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The co-evolution of innovation systems and context: Offshore wind in Norway and the Netherlands

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A B S T R A C T

This paper investigates the co-evolution of industry formation, innovation systems and context over time through an analysis of offshore wind in the Netherlands and Norway. We compare these two countries because of their historically weak domestic offshore wind markets, long legacies in the oil and gas (O&G) and maritime industries and active participation in the growing offshore wind market. Our analysis is informed by the technological innovation systems framework and context conditions and we derive our results from nearly 60 interviews with key stakeholders in both countries. Our results point to three main empirical findings: 1) The Netherlands focused much more on explicit innovation system building strategies than Norway; 2) O&G is a critical sectoral and political context condition with a profound impact on offshore wind in both countries: in Norway, O&G price shocks led to fluctuating offshore wind participation; in the Netherlands, offshore O&G has been on a decline since the early 2000s, leading to a constant pressure to diversify. 3) The Netherlands had closer industrial proximity alignment than Norway, leading to stronger innovation system emergence and industrial participation. We highlight three theoretical contributions: 1) Certain context conditions – in our case O&G sectoral and political contexts – play a stronger role than others in influencing TIS emergence; 2) Context conditions strongly overlap. The political and sectoral O&G context is intimately linked; 3) Contexts are not static. As context conditions evolve overtime, so do their effects on the innovation system.

1. Introduction

Over the past thirty years, offshore wind power has turned from an immature niche into a large industry and market with the ambition to facilitate the energy transition in coastal countries away from fossil fuel energy sources towards renewable energy. As the ocean offers almost limitless opportunities for strong and constant renewable energy whilst avoiding space limitations and NIMBY problems associated with visual pollution, offshore wind holds extraordinary potential. Offshore wind in Europe already covers the electricity needs of over 50 million individuals through the deployment of more than 25 GW of installed capacity; nearly 200 GW are forecast around the globe by 2030 [1,2]. Companies, mostly European, are hence flocking to this market and offering their skills, assets and competencies, resulting in an extraordinary job engine with a forecast expenditure of nearly 200 billion Euros from 2020 to 2024 alone [2,3].

However, the successful emergence of a new technology, such as offshore wind, depends on developing strong innovation systems, and thus markets and industries, but this is neither automatic nor easy. The rise of a new technology depends not only on the formation of the technological innovation system in itself, but also on the interplay with unique context conditions that evolve over time. Context conditions are critical in understanding technological innovation system (TIS) development, which are embedded in countries' histories, capabilities, institutional conditions and cultural background [4–6]. In this framework, we study the development of technological innovation systems and how context has affected innovation system development. Few studies thus far have taken an in-depth look into the role of context on the development of a given technological innovation system over time [7,8] and none, to our knowledge, has done so as a comparative study between countries.

The Netherlands and Norway provide for a unique and pertinent comparison. They share a number of similarities, including their geographic location in the North Sea, a long history in the oil and gas and maritime industries, a weak historical effort in developing a domestic offshore wind market and yet are active participants in the growing international market, which allows us to empirically compare the two cases [7,9]. While the Netherlands is now developing a strong

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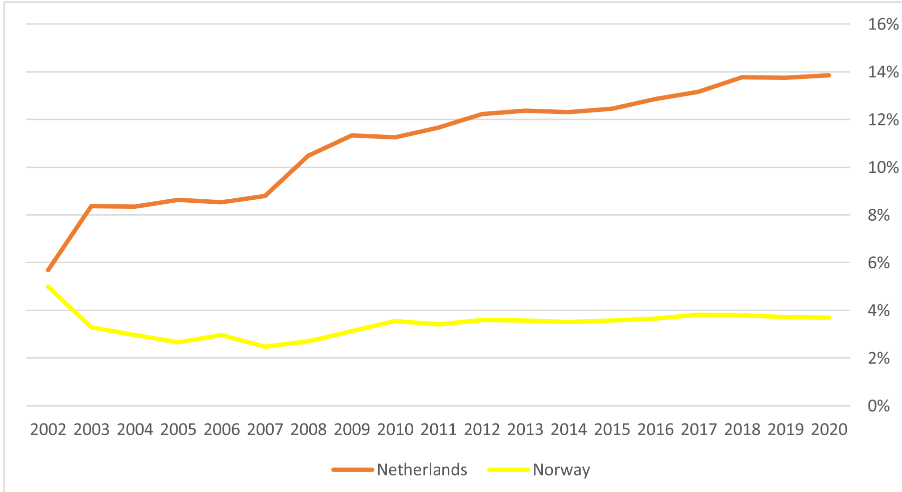

Chart 1. Share of Dutch and Norwegian stakeholder activity on non-domestic offshore windfarms [17].

domestic market, it was formerly exceptionally limited and fragmented [10]; Norway, for its part, has no domestic market. Despite a weak domestic market, both countries are active participants in the global offshore wind market [10–13]. Nonetheless, their performance is heterogenous, with the Netherlands emerging as a more successful industry leader than Norway over the past 30 years [14,15]. Therefore, despite similar starting points, these two countries pursued significantly divergent offshore wind pathways. Chart 1 shows how the Netherlands has grown from a 6% share of all non-domestic, European offshore wind activity in 2002 to 14% in 2020. Norway dropped from 5.9% of all activity on the first offshore wind farms to 3.9% by 2019.[1] Further, the Netherlands employs nearly 12,000 individuals in the offshore wind industry versus 2,277 in Norway, resulting in 70 people per 100,000 versus 42 per 100,000, respectively [3,16].

The relevance of this research hence speaks to the importance of the effect of context conditions on the emergence of technological innovation systems. By studying two countries with similar backgrounds, but divergent developments in a specific technological field, we can highlight not only key differences in the advent of the innovation system itself, but the role that unique context conditions have played on this development over time. Further, we understand that contexts are not static. As context conditions change overtime, so do their effects on the innovation system in question.

