNG, which is somewhat more mature as a technology, does not offer large enough emission cuts (Interview 9).

In near-shore shipping, several low-carbon technologies have recently emerged in Norway, especially with the help of the Norwegian government´s public procurement and research funding initiatives (Steen et al., 2019, Interview 9). Norwegian government has announced to continue decarbonization efforts with a mix of policies, including market segment specific instruments, carbon taxes and R&D funding (Regjeringen, 2019b). Especially the use of battery-packs in maritime use, creating hybrid vessels and even some fully-electric ones, has quickly emerged over the last 5 years. This has led to market opportunities for e.g. battery producers like Corvus and Siemens, who both opened a maritime battery production plant in Norway in 2019. Moreover, according to Menon (2018), in 2018 every third electric vessel of the world was used and produced in Norway, creating orders for Norwegian *shipbuilding* yards, such as Fjellstrand, which produced the first electric ferry in Norway, Ampere. Technology service providers in the *shipping support* segment, such as NTNU, SINTEF Ocean and DNV GL have also been in central position in developing new technologies.

Expected growing demands for LNG/LBG vessels create opportunities for *mechanical equipment* producers, such as engine suppliers like Rolls-Royce. Moreover, developers and manufacturers of flexible fuel engines for new vessels, capable of consuming multiple fuels, may experience increasing demand, as it is yet uncertain which alternative fuels will become available for commercial use in the future. Such flexibility is important for shipping companies who want to be sure that their vessel purchased today has available fuels also in coming decades (Interview 27).

The above example shows that while low-carbon technologies usually are seen as a market opportunity in the upstream maritime sector, the same is not as obvious in the user side, i.e. the *shipping* segment. For *shipping* companies, much of their assets are tied in their existing (fuel oil powered) vessels, making any fast transformation to low-carbon technologies unattractive. Moreover, as alluded above, the lacking alternative fuel infrastructure presents a ´chicken or the egg´ dilemma in the sector, and it is yet highly uncertain which low-carbon technologies will developed into fully commercial options. There is also currently little willingness to pay for greener maritime transport. As alternative fuels are under current regulations significantly more expensive than the conventional fuels, there have been few incentives for *shipping* companies to move to low-carbon technologies (Interview 9, 27). Clear exceptions have been the recent public tenders for public ferry and passenger routes in Norway, where low emissions have been set as a requirement for winning contracts. Nevertheless, the Norwegian Shipowner's Association, the interest organization of shipping companies, has argued that the Norwegian *shipping* segment is taking carbon reductions seriously, as tightening environmental regulations may produce a carbon risk in polluting vessels in future, reducing their value, thus influencing investment decisions already today (Norges Rederiforbund, 2018, Interview 9).

The decline of the oil and gas sector has forced the Norwegian maritime sector to look for other market segments, presenting an additional perspective on green transformations. Until the oil price crash of 2014, the offshore O&G supply market, with its demand for modern supply vessels etc., was dominant source of revenue for Norwegian companies. During the early years of 2010s, the high oil price attracted investments in a lot of offshore vessels to cater the needs of increasing investments in offshore platforms and subsea equipment. However, the low oil price led to a crash of investments in the NCS, and consequently also in the demand for offshore vessels. This led to an oversupply of offshore vessels, and a dramatic collapse of ship rates of offshore O&G vessels and orders for new vessels, leading to laying up of several modern vessels and vast economic problems for supply shipping companies (Menon, 2020).[7]

This collapse of O&G market has forced the maritime sector to cut cost and seek revenues in other market segments. *Yards* and *equipment* providers have been rather successful especially in the market segments of exploration cruise vessels (e.g. taking passengers to polar regions) and ferries, while some *shipping* companies have entered into offshore renewables, especially offshore wind (Interview 4). However, these market segments require simpler vessels than in O&G, and also provide less revenue, for which reason the companies struggle to make profits (Interview 7). Particularly the larger *shipbuilding* yards in Møre & Romsdal region have been particularly hit by the O&G market collapse (Interview 7). What is more, considering the most recent downturn of the O&G sector in 2020, it is possible that the golden days of a generous O&G market may never return. Even before the most recent crisis, DNV GL expected that the offshore O&G market for *shipping* will over the next decades increasingly move towards Middle East and South-East Asia, and globally enter into a permanent decline in the 2030s. Meanwhile, for instance the global offshore wind power market for shipping is expected to grow 200-fold by 2050 (DNV GL, 2017). The sector as a whole is therefore currently aggressively moving into such new markets (Interview 7).

[7] https://e24.no/hav-og-sjoemat/i/GGRGKB/her-ligger-offshorebaatene-og-venter-paa-oppdrag

7.2.3 Digitalization and the transformation in the maritime sector

7.2.3.1 Pressures and opportunities

The Norwegian maritime sector with its long roots has gone through a number of technological changes, from wood and sail ships communicating with mail or telegrams at ports, to modern vessels operating with constant internet and satellite links (Tenold, 2019a). In terms of digitalization, most attention has recently been directed towards increased possibilities for data collection and analysis (big data), automatization and artificial intelligence, and communication technologies, which all come together in developing autonomous vessels.

Autonomous vessels may come in different degrees of automatization. IMO has defined autonomous ships as 1) traditional vessels with automated processes and decision support, 2) remotely controlled ships with seafarers aboard, 3) remotely controlled ship without permanent seafarers onboard, and 4) fully autonomous ships (Munim, 2019). The key logics for developing autonomous vessels are increased cost-efficiency and more optimized logistics. They shall reduce the amount of crew on board (and thus cost) and are expected to make more optimized operational decisions for vessels. Moreover, safety is increased as fewer crew members are exposed to sometimes dangerous open sea conditions. Instead of being aboard the ship, the oversight and control of vessels is increasingly conducted from control rooms on land (Andersen et al., 2019, Kvamstad-Lervold et al., 2019).

The impact of the degree of automatization (see the types 1-4 from somewhat automized to fully autonomous vessels above) affects the potential disruptiveness of autonomous vessels in the sector, and thus the pressures and opportunities they may create. For instance, in deep sea cargo vessels the staff costs sum up to a relatively small part of the value of the cargo. Therefore, semi-autonomous vessels (especially types 1-2 above) are unlikely to create a radical change in that segment in terms of cost-efficiency. However, fully autonomous vessels open opportunities for completely new kinds of transport systems allowing e.g. more optimized use of vessels (e.g. in terms of speed and operating hours), to increase flexibility through a larger fleet of smaller cargo vessels, and for multi-modal transport combining naval and road transport in new ways. Autonomous vessels are also lighter due to the reduced need for accommodation and other space for the crew (Kvamstad-Lervold et al., 2019).

Other forms of digitalization may also lead to changes, albeit likely more in an incremental nature. For instance, sensors measuring the performance of the vessel, better data analytics through machine learning and artificial intelligence, and better integration and connectivity between vessel systems create opportunities to optimize the performance of vessels (Andersen et al., 2019, Kvamstad-Lervold et al., 2019). Similarly to the O&G sector, digital twins of vessels are also being developed, allowing to "test" equipment and vessels prior to building through modelling, and also afterwards by comparing the actual operations of a vessel (e.g. in different weather situations) to the model data (Andersen et al., 2019, Kvamstad-Lervold et al., 2019, Interview 27). Digital twins can be used as a platform for a different organizations to collaborate in performance and design (Interview 27).

Despite potentially increasing the safety on board, more prevailing digital technologies open new kinds of safety and security threats. To avoid accidents, autonomous vessels require common classification, standardization and regulatory framework, as well as coordinated operating procedures across different system providers. Also, many shipping companies are concerned that communication technologies may open the threat of cyberattacks, for instance by virtually hijacking a ship for ransoms (Andersen et al., 2019, Kvamstad-Lervold et al., 2019, Interview 13). Moreover, introduction of advanced modelling methods may also produce over-reliance on artificial intelligence. It is therefore necessary to validate shipping performance models with real world data, and continue experiment vigorously with new methods (Interview 27).

The rapid development of digital technologies also create pressures for legislation to keep up. Andersen and colleagues (2019) report that many organizations in the sector believe that legislation is lagging behind new technologies, or even hindering their adoption. However, authorities seek to amend regulations to comply with the new technologies. An example of this is the change in regulation to allow vessels to operate without a pilot (i.e. a local sailor who boards the ship to navigate a vessel) in dangerous and narrow waterways, e.g. near harbors, which is a highly pertinent change in the era of autonomous vessels (Andersen et al., 2019).

7.2.3.2 Transformations in the value chain

Digitalization affects the whole value chain of maritime sector. Companies from adjacent sectors with competences in digital technologies may seek to enter the sector, while the current maritime firms may seek to combine their existing competences with new digital technologies. According to the results of Andersen and colleagues (2019), firms across the value chain in a proportion of nine out of ten believe that digital competences are already important for their operations, while seven out of ten say that they currently lack sufficient skills in such technologies. Nevertheless, the Norwegian maritime value chain is considered to be willing to engage with and develop new digital technologies (Interview 27).

Autonomous vessels may create a disruptive change in cargo transport, and thus open up opportunities for *shipping* companies for new kinds of shipping, e.g. to operate a flexible fleet of smaller cargo vessels which may be able to compete with land-based transport in terms of cost, safety and environmental impact. Such cost-efficient sea transport along coast lines or rivers with autonomous vessels could allow to reduce road transport performed with heavy trucks. Some Norwegian *design* and *shipbuilding* companies have been active in engaging in this potential market of small autonomous container ships and ferries (Kvamstad-Lervold et al., 2019). For instance Yara Birkeland, the world's first fully electric autonomous container ship in short-sea shipping, will be built by Vard. Norwegian providers in *electric and electronics equipment* are well positioned to provide technologies in relation to various types of autonomous vessels, for instance auto-docking, auto-crossing, automatized crane operations (Kvamstad-Lervold et al., 2019, Munim, 2019). Autonomous vessels also require the integration of data from sensors and seamless communication of different systems in vessels. There is therefore growing demand for such system integration technologies (Kvamstad-Lervold et al., 2019).

For *shipping* companies, simulations and increased opportunities in data analysis provide various opportunities, for instance in planning complex operations with the help of real data. New digital technologies allow potentially more energy-efficient navigation and optimized route planning, leading to cost savings and reduction of emissions (Maritim21, 2016, Andersen et al., 2019). Sensors allow gathering of data from operations, which can be used in decision-making in operations, and e.g. in predicting maintenance needs of engines. Digital twin simulations, on the other hand, promise improved efficiency of operations. Shipping companies are therefore reportedly highly interested in such technologies (Interview 27).

New digital technologies may also transform the *design* of vessels and *shipbuilding*. Simulation and virtual prototyping enable testing of complete ship systems early in the design phase (Maritim21, 2016). Moreover, automatization and robotization can make the production of ships more efficient and cost-effective, making Norwegian yards potentially more competitive against foreign yards. It should be noted that the design phase has to be coupled with shipbuilding to allows this. For instance, the design of the vessels would have to allow robotized welding (Maritim21, 2016, Kvamstad-Lervold et al., 2019).