2. Theory

2.1. Technological innovation systems

The technological innovation systems (TIS) theory has evolved to become a popular framework to analyze the development and diffusion of novel technologies [18,19]. A TIS is defined as a network of actors and institutions engaging in the generation and diffusion of a technological artifact [18,19]. Actors are the key players in the innovation system, and can include private companies, government bodies, networking organizations and research groups. Institutions are the hard and soft rules that govern the technology, while networks are the dynamics that allow for the exchange of tacit and explicit knowledge and support interactions between actors. Infrastructure includes physical infrastructure – such as roads, power supply, ports and telecommunications – and knowledge infrastructure, such as the presence of technical universities. Via the introduction of the functional analysis in particular, the TIS approach contributes to a more dynamic perspective to analyze technological change [4]. TIS is typically composed of seven functions, or processes, that influence the generation and diffusion of a given technological artifact and are dependent on the actors, networks, institutions and infrastructure that make up its structure [4]. The seven functions are described in Table 1 below.

These functions are neither linear nor path dependent, but interact with each other in positive or negative feedback loops [4,18,20–22]. As such, feedback loops can perpetuate or break vicious cycles or virtuous circles.

Table 1
The seven TIS functions [4].

Function	Description
F1 Entrepreneurial activity	Private sector engagement in the industry, including incumbent diversification, startup activity and full-scale product demonstration
F2 Knowledge generation	Production of knowledge can occur at research institutes, such as polytechnic universities, independent research centers or within private companies in R&D departments. This is known as ‘knowledge by searching’. ‘Knowledge by doing, using and interacting’ occurs through knowledge gained whilst developing commercial projects.
F3 Knowledge diffusion	Knowledge diffusion is the exchange of knowledge and can occur between the varying actors that produce knowledge. It can be facilitated by networking organizations, R&D collaborations or on commercial project collaboration.
F4 Guidance of the search	Guidance of the search is the visions set forth by either the government in support of a new technology or from within the industry itself
F5 Market formation	Market formation is the concrete establishment of a new market, often mandated by the government in the initial phases of development and support by policy measures, subsidies, tax breaks, etc. Commercial market formation occurs once the technology has matured.
F6 Resource mobilization	Public resource mobilization dedicates financial and human resources towards supporting a new technology, such as through tax breaks, subsidies, funding research institutes, etc. Private resource mobilization occurs within companies that either invest in or diversify into a new technology. This can be either human or financial resources.
F7 Counteracting resistance to change/legitimacy	Legitimacy is the private, public and civil society acceptance of a new technology. Actors can either resist change or increase legitimacy for new technologies through the formation of networks or coalitions. Such coalitions may lobby for or against specific policies, or more generally place an issue on the political or public agenda.

(Hekkert et al., 2007).

[1] ‘Activity’ is measured by stakeholder contract entries, and does not indicate the value of the relative supply segments.

2.2. Technological innovation systems-in-context

The emergence of innovation systems does not occur in isolation. A technological innovation system (TIS) is embedded in a wider context that influences its development. In order to understand TIS development, the characteristics and interdependency with context structures in which TIS are embedded play an important role [6,8].

Bergek et al. (2015) distinguish four different context conditions – 1) sectoral; 2) geographical; 3) political; and 4) technological – that can influence the development of a TIS in different ways, whilst at the same time these structures can be influenced by developments in the TIS [6]. These context structures play a critical role in the emergence of an innovation system. "… Variation in context structures affects variations in TIS development, including different applications, designs, or pathways of a novel technology" (pg. 3.) [23]. However, the effects of diverse contexts on TIS dynamics and the emergence of innovation systems remain understudied [24].

The sectoral industrial context can harbor firms, assets and infrastructure that can be used in new industry formation [7,25,26]. A TIS can overlap with and be embedded in related sectors to varying degrees, for instance depending on the degree of technological relatedness, overlap of actors and the relative up- or downstream position of the sector to the TIS in question. Such overlaps may lead to competition over resources and attention, but may also lead to a transfer of resources where the TIS benefits from available resources and infrastructure in the pre-existing sector [27]. This occurs through firm diversification, triggered by decline or pressure on established sectors [28]. Indeed, the development of one industrial sector or technology co-evolves with – and is strongly influenced by – the development of other emerging or evolving sectors [29]. Sectoral contexts therefore shape the development of a TIS where such overlaps exist, yet the nature of such influence remains unpredictable [30]. This research attempts to elucidate some of the key factors affecting the co-evolution of TIS and industrial sectors.

Top-down innovation system builders, often governments, represent an important political context, for example by increasing environmental protection provisions. This may force companies to look for new markets or business opportunities. Moreover, governments may encourage investments in new industries by providing various investment incentives, R&D funding, market creation policies, or more generally by articulating long-term visions and expectations [31,32]. Naturally, this can work inversely through continued support for embedded institutions and structures, such as a pro-fossil fuel agenda. Thus, the focal TIS can also be understood to be embedded in a broader political system that may either constrain or enable the further development of the TIS [6]. Certain features of the political context can remain stable over time, but changes in public opinion [33] or changes in the composition of government [34] can alter the political feasibility of certain policies.

While technological innovation systems are international by definition and are set within a global innovation system, studies often focus on national determinants of system development, which highlights the important role that geographic context plays in influencing TIS emergence and development. TIS structures are embedded in political, economic, and social structures that are a historical result of alignment processes in a specific territory as well as natural context conditions [6]. Countries' institutional setups change very slowly and gradually, often exhibiting path dependent traits that explain the persistence of institutions [9,35]. These territory specific characteristics can provide favorable conditions for the development of certain industries and technologies and for the public support of certain markets [36]. A domestic market can feed back into the other TIS functions within a country and can thus help both the industry (technological generation) and market (diffusion) succeed [37,38]. Naturally, developments of a TIS in one country depend on TIS developments outside the country. Indeed, a study of offshore wind in the United Kingdom, Germany, Denmark and the Netherlands demonstrates that the four countries combined comprised a complete innovation system, whereas weak system functions were identified in each individual country [39]. Hence, international markets act as an additional geographic context condition when studying the national dynamics of a given TIS [6,40]. In addition to the role that domestic and global markets play on innovation system development, technologies – and particularly within certain value-chain segments of a technology – are also often strongly embedded in local and regional activities, hence creating and reinforcing elements of spatial stickiness [41,42].

Finally, the role of other existing or emerging technological innovation systems – known as 'TIS-TIS context' – can spur or clash with the TIS in question. Jointly building legitimacy for multiple renewable energy technologies may help foster confidence in the industries and even increase the availability of resources, such as subsidies. However, while such complementary relations can benefit the TIS, there can also be competition if two innovation systems are seen to be at odds with each other [43]. For example, developing a more expensive renewable energy technology may increase electricity prices, causing resistance from technologies that provide cheaper electricity. These multi-technology interactions are often embedded within an emerging technology, such as improving electrical transmission technology for renewable energy development [44]. While multi-technology interactions of emerging technologies can have a positive effect, the recombination and diversification of well-established technologies can also prove beneficial under the right conditions [26]. However, this is not a given as industrial transformations often face strong resistance from incumbent actors, hence requiring coordinated technology phase-out coupled with new industrial opportunities whilst capitalizing on existing technologies and incumbent resources [44,45].

Bergek et al. (2015) note that context conditions are not clearly delineated as they often overlap and interact with each other [6]. An important insight from studies of the political economy of sustainability transitions is that the nature of the relationship between the political context and new industry formation is also influenced by the industrial sectoral context [46,47]. The relations between established industries and governments are often characterized by a mutual dependency, which means that policies are developed to support historically important industries in a particular geographic context [48]. Indeed, previous literature has demonstrated the important sectoral and political influence of the oil and gas industry on the emergence of, and participation in, the offshore wind industry [7,27,49]. Hence, while we understand that all context conditions matter for the emergence of innovation systems, we propose that certain context conditions play a stronger role than others in the build out of new technological innovation systems. Further, we do not look at each context condition in isolation, but attempt to discern their interactions and co-evolution over time.

3. Methods

Our analysis aims to shed light on the key differences in the emergence of the offshore wind technological innovation system and the role and interplay of key context conditions in the Netherlands and Norway. We use the seven system functions, as described in the theory, to provide an analytical framework. We understand that functions do not perform in isolation, but 1) interact with each other in positive or negative feedback loops; and 2) are dependent on context conditions, such as competing industrial sectors and associated political contexts. We compare the emergence of the offshore wind innovation system in the two countries from 2002 to 2020.

Our research is informed primarily by semi-structured expert interviews with Dutch and Norwegian offshore wind companies, networking organizations and government officials. We conducted these interviews in-person or via digital communication platforms. Different company profiles illustrate different corporate challenges and strategies and highlight varying needs in the performance of the TIS. As such, we interviewed startups, recently established companies, large and small diversifying enterprises, networking organizations and government actors. In total, we conducted 56 semi-structured interviews in Norway and the Netherlands (25 and 31, respectively). Please see Appendix 1 for a list of interviews. We developed a standardized, cross-country interview guide to cover the seven TIS functions, the company or organization's historical engagement in offshore wind, market access strategies, barriers faced, the impact of policy on decision making, the effect of other industrial sectors – such as oil and gas – and the ability to apply existing skills and assets. Subsequently, we coded all interviews in NVIVO using a standardized set of labels to highlight the TIS functions and context conditions. All actors provided consent to record and transcribe the conversation and all quotes have been anonymized to ensure confidentiality. We substantiate and complement our interviews with key literature, including the 4C Offshore Wind database, official policy documents, research agendas and industry journals, such as Offshore WIND and Windpower Monthly.

4. Results

Our results point to a number of key differences in the emergence of the Norwegian and Dutch offshore wind innovation systems over the past two decades. We highlight prominent similarities and distinctions in the development of their respective innovation systems and evaluate the role of context in this evolution. Further, our results point to a high degree of relatedness – also known as proximity alignment – between existing competencies and the needs of the new industry and market [50].

4.1. 2000–2010: market formation phase overview

Following a period of small demonstration farms in the 1990s, the early 2000s began to see the rise of a European offshore wind market, albeit still heavily subsidized and politically supported. Ten small-scale demonstration farms were erected in the 1990s, led by Denmark, Sweden and the Netherlands. Denmark established the first commercial-scale farms in 2002 and 2003, followed by a rapidly emerging British market. The 1990s and early 2000s were also a period of strong growth in offshore oil and gas globally and in the Netherlands and Norway, both of whom have strongly embedded industries [7,51]. Previous research, official statements from both the government and industry and our interviews describe how the oil and gas industry represented an important sectoral context for the nascent offshore wind industry [2,27,30,39,52]. Since the 1970s, both countries promoted domestic offshore oil and gas production and hence developed expertise to provide services to the international offshore oil and gas services market [50,53]. However, since the 2000s, both global and domestic oil and gas dynamics have shifted. Notably, two oil price shocks in 2008 and 2014 rattled global markets and had a profound impact on the industries in these two countries [50].

4.1.1. Norway

Norway began to develop an offshore wind industry with a few firms starting up activity around 2005, indicating an initial impetus in entrepreneurial activity (F1) [54]. Common for these firms, such as Owec Tower and Norsk Hydro, was that they exploited existing competences from the offshore oil and gas industry [49]. The concepts developed by these firms were mostly focused on foundations. However, in 2005, seven energy companies founded the company Vestavind Kraft AS, thus creating another large actor in the Norwegian wind power industry, which led to the establishment of Vestavind Offshore in 2009. In this initial phase, several large oil and gas and electric energy companies, including Statoil, Statkraft, Shell and Lyse Energi, invested in offshore wind technology R&D projects in collaboration with the Norwegian Research Council (F2) [55].