Finally, the digitalization in the maritime sector also requires that the value chain can deal with the potential threats that such new technologies may cause. For instance, topics such as cyber security, collision avoidance, system integration, and machine learning provide opportunities for *electronic equipment* producers (Interview 13). Also, the standardization, classification and development of regulations provide tasks for different organizations in the *shipping support* segment, such as companies specialized in technology services, jurisdiction and R&D (Kvamstad-Lervold et al., 2019).

7.3 The aquaculture industry in Norway

The history of the Norwegian aquaculture industry began in the early 1970s when the first floating pen nets for fish farming were developed. Today aquaculture represents one of Norway's most important export industries, and also contributes to the creation of jobs in other countries (Norsk Industri, 2017a). Globally, aquaculture is witnessing rapid growth with various species being farmed in different bio-physical resource regions. In the Norwegian context, aquaculture by default refers to the farming of salmon and trout, which is the empirical scope covered here.

During the initial development of the aquaculture industry, the traditional fishing sector represented the main source of knowledge, technology and capital (Wicken, 2009, Aslesen, 2009). Developments followed the Norwegian tradition of small-scale decentralized industrialization based on practice-based innovation and limited formal R&D. Nonetheless, industrial scale aquaculture was enabled by significant research breakthroughs within especially breeding and feed production (Aslesen, 2009, Aasen et al., 2019, Fagerberg et al., 2009). In the 1980s the state defined aquaculture as a future growth sector, whereupon public R&D support was established to cater to the needs of the emerging sector. During the same period, some large established firms (diversifying incumbents) such as Norsk Hydro also entered the industry and contributed with significant R&D spending (Wicken, 2009).

In the 1990s the aquaculture industry went through a period of rapid growth in production volumes, driven by a strong and growing global demand for salmon. However, the Norwegian industry increasingly faced price pressures due to (global) supply outpacing demand, and also increasing competition from producers in other countries (e.g. Chile) with substantially lower operating costs. Innovation became an imperative for sustaining domestic aquaculture developments (Aslesen, 2009). As the industry matured, structural changes occurred with both horizontal and vertical integration. Some companies in different parts of the value chain (production, upstream supplier, downstream processing and marketing) grew into large multi-nationals. Currently, Norwegian fish farming companies and suppliers are strongly present in practically all international markets where salmon and trout are farmed, such as Scotland, Canada, Iceland and Australia.

Similar to other Norwegian resource-based sectors such as aluminum and petroleum, aquaculture is now regarded as a highly innovative sector. It has been characterized by Reve and Sasson (2012) as one of three Norwegian 'global knowledge hubs'.[8] While further domestic growth in aquaculture is imbued with "great expectations" (Hersoug et al., 2018), the industry is facing several environmental issues that need to be overcome. Nonetheless there are ambitious policy (and industry) targets, to dramatically increase value creation from aquaculture via expansion of existing lifestock production and by developing commercially viable farming of other marine species (Olafsen et al., 2012). Figure 6 illustrates the tremendous growth in the value of aquaculture exports over the last decade, greatly contributing to an overall 122% growth rate in seafood exports (Norges Sjømatråd, 2019).

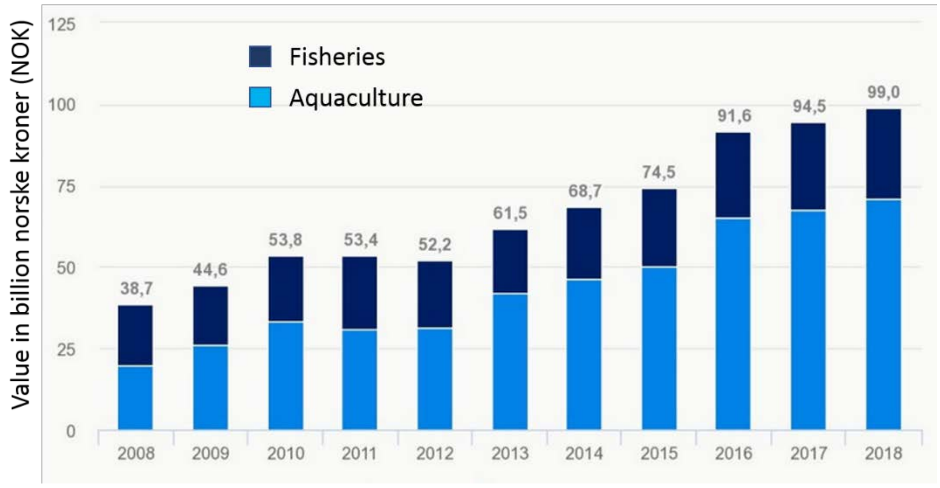

Figure 6 Value of Norwegian seafood exports 2008-2018. Adapted from Norges Sjømatråd (2019)

Developments to date have however not progressed smoothly. The development trajectory of aquaculture both in Norway and abroad has been through various crisis periods due to different economic and environmental factors (Fløysand and Jakobsen, 2016, Rigby et al., 2017). In recent years the aquaculture industry has increasingly been faced with legitimacy issues (Tiller et al., 2017) related to environmental concerns (Osmundsen and Olsen, 2017). Consultants EY (2017, 5) state that "*reputational risk related to sustainable production, fish health*[9] *and sound production may represent the greatest market risk"* for the Norwegian aquaculture industry. Another challenge confronting the industry is found in growing opposition from local municipalities (who allocate space for fish farming through their coastal zone planning) demanding more substantial local value capture from aquaculture activities in their waters (Hersoug et al., 2018).

As shown in Figure 7, the steady growth in production volumes stopped in 2015. Since then, it has been stable at roughly 1,2 million tonnes of slaughtered and sold fish (not including other farmed species). This has been due to environmental issues that we return to in subsequent sections.

[8] The other two being offshore O&G and maritime.

[9] To give but one example, fish mortality in Norwegian salmon farming in 2016 was a staggering 19%.

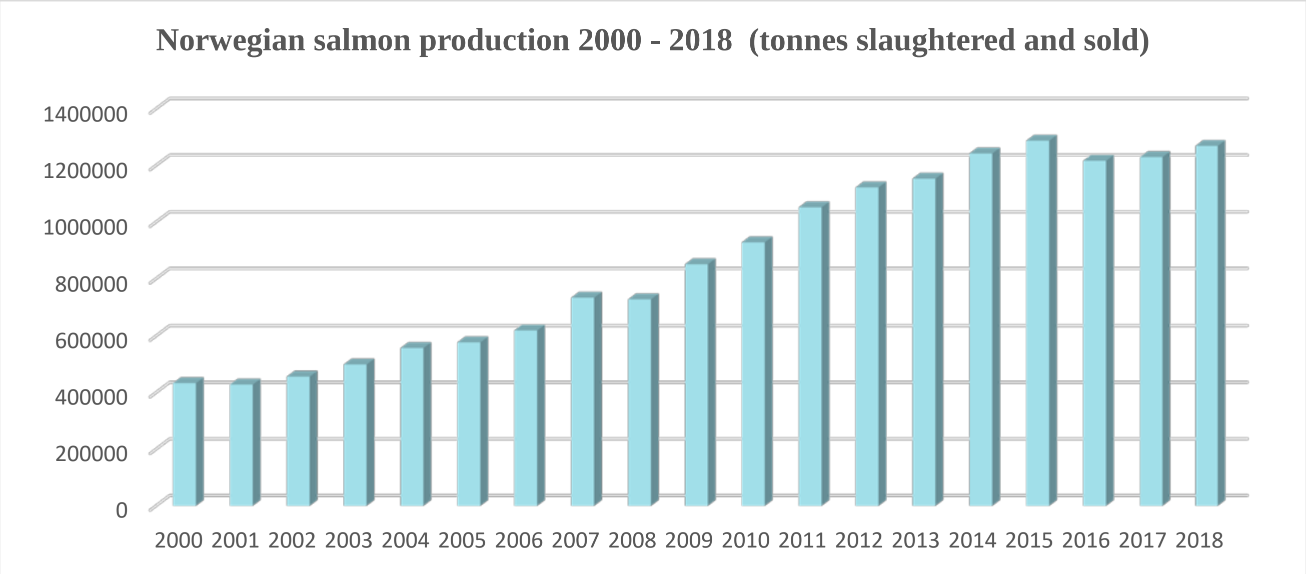

Figure 7 Norwegian salmon production 2000 - 2018 (Source: SSB[10]).

Achieving distributed regional growth from aquaculture activities has been a key concern for policy makers since the early days of salmon farming in Norway. In their analysis of licensing processes for aquaculture over the period 2002-2013, Hersoug et al. (2018) however find a shift from the focus on who should obtain a license and where, to a much stronger emphasis on environmental sustainability. This, they suggest, was due to the industry not being capable of meeting stricter demands related to sea lice and escapes that were imposed on the industry from the early 2000s. Policy strategies aiming to enable sustainable growth are presented in section 6.3.2.2.

7.3.1 The value chain of the aquaculture sector in Norway

At its most basic, fish farming occurs through three steps. Hatched fish (smolt) are kept in land-based facilities until they weigh approx. 100 grams. The fish is then placed in pen nets in the ocean where they are fed until they reach around 4-5 kg, whereupon they are brought back to land for slaughtering. The bulk of production is exported as whole gutted fish, with limited processing occurring in Norway. As an industry, however, the aquaculture value chain is more complex.

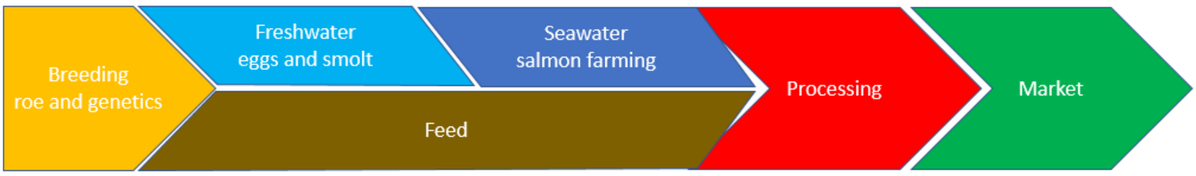

Figure 8 The salmon farming value chain main segments (Source: Steen (2019))

Figure 8 depicts the overall value chain for salmon (or trout) farming. The Norwegian aquaculture industry covers all these segments and has until recently set the benchmark for innovation and technology development internationally (Interviews 28, 33, 34).

[10] https://www.ssb.no/statbank/table/07326/tableViewLayout1/

Fish farming producers number approximately 140-160 companies in Norway, with the ten largest (e.g. Salmar, MOWI, Lerøy) being responsible for 67,5% of all salmon production in 2018.[11] Whereas the smallest producers (mainly family-owned) operate only a few fish farming localities in their home region, larger companies typically have various operation sites both domestically and internationally. The largest Norwegian company, MOWI, is listed on the stock exchange and has almost 15000 employees spread out across 25 different countries.

Aquaculture *suppliers* are claimed to be among the world's most innovative and technologically leading companies, at least regarding the farming of species such as salmon and trout. Salmon farming was as such developed in Norway, and practically all solutions (equipment, operations etc.) needed to be developed domestically. Domestic innovation processes in aquaculture have however been combined with successful extra-local technology transfer, itself contingent on substantial absorptive capacity (Steen, 2019). Suppliers are highly diverse. Some supplier firms (e.g. AKVAgroup and ScaleAQ) are very large and have the ability to deliver complete 'turn-key' production facilities, whereas there is a broad range of sub-suppliers that develop and produce various products and components and/or services. Today's largest suppliers have typically grown as a result of both organic developments as well as mergers and acquisitions. Smaller supplier companies have seen the need to become part of larger companies in order to secure jobs in an industry experiencing a fast technological change (Norsk Industri, 2017a).

Although some aquaculture suppliers sell products and services to clients in the petroleum and maritime sectors as well, most suppliers tend to be specialized within the sector albeit often serving large (international) geographical markets.

The value chain of the Norwegian aquaculture industry has begun to change in the past years. The primary reason for this has been the development and implementation of novel production methods (see section 7.3.2.2 below) that could help mitigate especially the environmental challenges that the industry has been facing. However, these developments in aquaculture have coincided with a downturn in the offshore O&G sector whereupon suppliers from that sector have sought out aquaculture as a diversification opportunity (Interviews 10, 33). Increasing attention to digitalization has led large international ICT firms such as IBM into the aquaculture business. A range of start-up companies that for example offer solutions based on digital tools (e.g. camera monitoring with machine learning) have also entered. As a result of these developments, we now see the contours of an industry with advanced surveillance systems and entirely new production concepts (Bjelland, 2019).

Both firms and non-firm actors are organized in various networking and cluster organizations, many of which are regionally based, that receive public support from the official Norwegian cluster programme. These include NCE Aquatech Cluster (in Mid-Norway), NCE Seafood (in Western Norway) and NCE Aquaculture (in Northern Norway). There are also large research centres focusing on aquaculture, such as SINTEF-led SFI Exposed which is developing new knowledge and solutions for large-scale aquaculture in harsh offshore environments. Finally, in addition to support from the Research Council of Norway, R&D in the sector is (partly) funded via a dedicated Norwegian Seafood Research Fund (FHF) which is financed by the industry itself through a 0,3% levy on seafood exports.

[11] https://www.fiskeridir.no/Akvakultur/Nyheter/2019/0519/Hvor-stor-er-oppdrettsnaeringen-i-Norge

7.3.2 Environmental topics and the transformation in the aquaculture sector

7.3.2.1 Pressures and opportunities

Although Norwegian aquaculture has a relatively good reputation regarding sustainability and its environmental footprint (Salmon Group, 2018), there are many challenges that require response. Currently these primarily relate to biological and ecological issues.

The main environmental challenge confronting the aquaculture sector is a tiny parasitic creature, namely the sea louse[12] (Osmundsen et al., 2017). The sea louse is also the one and only parameter currently used to decide whether or not production can be increased in different production areas along the coast. Whereas sea lice are a threat to salmon farming, the core issue from a natural resource management point of view is that large concentrations of sea lice (on farmed salmon) constitute a severe threat to wild salmon populations. According to the Norwegian Environment Agency (NEA, n.d.), "*the situation has become so serious that in certain locations, sea lice are threatening stocks of wild salmonids to the point of extinction.*" This has been exacerbated by warming of ocean waters in recent years, leading to increasing lice problems all year around even in the far north (Interview 28). Climate change therefore also constitutes a challenge facing the industry (Meld.St. nr.16 (2014-2015)).

Other important environmental pressure is the issue with salmon fleeing the seawater production sites (pen nets) and inter-breeding with wild salmon, as well as local pollution emanating from e.g. faeces and feed leftovers. Efficient use of resources has also been on agenda of the aquaculture sector. Seen as a socio-technical system, the aquaculture sector provides marine proteins and other biomass products (see Figure 9) primarily from the breeding of salmon. While processing primarily occurs closer to final end use markets, there has been considerable talk in recent years of increasing downstream activities (PwC, 2018), such as increasing the processing of finished foodstuffs. However there appear to be structural barriers (labour cost differences, tariffs etc.) to doing so. Another strategy for increasing value creation is to increase the use of marine rest raw material (MRRM) which represents an enormous economic potential (Nofima, n.d.). This is currently an important target of R&D funding. This energy-rich resource is currently used for producing biogas (in relatively small volumes), however the industry itself is first and foremost interested in developing higher-order bio-based products rather than bioenergy from MRRM ("higher-order waste") (FHL, 2012).

[12] Sea lice are parasites naturally found in marine waters that have "*reached unnaturally high concentrations in many of Norway's fjords and coastal waters due to intensive production of salmon and rainbow trout*" (NEA, n.d.). These parasites attach to salmon (or other salmonids) where they feed of the slime, skin and blood of the fish, with the effect that growth is retarded, the fishes' salt balance becomes disrupted, which in turn increases their vulnerability to other diseases and predation.

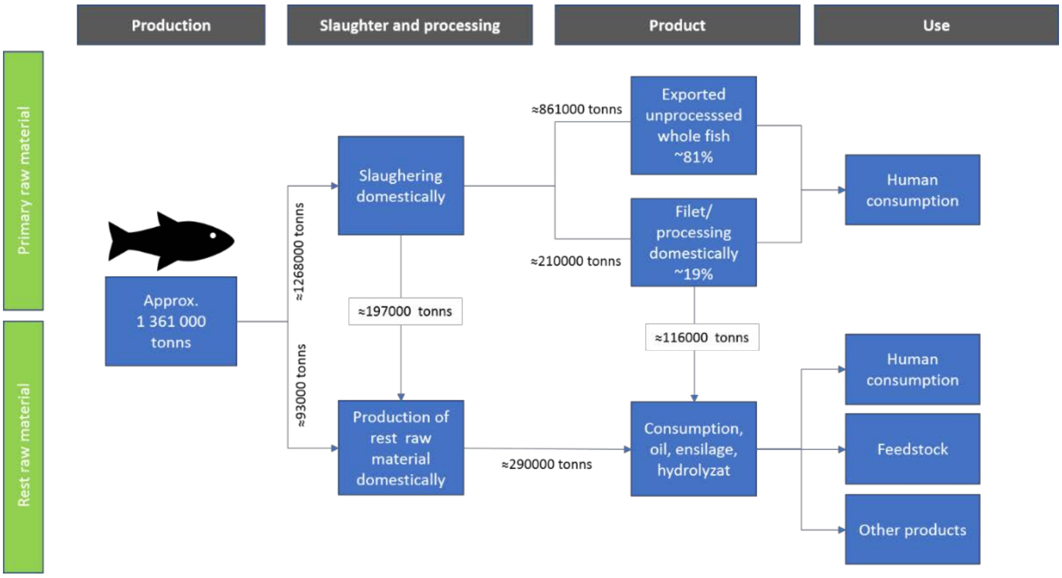

Figure 9 The 2017 Norwegian aquaculture processing and end use value chain segments with biomass volumes (adapted from PwC 2019).

There is also a political ambition for the industry to reduce its carbon footprint (Salmon Group, 2018), which in part is driven by an expectation that end customers increasingly will demand 'low-carbon' food (Steen, 2019). For the seawater production segment, there are two main forms of energy demand. First, energy is used on the production sites or locations (operation of feeding systems, lighting, water circulation etc.) The conventional solution here has been to use diesel generators installed on feed barges at production sites. Second, the aquaculture industry relies on different types of vessels (smaller work- or service boats), and carriers of fish and feed (some of the latter being very large). These vessels mainly run on fossil fuels, however the introduction of battery-electric solutions and other low- and zero-carbon energy solutions are slowly finding their way into the aquaculture sector(Steen et al., 2019).

Planned growth of the industry would lead to an increase in transport demand and represents therefore another environmental pressure that has to be dealt with. In addition, the focus on the environmental footprint of the salmon feed is also increasing (Norsk Industri, 2017a).

Different strategies are currently being followed to address the environmental challenges that the sector is facing. Reducing the sea lice problem, and thereby increasing the control of biophysical production properties (Irarrázaval and Bustos-Gallardo, 2018), can be done by shortening the period that fish spend in the sea by extending the onshore ('smolt') growth period in onshore hatcheries. A more radical change is complete production in onshore tanks, a practice that is common in many other parts of the world using recirculating aquaculture systems (RAS). Currently a few such sites are being developed in Norway, whereas Norwegian suppliers operate internationally with different RAS solutions. This, however, and notably the latter (full production on land) requires costly investments in onshore infrastructure. Other options include developing closed-cage systems for fish farming and moving production sites further from shore.

Maintaining growth while meeting environmental challenges has resulted in two main policy strategies (Fløysand and Jakobsen, 2016), one related to governance of (seawater) production areas, and the other related to supporting or pushing technological innovation. In 2014 the state imposed a more restrictive concession policy, with a traffic light system depending on concentrations of sea lice (Bailey and Eggereide, 2020). In 2013, the state awarded a number of 'green concessions'/'green development licenses'. In 2015, they granted a number of 'development licenses', with the aim of fostering innovation and novel ways of farming salmon to combat especially the sea lice and salmon escape challenges. Especially the development licenses were geared towards more radical technological change (Fiskeridirektoratet, 2018, Christiansen and Jakobsen, 2017).

7.3.2.2 Environmental transformations along the value chain

To understand how environmental issues (or meeting those) could transform the industry, a brief introduction to current practices in salmon and trout farming is needed, focusing on seawater production. Conventional aquaculture in Norway includes the following core technologies and services (Bjelland, 2019):

- Pen nets that contain the fish, with floater elements and anchoring systems
- Feeding barges with equipment (silos for feed, feeding system, generator, control room, living quarter, storage for equipment and ensilage systems)
- Work boats that operate daily, service boats for heavier operations (e.g. putting pen nets in place and anchoring), wellboats that carry live fish between land and pens (also used for treatments of fish in growth period), feed boats that carry feed to the production sites
- Remotely operated vessels (ROVs) for underwater inspection of production facilities, also as a substitute for divers
- Other production equipment and systems used for surveillance, handling dead fish, underwater lighting, including also solutions for the wrasse (fish species used to control lice) that have increasingly been used as a solution to the lice problem.

Production activities are relatively uniform across the country. It is however expected that this may change with an increasing diversity of production technology and equipment in general.