Total Norwegian oil and gas production reached a peak in 2004, after which production declined significantly, although large parts of this decline were offset by increased gas production. Nonetheless, oil and gas remained a significant part of the Norwegian economy, with extraction alone (excluding oil and gas services) representing between 35 and 53% of total Norwegian exports since 2000 [56]. With these changes in the sectoral context, offshore wind gained further steam in 2007 and 2008 in Norway. First, Statoil – the Norwegian state-owned oil major – announced plans to construct the first floating offshore wind turbine in 2007. A number of other large firms, such as Bergen Group and Kværner, entered the offshore wind industry that year (F1). Second, the political context changed in 2007 as climate change rose on the public agenda and a more environmentally conscious Minister of Petroleum and Energy took office in late 2007 who set up an expert group named the Energy Council and was given the task to deliver a special report on the potential for offshore wind in Norway. The increased attention to climate change materialized in a cross-parliamentary agreement on climate policy, which proposed that policy should support both R&D and demonstration of offshore wind (F2, F4). The settlement led to the establishment of eight publicly financed Centers for Environment-friendly Energy Research in 2009. Two of these Centers, NORCOWE and NOWITECH, were dedicated to offshore wind (F2).

Between 2007 and 2009, two offshore wind networks (Arena NOW and Arena Mid-Norway) were also formed in and around Bergen and Trøndelag [57] (F3). The clusters were initially established by firms with competences from the petro-maritime industry. The clusters were later complemented by research organizations, and received so-called Arena status from Innovation Norway, part of the Norwegian innovation policy tool-kit.

The first wave of offshore wind initiatives reached its peak in 2009 and 2010, which was set off by the decline in demand for oil and gas services following the financial crisis and oil price crash in 2008 (F4). The decline led many firms to look for new business opportunities in other areas, and offshore wind fit well given the existing infrastructure, knowledge base and assets related to the oil and gas industry (F6) [7]. The increased interest in diversification from oil and gas to offshore wind was accompanied by articulated ambitions from policy-makers, including several Ministers of Petroleum and Energy [55,57] (F4). A new law for the production of offshore renewable energy was adopted by Parliament in 2009, and Vestavind Offshore acquired a license for the 350 MW domestic offshore wind project, Havsul (F4) [58]. The government also established the public-private organization INTPOW to help firms gain access to international offshore wind markets (F3) [59]. However, despite a large potential for offshore wind in Norway, there has been a limited incentive for the rapid expansion of new renewable energy production in Norway due to the vast hydropower resources that cover nearly all domestic electricity consumption at a relatively low cost [60,61]. Therefore, no market creation policies were implemented and the only turbine commissioned was Statoil's floating 2.3 MW Hywind turbine in 2009 (F1, F5). Many of the firms interviewed suggested that the lack of a domestic market represented a barrier for their entry into offshore wind. According to one small oil and gas supply company: "What has been the problem in Norway is that we have had no domestic offshore wind market. It is very difficult to enter a market that does not have a domestic market."

While there was no public support for a domestic market, several large firms linked up with the growing international markets. Statoil and Statkraft became joint owners to develop the Sheringham Shoal project in the United Kingdom, and several oil and gas suppliers were involved in the Alpha Ventus wind farm in Germany [59]. For many firms, motivation for entering offshore wind was linked to the decline in oil and gas in 2009. However, for others, the main reason for diversification was the growth in the international offshore wind market around 2010:

> The drive for us to move into offshore wind was first of all that in 2010 the offshore wind market really started to kick off. It was of course an interesting business because there are a lot of synergies. It's basically the same type of competences, the same experience, the same skill set required for designing an offshore structure. (Medium-sized diversified oil and gas company)

4.1.2. The Netherlands

Offshore wind in the Netherlands in the 2000s was a period full of great expectations, inconsistent and changing policy and political context, weak market subsidies, strong R&D support, the occasional new offshore wind farm and steadily declining offshore oil and gas production. Nonetheless, the innovation system began to develop, with certain functions performing better than others. In 2002, the government set expectations for 6000 MW of offshore wind by 2020 and established two parks to be built under the 'Round one scheme', with the 108 MW Egmond aan Zee (2006) receiving additional financial and political support as a larger-scale demonstration farm (F4, F5) [62–66]. Subsequently, the government changed the regulations and opened up a large area in the Dutch North Sea to be permitted for offshore wind, known as the 'Round two scheme' (F4) [65]. As such, many companies applied for offshore wind permits (F1). However, the tremendously high costs, altered and weak subsidy system, high burden of risk shouldered by companies and the "lack of an operational institutional structure … brought the Dutch offshore wind energy supply market to a complete standstill" [67] (pg. 2052 [32,65]. Political bickering, coalition changes, fluctuating support schemes and uncertain market prospects prevented any major breakthroughs in offshore wind development despite reiterations for 6000 MW to be installed by 2020 [68]. Therefore, no additional farms came to fruition under the Round two program until 2015.

However, while the Netherlands was reticent to invest in expensive home market formation, it did heavily promote R&D, networking and knowledge development (F2, F3). Established in 1999, Delft University's Wind Energy Research Institute (DUWIND) became a leading institute in generic and offshore wind specific technology [69]. In 2008, the Netherlands established the Far and Large Offshore Wind (FLOW) R&D and networking program as the first major, dedicated offshore wind knowledge development and networking organization to support the industry in the country [68,70]. At this time, Dutch companies continued to invest in skills and assets – such as purchasing vessels, acquiring new equipment and dedicating private R&D resources to offshore wind – to supply the growing international market (F6) [3]. Not only were Dutch companies well-poised to address the needs of the growing offshore wind industry, buoyed particularly by the Danish and then British markets, but there was also a sense of expectation in support of offshore wind to achieve the six GW target.

As offshore wind began to takeoff around Europe, domestic oil and gas production in the Netherlands also shifted. Offshore oil and gas began to decline in 2004 as wells became smaller and decommissioning costs rose, leading to a drop in new offshore explorations [53]. This was offset by newly discovered onshore gas fields in the Province of Groningen, which were heavily supported by the government and led to a massive increase in onshore gas production [66]. Subsequently, the 2008 economic recession and oil price crash further cemented offshore wind as a viable industry [51,71]. According to one Dutch oil and gas supplier, there was a strong technological relatedness between the sectoral context and the emerging offshore wind TIS:

> In recent years, offshore oil and gas has slowed down obviously with falling oil prices. But even before that, offshore wind was picking up. And as a way of diversifying into more areas than just primarily oil and gas related, we started to focus also on offshore wind. Because from our perspective, building complex equipment for offshore purposes is really the same technology as you use in offshore wind as you use in offshore oil and gas.

Indeed, many established large and small companies stated that the weakening oil and gas market in the Netherlands and globally around 2008 influenced their decision to diversify into offshore wind. Some companies anticipated the trend, while others were forced to diversify, and the increasing consistency of offshore wind projects around Europe fed confidence. The total number of Dutch stakeholder activities (contracts) nearly tripled to 610 between 2007 and 2010, thus increasing its total European market share to 13% in 2010 [17]. According to one established SME:

> We moved in actually at a time where we just saw synergies. Oil and gas was flourishing at the time. So, when we started with offshore wind we had a really good business in oil and gas. But we wanted to diversify a bit, and we saw an opportunity, and we saw that there were not that many players active, and we thought that 'Well, this is something we have the disciplines for.'

Further, these established diversifiers explicitly stated that the two Dutch projects in 2006 and 2008 played no role in their decision to diversify nor in their ability to access markets; that is to say that many companies first internationalized and leveraged their existing skills, assets and connections to establish their first offshore wind project and then re-shored their expertise once the Dutch market began to develop. For example, one large Dutch company stated:

> And at that time [*early Danish project*] when people were asking for a [*product*], there was actually only one company who had the ability to make [*the product*] that they needed. So, logically, from a technological search, they landed with [*our company*] as being most probably the only company able to come close to what they needed.

4.2. 2010-present: the take-off phase

Following 2010, the international offshore wind market matured significantly and numerous 400–500+ MW projects were developed annually, leading to a new phase of technological diffusion. The United Kingdom continued to lead the market with Germany entering the fray and overtaking Denmark as the second largest market. Belgium followed, building out 10 farms from 2010 to 2020. The Netherlands ramped up market diffusion after 2015 and took third place in 2020. Oil and gas, for its part, started to recover after the 2008 crash, with prices rising; however, in 2014, the industry witnessed another price shock, sending prices to below even 2008 levels. The repercussions were felt worldwide and particularly in Norway and the Netherlands.

4.2.1. Norway

At the beginning of the new decade, the Norwegian innovation system did not significantly support offshore wind beyond knowledge development and some experimentation. Several lobby initiatives therefore took place between 2010 and 2011 in an attempt to convince decision-makers to fund large-scale domestic projects (F7) [55,57]. First, the company behind the Havsul project, Vestavind Offshore, dedicated significant resources to lobby for public support to realize the full-scale wind park. Second, the main actors in the two research and industry networks in Bergen and Trøndelag lobbied the government for public support for a demonstration park called Demo 2020.

However, two major changes in the sectoral and political context occurred at the beginning of this period. First, a major petroleum reservoir was discovered that turned out to be the largest discovery on the Norwegian Continental Shelf in 30 years [72]. Second, a new Minister for Petroleum and Energy was appointed who was less enthusiastic about renewable energy and prioritized oil and gas [55]. Thus, signals to Norwegian suppliers were that there would once again be lucrative contracts to be gained in the domestic oil and gas industry (F4). Moreover, an estimated 140,000 people were directly or indirectly employed in the petroleum and petroleum related industries, representing 5% of the total workforce, thus making any industrial shifts extremely challenging [56]. In the end, neither of the offshore wind lobby initiatives was successful and Vestavind Offshore terminated its offshore wind initiative in December 2012 [55].

Oil peaked again in 2014, driving a demand for products and services in the petroleum industry (F4). During the same period, there was a noticeable reduction in engagement in offshore wind by Norwegian firms [49] (F1).

> It boomed in the oil sector, and the oil price was over one hundred, and with the small margins we have in offshore wind it was harder to argue for investing in product development for offshore wind. (Medium-sized oil and gas supply company)

Several firms also left the NORCOWE Research Centre. However, some firms did remain in offshore wind during this period, and others made strategic decisions to diversify from oil and gas to offshore wind even during this period of high demand in the oil and gas industry.

In 2015, a second wave of engagement in offshore wind began by Norwegian firms, following the oil price crash in 2014. Many firms that had previously not entered offshore wind made decisions or received their first contracts in this period. Whereas most firms had the engineering and technological capabilities to diversify into offshore wind, many firms lacked sufficient sales and marketing competences [15]. In response, many firms recruited human resources with experience from the renewable energy sector (F6). In this period, firms that had entered offshore wind at an earlier stage continued diversification activities.

In 2017, the state-run oil and gas company Equinor (formerly Statoil) opened the world's first floating offshore wind farm in Scotland, and increased its presence in other fixed-bottom markets [49]. For many firms, Equinor's presence in offshore wind represented an important mechanism for accessing the international offshore wind market: "It is an advantage for us that Equinor goes more and more internationally with offshore wind. Because then we have our biggest customers in the oil and gas bit here at home that we have been working with since the '90s. We have very good relations." (Medium-sized oil and gas supply company).