Currently, several novel/alternative fish farming solutions are being developed and implemented:

- Recycling aquaculture systems (RAS) are used for onshore fish farming. RAS is a fairly mature technology that is currently limited in Norway but expected to grow. RAS has the obvious benefit of having much better control of various biological and ecological issues, notably sea lice. However, RAS is energy demanding and relatively costly. Many actors argue (e.g. interviews 28, 36) that whereas RAS makes sense in many places of the world, they contradict the very physical conditions that gives Norway a competitive advantage in salmon and trout farming internationally: the availability plentiful near-coast locations with good sea conditions (currents, temperatures) and access to fresh water. The firms that are in the forefront of developing RAS in Norway are established aquaculture suppliers.

- Closed seawater systems are meant to benefit from good physical conditions in the ocean, whereas the farmed fish are sealed off from surrounding ecological systems by preventing lice and salmon from escaping. The actors involved in developing closed seawater systems are typically smaller technology suppliers working in collaboration with aquaculture companies.

- Large-scale offshore fish farming has emerged as a result of the development licenses implemented in 2015. To date, several very large aquaculture systems designed for hasher waters more offshore have been built. The consortium behind these projects typically involve large established engineering companies from the offshore petroleum industry alongside fish producers (who make the investment).[13]

Reducing carbon footprint from seawater production has come quite some way, with approx. 50% of all Norwegian aquaculture seawater production sites now having power-from-shore (ABB and Bellona, 2018):

- Electrification and hybridization of vessels involved in the production processes, as well as use of shore power
- Electrification of onshore fish farms, i.e. feed barges that contain operation equipment.
- Effectivization of energy use of slaughterhouses and fishing grounds (Norsk Industri, 2017a)

In addition, several other technology development projects are taking place that build on principles linked to circular economy/industrial symbiosis. These include for instance using waste from process industry to produce algae, and also recycling of nutrients from waste, both for use in aquaculture feed production. There have also been feasibility studies of using oxygen and excess heat from (green) hydrogen production for fish farming. Another example is the use of wind energy, LNG-driven and natural gas for some operations in the MOWI's fish feed factory at Valsneset (Norsk Industri, 2017a).

7.3.3 Digitalization topics and the transformation in the aquaculture sector

7.3.3.1 Pressures and opportunities

Digital technologies have been used for many years in aquaculture, and industry experts see digitalization in the aquaculture sector primarily as an opportunity rather than as a pressure. That is, digital technologies are seen as a means to remedying many of the pressing environmental challenges confronting the industry (Interviews 7, 28, 33). Digitalization is also seen as an enabler of increased predictability, efficiency, and productivity. Examples of technologies that are in use already are drones (e.g. for inspection of production facilities), integrated cameras, sensors and remote control (e.g. to recognize individual fish and improved sorting) and automated measurements of biomass (Norsk Industri, 2017a). Digital technologies are also introduced because of their positive effects on health and security issues for people working in the industry (Norsk Industri, 2017a). Regarding the latter, aquaculture is one of the most hazardous industries to work in in Norway (Kongsvik et al., 2018), implying that automation of routine tasks is welcome.

All fish farming companies collect considerable amounts of data related to biomass, fish health, environmental data, feeding etc. This data is currently used for planning operations and slaughtering. Two large established supplier companies now control this data (although data is owned by fish farming companies) by owning the structure of the data bases and providing information services to fish farmers.

[13] See for example: https://www.intrafish.no/nyheter/disse-har-sokt-utviklingtillatelser/1-1-752348

New digital tools and technologies that are developed and implemented with environmental gains in mind, such as related to fish health, lice, waste and escape problems, span broadly. Generally they relate to two overall trends (Bjelland, 2019). The first is the use of digital technologies to improve operations. Here digitalization can be used for observation and monitoring (sensor-based collection of various data), interpretation and assessment (algorithms and models that place observations in broader context), decision making (automated or support operators) and operations (e.g. automated cleaning systems). In general terms, the industry has come some way in terms of using digital tools for enhanced operational control (e.g. using drones for monitoring of feeding operations), and also in thinking about novel applications, but this work is still in an early phase for the industry as a whole (Interviews 29, 33, 34). Sensors and camera-based monitoring could decrease maintenance costs and operational risks, whereas 3D-printing could reduce time and cost of supply for replacement parts (EY, 2017). The second trend relates to the development of novel fish farming production systems, both for use in the sea and on land. For example, the introduction of offshore fish farming depends on the development of technologies that can enable predictable and secure operations (Bjelland, 2019).

Digitalization is also believed to bring opportunities to the industry related to new business models and partnerships based on data. There is considerable belief in the potential for further optimization and effectivization using cross-value chain, data-driven analysis and digital supply. This however requires standardization of data and the development of open application programming interfaces (APIs), i.e. digital platforms that allow for interaction across different companies and segments of the value chain. A project (Aquacloud) by NCE Seafood Innovation that involves 40-50% of all fish farming companies in Norway and 60-70 suppliers has begun to do this kind of work. By using big data and artificial intelligence (AI), one hope is for example that digital platforms and data sharing can help warn against lice two weeks in advance (EY, 2017). Several interviewed industry stakeholders see considerable potential for cost savings and improved environmental performance of fish farming if fish farmers within larger production regions can use digital tools to collectively plan various operations.

Experts also argue that digitalization can potentially help the aquaculture industry to solve its problems regarding land access, as it enables use of advanced planning instruments and knowledge accumulation (MTIF, 2018).

7.3.3.2 Digital transformations along the value chain

The use of digital tools primarily for operational purposes is expected to increase considerably, although fish farming companies appear to be very varied in their approach to adopting digital technologies (Interviews 7, 33, 28, 34). This applies for instance to automation of many operational tasks, such as feeding and cleaning of production equipment. A result of this may be that the need for people on site (of fish farming) may be reduced and that operations are remotely controlled from onshore monitoring hubs. In fact, the latter has already been introduced notably for feeding systems (Bye, 2017).

Digital technologies are central to the realization of many of the novel production system solutions (offshore, closed coastal, onshore) that are being developed. In these, key aims are to better control both fish health and growth as well as reduce negative environmental consequences of fish farming. For example, SalMar's "Ocean farm" is equipped with more than 20.000 sensors, allowing complete automation of monitoring and feeding

(Berge, 2017). Similarly with many other sectors, increased digitalization will influence not only operations but also the design of technological equipment (pen systems, vessels etc.) in use in aquaculture.

Fast technological development in the industry has led to several changes and challenges. For example, the need for new competencies is crucial to understand the potential benefits and enable the use of new technologies. Increased dependence on technologies however also implies higher operational risks (EY, 2017). Data standards need to be developed, and measurement and data integration need to be improved in order to enable data sharing and beneficial collaboration across the value chain, but data sharing is related to new risks as well (EY, 2019a). Digitalization is also expected to be accompanied by the introduction of new business models related to data, whereby suppliers collect and analyze data and offer real-time decision support to fish farmers.

Many of the new actors that have entered the aquaculture sector (or attempted to do so) in recent years are start-up companies with solutions that in different ways are based on digital technologies. For start-up companies with ideas on how to utilize data have better, there appear to be certain barriers in the ways in which that treatment and sharing of data in the industry is currently conducted (Interview 33).

7.4 The manufacturing industry

The role of defense industry and its collaboration with civilian markets is often emphasized for the development of the Norwegian manufacturing industry (Lund and Karlsen, 2019, Ministry of Trade Industry and Fisheries, 2017). The development of the defense industry in Norway is associated with clusters in Raufoss and Kongsberg. The development of the cluster in Raufoss started with the relocation of state ammunitions factory to Raufoss (Vestoppland region, Oppland county) and the consequent development of the manufacturing in the region (Lund and Karlsen, 2019). Today, NCE Raufoss is the national center for lightweight materials and automated production. The members of this cluster currently deliver their products to the global automotive industry, defense industry and electronics (NCE Raufoss). Kongsberg Våpenfabrikk (KV) became a core for what today is known as Kongsberg Klyngen (NCE Systems Engineering), a cluster of high-technological companies in the Kongsberg region (Lund and Karlsen, 2019).

Industrial environments representing other segments of manufacturing industry can be found in other parts of Norway. Rørosklyngen (Industrial cluster of the Røros region) is a relatively new cluster founded in 2018 in the Røros municipality of Trøndelag county. The cluster's composition is very diverse, as it is represented by different manufacturing companies, such products as furniture, doors and windows, wool products and many others. The common feature of the members, despite the big variety in their products, is their dedication to the principles of customized mass production and companies' export-orientation. In addition, the companies have long historical traditions, although some of them have recently changed their profile (Interview 24).

As a part of the Norwegian industry, manufacturing today is characterized by high production costs and high level of competence among employees. Norwegian manufacturing produces a variety of products for global markets and is, therefore, under a constant pressure of strong international competition (Ministry of Trade Industry and Fisheries, 2017). This pressure, nevertheless, varies between different branches being somewhat smaller for companies producing specialized products (SSB, 2014). While operating in global markets, Norwegian companies are strongly anchored in their local environments, playing an important role for the regional development and employment. The companies representing this industry also vary a lot but can be roughly divided into 2 groups: suppliers and producers of consumer goods (Ministry of Trade and Fisheries, 2017). These two groups can be subdivided into further categories depending on the product or client type.

The diversity of the Norwegian manufacturing industry is reflected in the extent to which different branches get influenced by the same trends, for example, the financial crisis in 2008. However, it generally influenced the Norwegian industry negatively, causing decrease in the production (SSB, 2014). The Norwegian industry (both manufacturing and process) is strongly dependent on the developments and investments made in the O&G sector (SSB, 2017).

The recent years have been marked by a relatively stable level of investments within certain branches (furniture and apparel industry), while the industry for electronic equipment and ICT and machine industry have experienced more radical changes (see Figure 10). The investments level in the industry for electronic equipment and ICT was approximately at the same level between 2014 and 2017, followed by a slight decrease in 2018. This trend was kept in 2019. The machine industry experienced a bigger decrease in investments between 2014 and 2017. However, this development changed in 2018, and investments continued to increase in 2019.

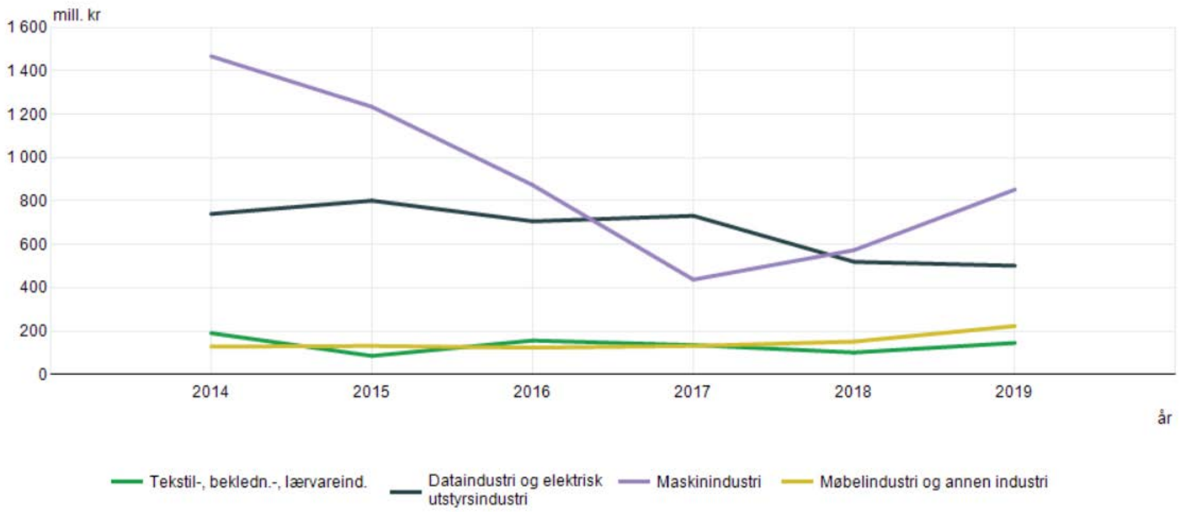

Figure 10 Investments statistics by industry type and year. Source: Statistics Norway.

Turnover in the industry (both manufacturing and process industry with an exception of O&G suppliers) increased slightly from 2014 to 2015, followed by a small decrease in 2016. Since 2016 turnover in the industry has continued to increase. See Figure 11.

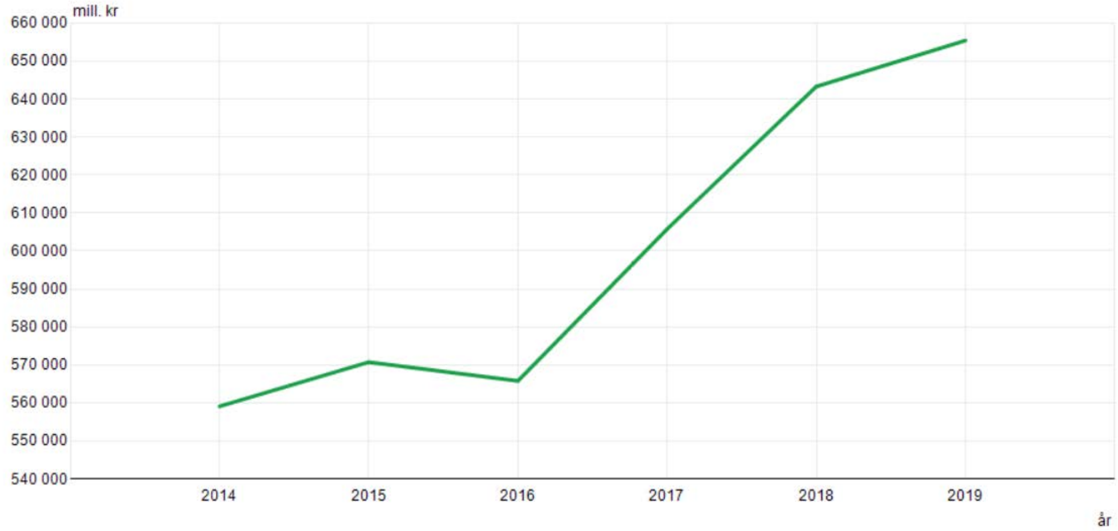

Figure 11 Turnover for industry (except for suppliers in O&G) statistics by year. Source: Statistics Norway.

The overall trend for employment in industry (both manufacturing and process industry) demonstrates decrease for the given years (1970-2018), although some fluctuations can be seen. See Figure 12.

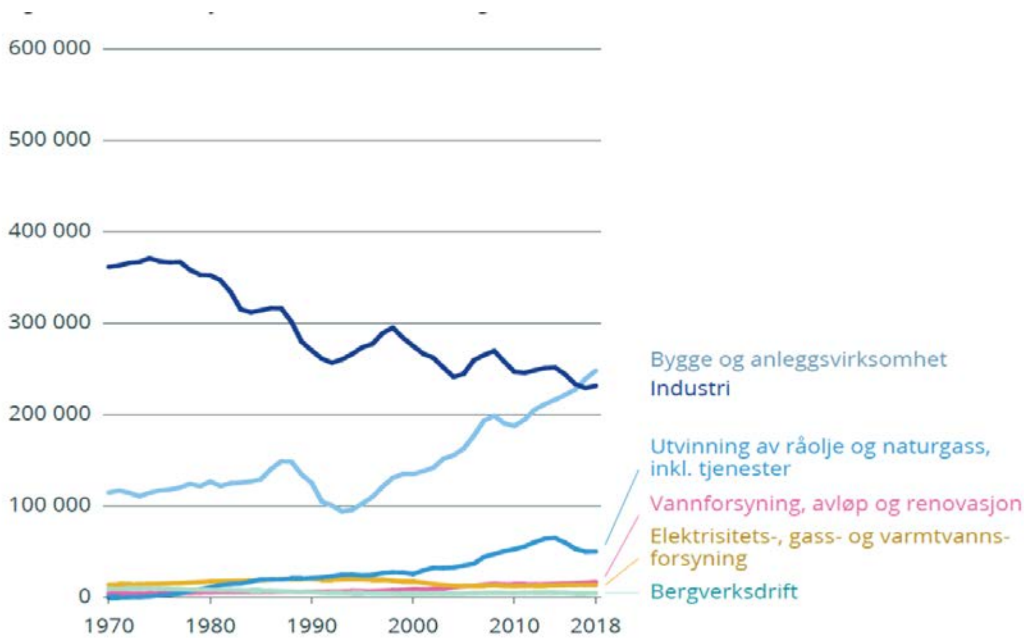

Figure 12 A number of employed in different sectors. Source: Statistics Norway.

The Norwegian manufacturing industry is strongly influenced by formal institutions, such as tax exemptions, support programs for research and innovation (e.g. via the Norwegian Research Council, Innovation Norway etc.). In addition, companies have a possibility to get access to capital from different national and international sources or apply for a loan, depending on the company size (Ministry of Trade and Fisheries, 2017).

Public procurement practices also shape the institutional context of the manufacturing industry and the Norwegian Government encourages public authorities to use their purchasing power in order to stimulate innovation and supplier development (Ministry of Trade Industry and Fisheries, 2017).

The Norwegian model and tripartite collaboration (*trepartssamarbeid)* are often mentioned as important and beneficial for the manufacturing industry (as well as the Norwegian industry in general). The main characteristics of the Norwegian model are reflected in the high autonomy of workers, their ability to contribute to the decision-making processes, importance of learning and good possibilities for that, as well as lower hierarchy compared to other models (Ministry of Trade Industry and Fisheries, 2017). Tripartite collaboration refers to a way of organizing working life, characterized by close collaboration between the state, industry, and different parties representing workers (Regjeringen, 2018). The associated working culture is characterized by a high level of knowledge exchange and involvement of employees in innovation activities. These features constitute one of the perceived strengths and competitive advantages of the Norwegian industry (Ministry of Trade and Fisheries, 2017, Ravn and Øyum, 2018).

The Federation of Norwegian industries (Norsk Industri, 2019a) provides an overview of the industries, according to which the following will be further related to as a part of Norwegian manufacturing industry:

- Design industry
- Electrotechnical industry
- Technology producers

Although manufacturing includes suppliers to aquaculture, oil and gas and maritime, these will not be considered in this part of the report. The close connections to these industries, nevertheless, make the manufacturing industry in Norway sensitive to developments happening there. For example, decrease in oil price in 2014 led to decrease in activity levels regarding deliveries to O&G industry and portfolio restructuring of manufacturing companies. Another trend observed in recent years relates to increased servitization of Norwegian industry (Ministry of Trade and Fisheries, 2017).

7.4.1 Branches/segments in the Norwegian manufacturing industry

The design and technological equipment industries are not based on Norwegian natural resources in contrast to other industries. This segment is represented by both big and small and medium-size companies spread across the whole country, often concentrated in one area/within one industrial cluster. These companies operate within defense, aerospace, production of car components. In addition, companies from this segment represent important suppliers industry for other sectors, such as oil and gas, maritime and energy (Norsk Industri, 2017b). The electrotechnical industry has developed in close relation with the development of Norwegian energy sector that in its turn is strongly based on domestic natural resources (Norsk Industri, 2016b).

Examples of larger manufacturing companies in Norway include Kongsberg Gruppen, GKN Aerospace, Wärtsilä, Havyard Group, (Kapital, 2017); ABB AS, Nexans Norway AS, Siemens AS, Adax AS, Honeywell AS, Demas AS (Norsk Industri, 2019b); Jøtul, Ekornes, Flokk, Swix (Norsk Industri, 2016a).

7.4.2 Environmental topics and the transformation in the manufacturing sector

7.4.2.1 Pressures and opportunities

Global developments regarding sustainability issues also apply to the Norwegian industry, as Norway actively works to implements the UNs SDGs (Regjeringen.no, 2016). Increasing attention around Goal 12 (Sustainable production and consumption) and the concept of 'Circular Economy' on both European (EC, 2015) and national (KMD, 2017) level are also relevant in the context of the Norwegian manufacturing industry. The furniture segment of design industry will be used to give more specific examples of the environmental transformations in the Norwegian manufacturing industry.

Norway has set itself a goal to become low-emission by 2050, requiring changes in the Norwegian industry, including manufacturing (KMD, 2018). The Norwegian industry in general and manufacturing as part of it have historically had lower production emissions due to the use of renewable hydropower energy. The industry is expected to contribute to sustainable development by delivering sustainable solutions both at home and abroad. In addition, the industry's own emissions represent a problem that must be solved. The spread of environmental toxins, reduction of biological diversity, local pollution and limited water resources are among the main challenges Norwegian industry has to relate to(Ministry of Trade and Fisheries, 2017).

Increasing attention to environmental sustainability is believed to bring new opportunities in form of new markets (Interview 23) and business models (Interview 25). Responding to the increased requirements for more sustainable products, companies try to reduce their use of raw materials, increase the lifetime of different products, and improve the products' quality (Interview 23, 26). However, the demand for more sustainable products is relatively low, although still higher than some years ago (Interview 22). In addition, the complexity of value chains often represents an environmental challenge in itself because of the complex logistics (Interview 24, 26).