However, some firms highlighted the risks of overreliance on this one large company for market access. Moreover, about half of the interviewed firms argued that there was still a need for full-scale domestic projects. A reason for this is that some firms found it challenging to secure contracts without having previously demonstrated their products or services [13,15].

The oil price downturn in 2014 lasted for several years and kick-started a debate about the future demand for Norwegian oil and gas. Two government white papers published in 2017 pointed to this decreased demand as one of the most pressing concerns for the Norwegian economy and argued for increased attention towards diversification [73,74] (F4). With increased attention to climate change, the need to electrify other sectors in Norway and future decline in demand for oil and gas, offshore wind had once again risen on the political agenda. In 2016, parliament asked the government to provide a support scheme for the realization of a demonstration project for floating offshore wind no later than 2017 [75]. The political opposition later argued that this had not been followed up by the government, and it continued to argue throughout 2017 and 2018 for government funding for offshore wind demonstration projects (F7). However, there were still no concrete plans for developing a Norwegian demonstration farm or commercial market by the end of 2018 (F5).

Even though offshore wind was kept as a prioritized topic for energy related research and retained public investment, the NORCOWE and NOWITECH research centers on offshore wind ended their lifetime as publicly funded research centers in 2016. However, they have continued as formal research networks (F2). Moreover, R&D statistics for the period 2007 to 2016 show that, following the increase in renewable energy funding in 2009, both public and private R&D expenditure remained stable, whereas petroleum related R&D in the private sector grew significantly (F2) [76].

In 2019, the Ministry of Petroleum and Energy approved 2.3 billion NOK (roughly 230 million Euros) for Equinor's 88 MW Hywind Tampen floating offshore wind project. The motivation behind the funding, administered through the state agency Enova, was that it would contribute towards the commercialization of floating offshore wind and assist Equinor and Norwegian suppliers in their international ambitions whilst reducing carbon emissions from petroleum production [77].

In summary, many firms have now made a strategic long-term commitment to offshore wind because they believe that, even though there will be a market for oil and gas for some time, it makes strategic sense to be established in several markets. However, a lack of political commitment to support such a diversification strategy has dampened some firms' expectations for the future profitability of offshore wind:

> I think oil and gas has come back to lower level than before, but I still think it will be in this order of magnitude for 15–20 years. Offshore wind is very difficult to say, depending on what happens in Norway, but I don't think it will be that big as an export industry. (Medium-sized oil and gas supply company)

The political commitment to support a diversification strategy remains unclear. The Prime Minister stated as late as in November 2018 that the Government's *"main policy aim is to provide a framework for the profitable production of oil and gas in the long term"* [78]. Further, the Prime Minister has downplayed the Government's responsibility to develop an offshore wind industry in Norway, stating "it would have to be private actors that will have to make the decisions to invest" [79].

4.2.2. The Netherlands

The offshore wind innovation system continued to develop in the Netherlands, new expectations were formulated and offshore oil and gas continued its decline. Larger-scale projects were on the European horizon and the Dutch industry continued to perform very strongly, reaching 14% of stakeholder activity on all non-Dutch European farms by 2018 (F1). However, the domestic market still struggled to take-off in the early 2010s. The conservative government that took power in 2010 altered the subsidy system and forced offshore wind to compete with other, cheaper renewable energy technologies [68]. Therefore, due to the extraordinary costs, high risk and long lead-time for offshore wind projects, only the relatively small Eneco Luchterduinen (129 MW) and the nearshore Westermeerwind (144 MW) came online by 2015, at a time when Germany and the United Kingdom were commissioning 500+ MW projects annually (F5). In 2013, the new Dutch Energy Accord was published following the formation of a new center right-center left coalition in 2012, which set sights on a significant domestic market for offshore wind in the near future to be able to meet its new renewable energy commitment of 16% by 2020 (although quickly set back to 14%); offshore wind was a means to address the space constraints of onshore wind and solar and the government committed dedicated funds for offshore wind, thus decoupling it from the traditional renewable energy subsidy system (F4 F6) [68,80–82].

Despite a slow start for the Dutch market in the early 2010s, The Netherlands began to invest further in helping the offshore wind innovation system emerge. Significant government resources were allocated to develop business networking and lobbying organizations and R&D funding [68,83]. For example, in 2010, the Northern Netherlands Offshore Wind association was established with the objective of "supporting the ambitions of the business world in Northern Netherlands that is or plans to be active in the offshore wind industry by joining forces as businesses, knowledge institutes and government bodies" [84]. In 2013, the Buccaneer Delft incubator and startup accelerator, which is explicitly focused on offshore energy (and hence largely offshore wind), was founded (F2) [85]. In 2015, the FLOW R&D and networking organization was rebranded as GROW (Growth through Research, Development and Demonstration in Offshore Wind) and received a significant boost in funding to support innovation (F2, F3, F6) [70,86]. In 2015, DUWIND released its 2015–2020 R&D agenda, explicitly shifting towards offshore wind (F2) [87]. Despite a still relatively weak domestic market and shifting policies for offshore wind from 2010 to 2015, it is clear that the offshore wind innovation system was developing, along with massive private investments in new vessels, personnel and R&D. [88] (F6).

At this time, the domestic offshore oil and gas market continued to decline in the Netherlands, and a second, even larger oil price crash hit global markets in 2014; many of the traditional oil and gas firms therefore continued to diversify and solidify their presence in offshore wind [53]. According to one Dutch oil and gas incumbent:

> I know that a lot of companies are now in offshore wind. In the good oil and gas time, [*they weren't*] looking at wind. There is no oil and gas at the moment. There is completely nothing. All the jack-ups were lying beside the quay because there was no work. We already missed for two years oil and gas. It's a very difficult world for oil and gas. Nobody wants to invest any more.