Lately, the Norwegian Digitalisation Agency (Digdir) has been leading the development of new criteria for green public procurement. The aim is to stimulate the market to reduce negative impacts on the environment and promote climate-friendly solutions. The furniture industry has been selected as one of the focus areas. The work has been carried out by an expert group consisting of representatives from the industry and a reference group with different representatives, from both companies and R&D organizations. The result of the process is seen as important for the transformation processes in the industry. Although innovative public procurement has been given attention in recent years, the sustainability aspects has been limited. The industry itself has been willing to participate actively by giving input to policy development. First, there has been a lack of consistency in how public procurers address the environmental aspect in public tenders. Second, public tenders represent a potentially big market for the furniture industry.[14]

Increasing attention to environmental sustainability also characterizes the furniture segment in the recent years (Norsk Industri, 2016a), although some companies have a long record track of sustainability work. They experience, among other, many different requirements from customers (both public and private) and, therefore, increasing competition among furniture producers. Due to the existing framework regarding ownership rights, it is difficult for the producers to address how the product is treated in its end-of-life phase. However, some

[14] Project workshops and interviews with a furniture producer (2018-2019).

producers focus on the possibilities to enable reuse of their products' components.[15] In addition, some underlying concepts of companies' activities, for example, "mass-produced customized" could raise environmental challenges resulting from more advanced logistics, more choice options for a customer etc. At the same time, there are opportunities regarding higher sustainability of solutions produced using the principles of this concept, as "fit-in" solutions should be based on better quality and, therefore, longer lifetime of the products, and the production is order-based, implying that every product already has its end user. In addition, this concept builds around modularity principle that opens opportunities for recycling (Skjelstad et al., 2018).

7.4.2.2 Transformation in the value chain

The furniture companies represent around 50% of members in the Association of Norwegian Design, Furniture and Interior Industry (Interview 22). The manufacturing in this segment is characterized as advanced and not based on advantages provided by natural resources (Norsk Industri, 2016a). The furniture segment is also diverse represented by companies producing various products – from outdoors furniture to office furniture solutions. The furniture value chain can be summed up as: suppliers of the (raw materials and) components to the furniture producer – furniture producer – logistics operator - retailer. Nevertheless, it should be emphasized that actors present in different value chains depend on the type of product produced by the furniture company.

Overall, the design manufacturing industry perceives its starting point regarding sustainability as good, but acknowledges a number of challenges that producers face: treating waste flows, recycling, certification and documentation of own products, as well as materials and components brought from suppliers. At the same time, the demand for more environmentally sustainable products is still low (Norsk Industri, 2016a). In addition, some producers experience somewhat limited access to certain materials (e.g. plastics) of necessary quality and are dependent on their suppliers in this regard. Responding to the mentioned environmental pressures would require new partners and collaboration forms.[16]

The traditional business model of manufacturing companies in the furniture industry is based on selling their products through dealers from factories to costumer. One of the responses of the furniture manufacturers to the environmental pressures includes continuous improvement of the design of their products, as well as choice of materials. Despite the success of this business model, the industry acknowledges the need for value creation in a more sustainable way. One step towards a more sustainable industry, could be through selling product-as-a-service. This type of business model will typically include new partners and value chain constellations. Although this could represent a more sustainable way, it also involves uncertainty about how the market will respond. The process of experimentation and interaction with newcomers is mentioned as one of the strategies taken.

[15] Project workshops and interviews with a furniture producer (2018-2019).
[16] Project workshops and interviews with a furniture producer (2018-2019).

7.4.3 Digitalization and the transformation in the manufacturing sector

7.4.3.1 Pressures and opportunities

The impact of high speed of digitalization is believed to change the nature of Norwegian industry and influence different stages of the production (Ministry of Trade and Fisheries, 2017). Although the manufacturing industry is very diverse, it is difficult to differentiate between the ways in which digitalization affects the different segments. However, it can be challenging and demanding for all actors independent of which sector/segment they represent (Interview 25). The complexity of specific value chains can be one factor that influences how challenging digitalization might be for a specific segment (Interview 26). Digitalization at the current level is believed to bring more opportunities than challenges (Interview 22, 24, 25), for example, for reshoring of the Norwegian production (Interview 26, Lund and Steen, 2020) or providing services in addition to products (Interview 25). At the same time, companies vary in their maturity level regarding their utilization of the opportunities digitalization provides. They also face different drivers to take new technologies in use (Torvatn et al., 2019), Interview 23). Some of the studied companies emphasize that they "do not digitalize for the sake of digitalization" (Interview 24), but prefer to test and choose the solutions seen as most appropriate for their specific needs. Exploring all of the available technologies at the same time would be too expensive and otherwise demanding. The use of digital solutions by the Norwegian companies is, therefore, mostly customized to their specific needs (Interview 26).

The same possibilities and challenges, including the lack of necessary competences, are seen within the Norwegian design and interior (including furniture) manufacturing (Interview 24, 25). While digital solutions might create opportunities through influencing consumer behaviour, reducing transaction costs as well as the distance between producer and final consumer (Norsk Industri, 2016a), some furniture producers experience challenges related to data sharing (both in form of suppliers unwilling to disclose all required information, as well as producers' interest in keeping their suppliers "for themselves"), variety and incompatibility of the existing solutions, and lack of competence needed to apply the solutions correctly.[17]

7.4.3.2 Transformations in the value chain

Due to digitalization, the manufacturing industry is also seeing new value chain constellations, as some of the manufacturing companies in the furniture industry introduce online sales in addition to selling their products through their dealers. [18] Potentially, this could lead to changes in the value chain, by changing the role of dealers in the manufacturing value chain.

Although there is a belief that use of digital solutions in manufacturing industry can contribute to increased environmental sustainability, currently, there are few specific examples in this regard (Interview 23). Moreover, there seem to be tensions between these transformations, as more effective production (resulting from more digitalization) would lead to increase in climate gas emissions (Interview 25). Nevertheless, it has been suggested that both digitalization and increased focus and requirements regarding environmental sustainability will shape the future of the Norwegian manufacturing industry (Interview 22, 24, 25).

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[17] Interview with a furniture producer (2019).
[18] Workshop with a furniture producer (2018).

7.5 The process industry

The Norwegian process industry has been developed on the basis of advantageous natural resources and topography. The availability of water basins, rivers and waterfalls enabled the development of power plants and access to hydroelectric power, a crucial energy source for an energy-intensive process industry (Interview 17). The initial development of the process industry is often associated with Sam Eyde, a Norwegian engineer, who recognized the importance of waterfalls and the potential of hydroelectric power for industrial development in Norway. Eyde facilitated Swedish investors' acquisition of waterfalls in Norway in the early 20^{th} century, laying the foundation for hydropower development (Rabben, 2018). The utilization of waterfalls in industry was not a new phenomenon by Norwegian standards, as it had been used for mechanization of industries since the late 19^{th} century. However, the electrification of the industries enabled new production methods, new products and increased industrialization.

The continued development of the process industry was supported by the Norwegian state in the post-war period (after 1945), as industrialization was considered essential for the rebuilding of the nation. This entailed building new aluminum smelting plants in Årdal and Sunndal and the establishment of the state-owned company Årdal og Sunndal Verk (ÅSV) (Sæther et al., 2011). The Norwegian state also became the majority shareholder (45 %) of Norsk Hydro as they acquired German shares after WWII. The two companies merged in the 1980s. In addition to developing their own R&D units, the state-owned companies developed close ties with key knowledge institutions within the national innovation system in the 1970s and 80s. The most influential of these were NTNU (the former Norwegian Institute of Technology) and SINTEF (Sæther et al., 2011). In the same period, the aluminum industry gained a strong position in industrial policy (Midttun, 1988). Although aluminum production has been an influential segment within the Norwegian process industry, the industry is diverse in terms of products and markets.

Norsk Industri (the Federation of Norwegian Industries) (2016b) identifies 7 industry segments that constitute the Norwegian process industry: (1) aluminum, (2) ferro-alloys, (3) chemical industry, (4) mineral industry, (5) mineral fertilizer, (6) refineries, and (7) pulp and paper (see Figure 13). Firms within the industry have often represented a cornerstone companies which have had great influence on local and regional economies. The distribution of the different industries (see figure 8) illustrates how the process industry contributes to economic activity in many parts of the country, and particularly in non-city regions. The process industry is important for Norwegian value creation, as it accounts for 50% of the total mainland exports (20% of total exports in 2013) approx. 236 billion NOK in 2019 (Norsk Industri, 2016b, SSB, 2020). As an export-oriented industry, it is vulnerable to changes in the global economy. Following the 2008 financial crisis, the industry experienced a substantial drop in value creation. This has stabilized in later years (Norsk Industri, 2016b), although the current COVID-19 situation could potentially could have great impact, as global demand for input materials might fall (Fjose et al., 2020). Within the last 15 years, the employment rate in the process industry has fallen, mostly due to rationalization processes. Currently the industry employs approx. 30 000 workers (SSB, 2019), with approx. 17 000 of these working within the energy-intensive industries (i.e. production of pulp and paper, chemical raw materials, iron and steel (including ferro alloys) and non-iron metals) (SSB, 2015).

Figure 13 – The geographical distribution of firms in the Norwegian process industry (adaptation from Norsk Industri, 2016b)

Many of the companies within the Norwegian process industry produce input materials used in manufacturing. This entails that most of the trade is business-to-business, where the Norwegian producers are sub-suppliers to different industries (Interview 16), e.g. automotive (aluminum), pharmaceuticals (lignin) and solar (silicon carbide). However, there are also examples of companies that have internalized their entire value chain. Hydro is one such example. The company, which initially produced primary aluminum, now controls the entire value chain from mining raw materials (bauxite) to producing finished aluminum profiles (Interview 16), after acquiring Sapa's downstream activities in 2017 (Selvik, 2017).

Within the last decades, the political and societal attitude towards the process industry has changed. The industry has been regarded as an old and dirty industry, which was most likely to be outsourced and offshored (Interview 17). However, in recent years, the industry has received renewed political interest and is increasingly regarded as a solution rather than a problem to both climate change challenges and industrial development (Interview 15, 17). The process industry has transformed from being first and foremost based on cheap hydro power, to becoming more concerned with process and product innovation. The industry, in general, has become more oriented towards doing products and processes development through incremental innovation (Interview 14). This includes e.g. implementing LEAN methodologies and specialization of products in collaboration with international customers (Interview 14). The competence that was built up over the course of the last century, under the auspice of cheap hydro power and in collaboration with key national knowledge institutions, has become a key competitive advantage (Interview 17, Norsk Industri, 2016b). The combination of continued access to hydro power and the knowledge and competence base in the industry provides the industry actors with a strong foundation when facing transformation pressures related to sustainability and digitalization. In order to coordinate the industry's development efforts, the Ministry of Trade, Industry and Fisheries established *Prosess 21 (P21)* in 2018. P21 is a forum consisting of several expert groups (with industry experts) that are to advise industry and public policy actors on key topics related to the development of the Norwegian process industry (Prosess 21, 2020).

7.5.1 Clusters and regions

Due to the process industry's energy-intensive nature, companies and production sites are spread out across the country. As the key production factor is energy, access to hydropower is essential and proximity to favorable natural resources has influenced the localization. Additionally, the access to raw materials (particularly timber for the pulp and paper industry) and transport infrastructure is important. Most of the production sites (as illustrated in Figure 5) are therefore located on the coast near ports which are essential for distributing large quanta of processed materials. Although the industry is scattered, some regions and clusters stand out in terms of acting as focal points for the development of technology and processes that enable a more sustainable production.

7.5.1.1 Grenland, Southeast Norway

One region that is positioning itself as a green process industry region is the Grenland region (Southeast Norway), one of the earliest and largest industrial areas in Norway. The region hosts two clusters working towards a 40% reduction in greenhouse gas emissions set out in the Paris agreement. The Industrial Green Tech cluster (IGT – funded by Innovation Norway's cluster scheme) consists of 31 core firms and is particularly geared towards a sustainable transition of process industry. The Green Industry Cluster Norway (GIC Norway[19]) consists of c. 70-75 partners, both processing firms, technology suppliers and public actors. The cluster is a multidisciplinary network organization that aims to contribute to development of industry and technology within the Grenland region, both on- and offshore. Both cluster HQs are located in the Herøya Industrial Park, which also hosts R&D units for multinational companies such as Hydro and Equinor. As the largest industry region in Norway and host for a range of large (multinational) firms such as Yara (fertilizer), REC Solar (silicon), Norcem (cement) and Eramet (manganese alloy), the region accounts for more than 20% of industry related CO_2 emissions in Norway[20]. Grenland also hosts the Norcem Brevik cement plant, which is the locus of one of the two capture projects that are currently being developed, as part of the full-scale carbon capture and storage (CCS) project in Norway funded by the Norwegian government (see section 7.4.3) (CCS Norway, 2020).

[19] https://greenindustrycluster.no/om-oss/

[20] https://industrialgreentech.com/om-igt/

7.5.1.2 Agder, Southern Norway

The Agder region (Southern Norway), with Kristiansand and Arendal as the main cities, hosts several large (multinational) processing firms, such as Elkem, Eramet, Hydro (primary aluminum), Alcoa (primary aluminum), and Fiven (silicon carbide). NCE Eyde[21] is a core cluster in the region with an emphasis on transitioning the process industry towards a sustainable future (Kyllingstad and Rypestøl, 2019). The region also hosts the Norwegian Catapult Centre on Future Materials[22], located in Grimstad. Additionally, the region is known for being leading within technology, products and services for energy and maritime industries, with GCE Node[23] (part of Innovation Norway's cluster scheme) in Kristiansand as the focal point.

7.5.2 Environmental topics and the transformation of the process industry

The Norwegian process industry has been identified as a key industry in relation to dealing with global climate change, as the main production factor is hydro power (Melvær and Brastad, 2019). Nevertheless, at present the industry is responsible for substantial greenhouse gas emissions.

7.5.2.1 Pressures and opportunities

The Norwegian process industry has an explicit goal to become a zero-emission industry by 2050 (Norsk Industri, 2016b). There has been an increase in attention towards environmental issues and climate change in Norwegian process industry the last four years, particularly after the Roadmap for the Norwegian process industry (Norsk Industri, 2016b) was published in 2016 (Interview 18). At the same time, the industry is responsible for approx. 60 % of CO_2 emissions from Norwegian industry (20% of Norway's total greenhouse gas emissions). The industry segment that is most responsible for these emissions is the metals industry (40% of total industry emissions), where ferro-alloy and aluminum production emit the most (MTIF 2017). The largest sources of CO_2 emissions, >500.000 tons per year, are Equinor at Mongstad, Yara at Herøya, Norcem at Brevik and Hydro at Sunndalsøra. Most of the low-cost measures that reduce CO_2 emissions have been implemented within the last 25 years (Norsk Industri, 2016b). An example of such measures is replacing coal with alternative fuels in cement production, reducing Norcem's CO_2 emissions from their two factories with 150 000 metric tons per year. This entails that further cuts depend on technological innovation and the development of new green solutions. To develop these solutions, the process industry depends on financial support and funding from the state (Norsk Industri, 2016b, MTIF, 2017).

The major challenges connected to greenhouse gas emissions and global warming poses a great challenge for the process industry to accelerate its efforts to reduce emissions. However, the global challenges also provide opportunities for the Norwegian process industry. The Bellona Foundation recognizes the process industry as essential in the transition towards a zero-emissions society. According to Melvær and Brastad (2019), Norwegian process industry has been a frontrunner in terms of reducing its CO2 emissions and thinking in a circular economic way. The industry has been particularly affluent in utilizing waste to create value added, e.g. Elkem Solar who uses silicon slag from solar cell silicon production as lime (Solaritt) used in agriculture

[21] https://www.eydecluster.com/en/about/
[22] https://www.futurematerials.no/eng/
[23] https://gcenode.no/about-node/

and Norcem who replaces clinker (the lumps found in cement) with light ash from coal power plants in cement production (Melvær and Brastad, 2019, Norsk Industri, 2016b). The access to hydro power is recognized as a key competitive advantage in the future, as industry actors expect customer demands for climate-friendly products to increase in the coming years (Interview 17). In relation to power availability, the industry actors argue for stable long-term framework conditions that secures the industry's access to green and cheap hydro power. In this regard, the Third Energy Package and the establishment of The European Union Agency for Cooperation of Energy Regulators (ACER), which formalized energy collaboration between EU and EEA countries, is regarded as challenging by industry actors as it increases the electricity prices in Norway (Interview 15).

In recent years, there has been an increase in attention towards the circular economy concept and circular business models in both policy, academic and industry circles (MTIF, 2017, Norsk Industri, 2016b, EMF, 2013, Baldassarre et al., 2019). Circular economy is by the Norwegian government regarded as a contributor to increasing Norwegian industry's competitive advantage (Ministry of Climate and Environment, 2017). P21 recognizes circular economy as one of the decisive megatrends influencing the competitiveness of Norwegian process industry (Prosess 21, 2020). Thus far, the process industry has focused mostly on linear processes such as raw material costs, production process efficiency and minimizing waste and biproducts. Energy efficiency and energy recovery has also been emphasized. However, the industry recognizes that there is still a large potential for making use of waste and side streams for value creation (Norsk Industri, 2016b, Norsk Industri, 2019c). An example of a product produced as a result of increased awareness and focus on reuse and recycling is Hydro's *CIRCAL 75R*, which consists of more than 75% recycled post-consumer scrap aluminum. The company is experiencing more demand for this type of product, particularly among architects and some parts of the construction industry. Certification of "green" aluminum has also been a focus for Hydro and resulted in the product series REDUXA, which is certified by DNV GL (ISO)as a new low-carbon aluminum (less than 4.0 kg CO_2 per kg aluminum)[24]. However, the lack of willingness to pay for such certified low-carbon products constitutes a barrier for companies providing such low-carbon products (Interview 16).

Although the concept of circular economy is rather new in terms of popularity (Baldassarre et al., 2019), the ideas have been apparent in Norwegian processing firms for many years. Borregaard, originally a cellulose and wood fiber producer, is a good example of how valorizing side streams have become important products for the company. The product portfolio that Borregaard has today is mostly based on what used to be waste (Interview 19), and is currently Europe's largest producer of bioethanol from wood (Norsk Industri, 2016b). The company is also part of a network in the lower Glomma area dedicated to industrial symbiosis (Baldassarre et al., 2019) and developing new circular business models on the different firms waste and side streams (Interview 19).

7.5.2.2 Environmental transformation along the value chain

The Norwegian process industry mainly consist of sub-suppliers of materials. As such, it is influenced by demands put forward by their customers, also in terms of producing more environmentally friendly products. Along the different value chains there are underlying industry specific drivers that can provide an increased

[24] https://www.hydro.com/Document/Index?name=REDUXA%20brochure.pdf&id=118154

demand for products with low-carbon footprints (primarily due to hydro power) produced in Norway. In the automotive industry, for example, reducing weight is one of the strategies to reduce the total CO_2 footprint. This is done by substituting heavier metals with light-weight aluminum components, and thus has an indirect positive influence on the aluminum industry. This is also driven by policy demands in the EU as it aims to cut transport emissions with 60% by 2050 (European Comission, 2016).

In the construction industry there has been an increased attention towards climate neutral buildings. ISO standardized environmental product declarations (EPD – based on a life-cycle assessment) for products used in the construction of buildings have become common (EPD International, n/a, EPD Norge, n/a, Bovea et al., 2014). The EPD provides customers with information on the overall environmental impact of a product, based on e.g. energy consumption in production, degree of recycled raw material input and degree of recyclability output. An increase in customer demand for environmentally friendly products incentivizes suppliers to the construction industry to provide products with qualities beyond price. Norwegian companies have taken measures to accommodate these emerging demands e.g. by altering production inputs from virgin to recycled materials. The above-mentioned examples of Hydro's low-carbon aluminum products (REDUXA and CIRCAL) are examples of EPD certified products. Another example is Norcem, which have reduced the carbon footprint of its most environmentally friendly cement with more than 30% (Norsk Industri, 2016b).

7.5.2.3 Carbon capture and storage (CCS) and utilization (CCU) technology

In order to achieve the goal of a being a zero emissions industry by 2050, the process industry relies on widespread implementation of carbon capture and storage technology (CCS) (Interview 17). CCS technology was developed in 1986 by researchers at the Norwegian research institute SINTEF, and has been utilized on the Norwegian continental shelf by oil and gas companies such as Staoil (now Equinor) for decades (Karimi et al., 2012). Carbon capture and storage (CCS) and bioenergy with carbon capture and storage (BECCS) technologies are essential for the process industry's sustainability transition towards a more process industry. In four mitigation pathways put forward by the IPCC (2018) in the *Global Warming of 1.5 ˚C* report, only one pathway is achievable without the use of (BE)CCS technology. CCS technologies can be divided into pre-combustion, post-combustion and oxyfuel. For the process industry, post-combustion technology is the most relevant as the aim is to capture CO_2 in the flue gas, where the CO_2 emissions from industry production is found (GCCSI, 2016). CCS technology captures about 90% of the CO2 in the flue gas, transforms it into liquid CO2 that can be transported to a CO2 storage facility before it is pumped into depleted oil and gas reservoirs (aquifers). BECCS is a negative emission technology (NET) where plants or trees binds CO2 in the atmosphere, before it is used as energy carrier in heating or industrial purposes. The CO_2 emissions from these processes are then captured and stored in the same manner as described for CCS. Captured CO2 can also be utilized for different industrial and commercial products. Carbon capture and usage (CCU) is already a widely applied process where carbon dioxide is used for industrial purposes in e.g. the food industry (e.g. carbonated drinks), the process industry (production of fertilizer) and the oil and gas industry (EOR – enhanced oil recovery) (Risberg, 2012).