Following 2015, a significant step was made to complete the missing links in the Dutch innovation system. This included the commissioning of the world's largest offshore wind farm at the time, the 600 MW Gemini park in 2017 (F5) and The *Roadmap to 2020* (published in 2015), concretely set its sights on 4.5 GW of offshore wind by 2023 (F4, F5) [10]. To achieve these targets, the Dutch government reformulated the permitting system for the third time, shifting to a government-administered tendering system, thus making it simpler, easier and clearer for developers to construct offshore wind farms (F4, F5, F7) [10]. The government agreed to determine the locations for new offshore wind farms, guarantee permits and subsequently tender bids to potential developers. In addition, the government still arranges all preliminary work, including conducting wind resource assessments and geological surveying. Finally, it took responsibility for grid connectivity, including the offshore substation, thus dramatically reducing the costs and risks for offshore wind developers [10]. At this time, new networking organizations were formed, such as the Port of Rotterdam Offshore Wind Coalition (2016) and the Offshore Wind Innovators (2017), which are designed to help companies, and especially startups, network and develop their products (F3) [89,90]. According to one business networking organization:

> We're trying to help startups and SMEs to bring their innovation quicker to the market by focusing on the business aspects, business challenges they have. Secondly, finding launching customers for your first product, which is the most difficult to do. And three, get the innovation visible and help them with marketing. Fourth is the peer-to-peer sessions. Entrepreneurs around the table from startups or SMEs. We talk about the business challenges they have around a theme we choose up front.

These organizations operate outside of domestic market formation and are tailored to industry formation, regardless of where the market is. The government also sponsored the 20 MW Borssele V demonstration zone, designed to promote innovation and help companies test out high technology-readiness-level products offshore and in real-world conditions (F1) [91]. Therefore, we see 2015 as a transformative year, in which the Netherlands began to complete its missing components of the innovation system. As a result, a new roadmap was formulated in 2018 that outlined an additional 7.5 GW of new installed capacity from 2023 to 2030, for a total of 11.5 GW [92].

5. Analysis

The Netherlands has become more successful in creating the conditions for the emergence of an offshore wind innovation system than Norway over the past two decades. Despite a historically weak domestic market, Dutch companies forged ahead in the European market. Norway, for its part, has had a more erratic industrial participation record with different periods of increasing and declining interest. We highlight a number of key differences in the emergence of the innovation systems and the context conditions that played a role in the evolution of offshore wind. Further, industrial proximity appears to play a strong role for the growth of many companies in offshore wind, with both Dutch and Norwegian companies relying on existing competencies to participate in these new markets. However, many Dutch companies were better aligned with the growing international offshore wind market than their Norwegian counterparts, thus allowing them a greater share of access, which fed back into the emergence of the innovation system. We discuss these elements in the sections below.

5.1. Innovation system conditions

In a first instance, we can highlight a number of key differences in the emergence of the innovation systems in the two countries. First, due to a need to increase the share of renewable energy in the energy mix, the Netherlands set high expectations for offshore wind at a very early stage. Without inducing the space constraints of onshore wind or large-scale solar photovoltaic, offshore wind was seen as a key Dutch solution. Indeed, it sponsored two demonstration farms in the 1990s (Irene Vorrink and Lely), and in 2002, the government announced a vision for six GW of installed capacity by 2020 [66,93]. While the Netherlands failed to achieve its targets, there were high expectations for offshore wind. Norway's electrical system was already decarbonized through a high utilization of cheap hydroelectric power [60]. Visions for an offshore wind market were seen as a means to buffer the existing system and provide a space for Norwegian companies to gain offshore wind experience.

Second, the Dutch established explicit and dedicated offshore wind networking organizations, such as the Offshore Wind Innovators and the innovation cluster TKI Offshore Wind, amongst others; they are designed for and tailored to the Dutch offshore wind industry to help develop and export products and services and only minimally focused on market formation. Further, the government offers hundreds of millions of Euros in R&D funding dedicated to the offshore wind industry, which is administered through research networks (FLOW/GROW) or research institutes (DUWIND), resulting in a number of successful spinoffs, such as the world-leading motion-compensated gangway company, Ampelmann.

In Norway, while a number of research networks linked to offshore wind have been established since the industry started to develop in the early 2000s, the purpose and impact of these networks have varied significantly. The first networks were set up to facilitate cluster activity and to act as a hub for local firms. While these networks facilitated knowledge exchange and collaboration, they were explicitly not set up to engage in any form of lobbying [57]. The publicly funded research centers, NORCOWE and NOWITECH, have acted as important research hubs to facilitate not only knowledge production, but also knowledge exchange. However, their primary mission is "pre-competitive research laying a foundation for industrial value creation and cost-effective offshore wind farms", (supporting low technology readiness level knowledge development), similar to Dutch R&D strategies [94,95]. NORWEP, for its part, is a third type of networking organization, which, besides focusing on the oil and gas industry, also helps facilitate meeting-points between Norwegian offshore wind suppliers and international customers and coordinates offshore wind related events. However, none of the networks is dedicated exclusively to lobbying for improved offshore wind policies, contrary to the Netherlands.

5.2. The sectoral and political context

We observe that contexts have a strong influence on the innovation systems in the two countries. In both cases, the oil and gas industry represents a critical sectoral context, which is strongly intertwined with the political context. However, the oil and gas sectoral and political context evolved differently and thereby had diverging influences on the respective TIS over time. Despite a long history in oil and gas in both countries, they began to go their separate ways in the early 2000s. In 2004, Dutch offshore gas extraction began to decline while transitioning to the more lucrative and accessible Groningen onshore gas fields, spurred by strong political backing. Offshore extraction costs rose significantly due to fewer and smaller fields, leading to increased sectoral pressure that triggered diversification [96]. Indeed, many companies even started to diversify before this decline. Norway also witnessed a shock to the oil and gas industry in 2008 and many companies took an interest in offshore wind. As companies that were heavily involved in the oil and gas supply chain either predicted or felt economic stress, offshore wind offered a logical transition and diversification opportunity. However, offshore oil and gas rebounded in Norway, while it never fully recovered in the Netherlands despite globally increasing prices from 2010 to 2014. At this time, Norwegian suppliers continued to rely on domestic oil and gas as their main industry. In contrast to the Netherlands, the overlaps between oil and gas and offshore wind in Norway were characterized by competition over resources [27]. While there was certainly a spike in interest in offshore wind, the high investment levels in oil and gas on the Norwegian Continental Shelf between 2011 and 2014 meant that interest in offshore wind was relatively short lived. Indeed, we see greater political support exactly in this period in Norway, which then rapidly died off as oil and gas prices rebounded. The story holds true for the second, bigger oil price crash in 2014. In the Netherlands, the price crash only exacerbated the continued decline in the industry and domestic market.