Norway has had a leading role in the development of CCS which was put on the political agenda in 2006 with the government initiative to develop the Technology Centre Mongstad (TCM), which was finished in 2012 (Karimi et al., 2012, Technology Centre Mongstad, n/a). In 2005, the Norwegian state set up Gassnova (a state enterprise), which has been responsible for facilitating the development of CCS technologies and solutions

(Gassnova, n/a). The TCM is co-owned by Gassnova (77,5%), Equinor, Shell and Total (7,5% each). Gassnova is currently coordinating the two carbon capture projects at Norcem's cement factory in Brevik and Fortum Oslo Varme at Klemetsrud, which are part of the full-scale CCS project in Norway. The transport and storage part of the project, called Northern Lights, is developed and operated by Equinor, Shell and Total. The full-scale project aims to develop a transport and storage infrastructure for both the national and European market with a terminal at Kollsnes (Western Norway) (see Figure 14).

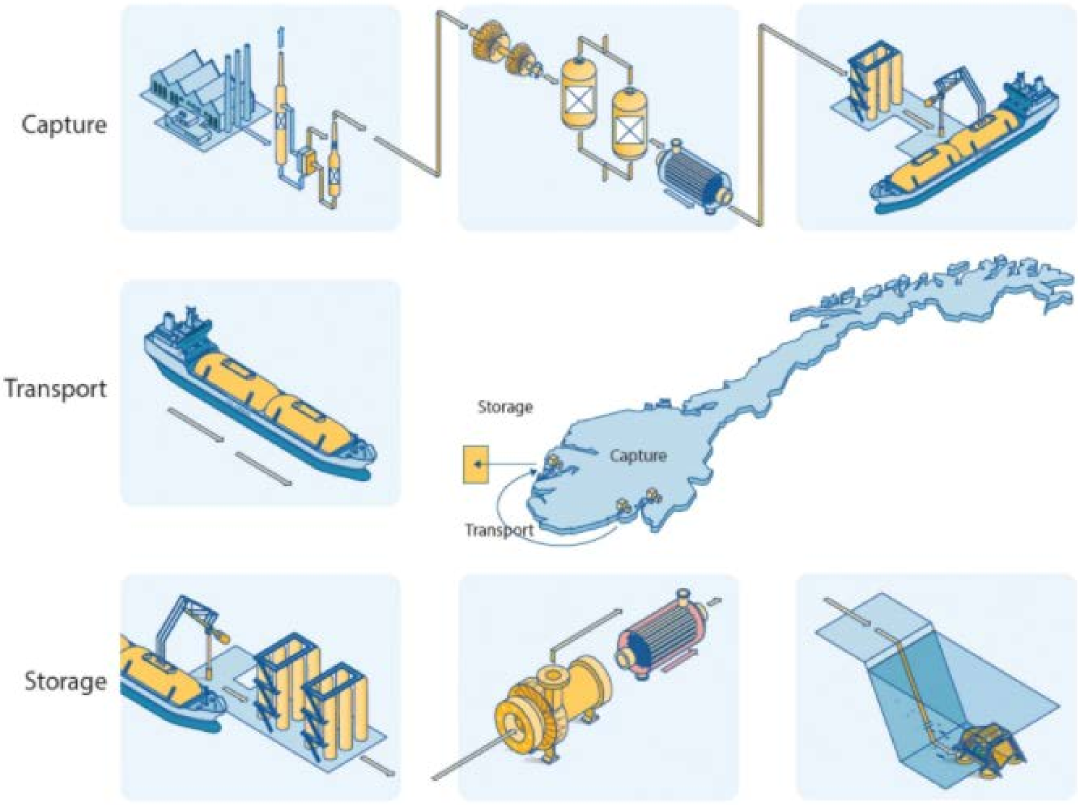

Figure 14 - The full-scale CCS project in Norway (Source: Gassnova)

In addition to the TCM and the full-scale project, the headquarters of the European Carbon Dioxide Capture and Storage Infrastructure (ECCSEL)[25] is located in Trondheim (Norway), along with the FME NCCS[26] (an 8-year research center aiming to fast-track CCS deployment). With substantial state funding and a leading academic position Norway has a substantial role in the development and dissemination of CCS technologies and contributing to the deployment and implementation of industrial CCS.

There are several drivers that push the development of CCS technologies. Several influential reports have identified CCS as an important climate change mitigation measure (IPCC, 2018) and key technology for decarbonizing the energy and industry sectors (IEA, 2017), which has provided momentum for faster

[25] https://www.eccsel.org/about/eccsel-eric/about-eccsel/

[26] https://www.sintef.no/projectweb/nccs/about-us/

deployment. However, despite proven technological concepts of the capture technologies, and potentially proven concepts of transportation and storage with the Northern Lights project, CCS remains a limited phenomenon.

In 2012, Karimi et al. identified 'the absence of comprehensive climate policies that would place a significant market value on avoided emissions' as the main barrier for wide diffusion and implementation of CCS technologies. Nearly a decade later, the lack of a market and the high price levels on CCS technologies continues to be the largest barrier. The CEO of Gassnova recently stated that it is 'too cheap to emit CO_2' in a TV special on CCS on the national broadcaster NRK. As such, there is no first-mover advantage for companies to invest in CCS and CCU technologies (Interview 18). It has been suggested that the only viable option for full-scale CCS (including capture, transport and storage) is a large public investment in a full-scale project, such as the Northern Lights project, funded by the central government budget (Interview 18). On 21 September, the Norwegian government launched its plans for CCS in Norway, entitled 'Longship'. The plan includes the government contributing with NOK 16.8 billion (approx. USD 1.7 billion) of the total NOK 25.1 billion needed (including 10 years' operating costs). This covers the costs for the full implementation of carbon capture at Norcem, the Northern Lights project, and partial funding for carbon capture at Fortum Varme (provided that they can secure sufficient own financing)[27]. The funding for 'Longship' enables the development of a full-scale CCS value chain, an important step in reaching a 50-55% reduction in domestic emissions by 2030.

7.5.3 Digitalization and the transformation in the process industry

7.5.3.1 Pressures and opportunities

Implementation of digital technologies is not a new phenomenon in the process industry. In the last decades, the industry has been increasingly digitalized and automated with the implementation of remote supervision of production processes and robots (Interview 19, 21). However, in recent years there has been an increased attention towards digitalization and automation of production processes, which is expected to challenge the knowledge and competence of those working in the industry (Norsk Industri, 2016b). The process industry is currently not at the forefront in terms of implementing advanced production technologies in existing production plants (Interview 14). 53 % of Norwegian industry (including process industry) report that their production has a low degree of digitalization and automation (MTIF, 2017). One reason is the cost of production equipment. The costs of replacing existing production technology with new, more automated technology is too high, thus making it less profitable and not a viable option (Interview 14). Secondly, the number of operators in production is rather low in the process industry, thus the direct cost of labor wages is relatively low, making automation of production processes less necessary in terms of remaining competitive (Interview 16). Another factor that plays into the degree of automation/digitalization of production is safety. Some companies are hesitant in terms of implementing new technologies and do not want to be first movers (Interview 19). Rather, they will invest in new technologies when they have been proven to work in full-scale production sites, within the set safety requirements (Interview 19). Although informants have described the degree of digitalization within the industry as low, which of course differs within the industry, there has been an increased use of digital technologies, particularly related to the control and supervision of processes. One such example is Borregaard, where production in all of their production lines at their HQ facilities are

[27] https://www.regjeringen.no/en/aktuelt/the-government-launches-longship-for-carbon-capture-and-storage-in-norway/id2765288/

supervised and controlled from one control room. This has resulted in a decrease in numbers of operators working on the factory floor and a less physically demanding work situation for operators (Interview 19).

7.5.3.2 Digital transformation along the value chain

The integration of value chains is regarded as a potential future business model for Norwegian processing firms. Furthermore, a recent report from P21 underlines the importance for Norwegian processing companies to develop new business models, drawing on the digital transformation that is takin place, in order to avoid 'the commodity trap' (i.e. producing high shares of standardized commodity products 'that customers perceive to be identical regardless of suppliers') (Prosess 21, 2020). Yara, a fertilizer producer, has recently taken advantage of digital technologies to offer digital services, in addition to its core product, to customers. In 2018, Yara introduced the *Atfarm* software, which utilizes satellite imagery to optimize the use of nitrogen and fertilizer. In 2019, the company introduced the *YaraIrix* app, which makes smartphones into nutrient sensors by connecting a *N-clip* (a nutrient sensor that clips on to the crop), resulting in detailed information on the crop and optimizing fertilizer usage (YARA, 2020, Norsk Industri, 2016b). Yara has extended its product portfolio by providing services that are custom made to fit with their primary product. The integration of products and services is something that Hydro considers as an important future business opportunity that can be facilitated by digital technologies. Potential services could be tracking of materials, quality control and predictive maintenance (Interview 16). The ability to trace material could also lead to increased recycling and reuse of materials such as aluminum, thus contributing to a circular economy (Interview 15, 16, 17).

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Appendix: Interviews

Table 6 Semi-structured interviews (O&G = oil and gas, MA=maritime, AQ=aquaculture, PR=process industry, MN=manufacturing industry)

	Organization type	Respondent	Sector
1	Research organization 1	Professor	O&G
2	Research organization 2	Two senior researchers	O&G
3	Cluster organization 1	Project manager	O&G
4	Cluster organization 2	CEO	O&G, MA, AQ
5	Classification and standardization organization 1	Director & Regional Manager	O&G
6	Industry interest organization 1	Advisor	O&G
7	Cluster organization 3	CEO	MA, O&G
8	Classification and standardization organization 1	CEO	O&G

9	Classification and standardization organization 1	Environmental consultant	MA
10	Supplier company 1	VP and Assistant Manager	AQ, O&G
11	Supplier company 2	Business development manager & Director	O&G, MA
12	Supplier company 3	Manager	O&G
13	Supplier company 4	Two VPs	MA, O&G
14	Cluster organization 4	Manager	PR
15	Cluster organization 5	CEO	PR
16	Process industry company 1,	CTO	PR
17	Trade union 1	Secretary	PR
18	Industry interest organization 2	Manager	PR
19	Process industry company 2	CTO	PR
20	Cluster organization 6	CEO	PR
21	Process industry company 3	Technology director	PR
22	Industry interest organization 3	Director	MANUF
23	Industry interest organization 4	Director	MANUF
24	Cluster organization 7	Chairman	MANUF
25	Cluster organization 8	RD&I Manager/EU Advisor & Project Manager	MANUF
26	Industry interest organization 5	Chief advisor	MANUF
27	Research organization 3	Research Manager	MA
28	Supplier company 5	Chief technology officer	AQ
29	Cluster organization 9	Senior advisor	AQ
30	Industry interest organization 6	Director aquaculture	AQ
31	Public authority 1	Head of section	AQ
32	Cluster organization 10	General manager	AQ
33	Cluster organization 11	Innovation manager	AQ
34	Supplier company 6	Chief technology officer	AQ
35	Aquaculture company 1	R&D manager	AQ
36	Supplier company 7	General manager	AQ
37	Supplier company 8	Senior advisor	AQ

In addition to these interviews, approx. 20 shorter interviews were conducted in May and June 2020 to assess the impacts of the COVID-19 pandemic.

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