Further, the sectoral oil and gas context played a strong role in the ability of industrial actors to diversify and enter the offshore wind market, particularly due to the high degree of relatedness between the two industries. The offshore wind industry is composed of a wide array of actors, including turbine and foundation manufacturers, installers, vessel suppliers, cable producers, developers, geological surveyors, consultants, owners and financial institutions, amongst others. As our results show, both Norwegian and Dutch suppliers were able to engage in the offshore wind industry, often by applying existing skills and assets garnered from the oil and gas or other related industries. However, the Dutch industry has been more successful in penetrating the offshore supply chain than the Norwegian industry. Chart 2 shows Dutch and Norwegian market penetration by each stakeholder type. It becomes immediately apparent that the Netherlands has taken a large share of numerous offshore wind segments, particularly vessels, foundation manufacturing and offshore wind installations. Dutch high-end vessels were, at the outset, surplus capacity from the offshore oil and gas sector. The decline of Dutch offshore oil and gas led to an oversupply of vessels, whereas, as our results show, the Norwegian offshore oil and gas sector rebounded.

While the Netherlands is historically a large manufacturer of steel tubulars (for monopiles and transition pieces), Norway, for its part, has more experience in jacket foundations. Steel tubulars were widely used in the Dutch offshore oil and gas industry, leading them to be primed to capitalize on the burgeoning international offshore wind market even before the Dutch market took off. Monopiles are a simpler and lower cost product suitable for shallower water depths, whereas jacket foundations are designed for deeper waters. Both countries actively promoted their respective foundation industries and invested in R&D. Nonetheless, a deliberate choice was made for monopiles to become the standard on three-quarters of all offshore wind projects due to their advantageous application in shallower waters and simplicity of manufacturing and installation.

In another example, the Dutch have a number of ports that are geographically and physically well-suited to the existing offshore wind market, such as the ports of Vlissingen and Eemshaven, which are located near Belgian and German waters [97,98]. The Netherlands proves to be a much more active and diverse participant than Norway, buoyed by vessels, installations and industrial manufacturing. Norway, while also a smaller country by population, does contribute to the vessels and installation segments and holds a unique position in the consulting sector.

Therefore, both Norway and the Netherlands have a number of competencies that serve them extremely well in the offshore wind market, which are typically derived from existing skill-sets, and further

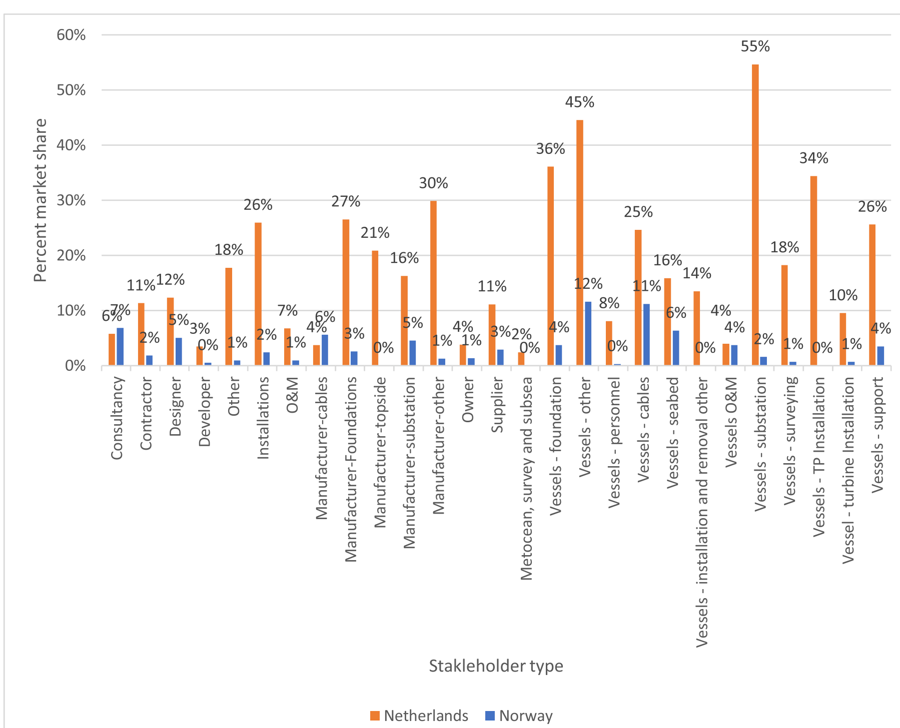

Chart 2. Dutch and Norwegian market penetration by stakeholder type on non-domestic European offshore wind farms [17].

indicates the importance of sectoral context conditions [39,49]. While both countries benefit from industrial proximity, the Netherlands has had greater success with proximity alignment than Norway.

Politically, oil and gas in Norway has remained high on the agenda and has persisted as a cornerstone of the Norwegian economy, demonstrating that the oil and gas price shocks were more anomalies than part of a steady downward trend. Hence, political, financial and industry attention largely remained oriented towards oil and gas rather than offshore wind. Indeed, even the proposed 88 MW Hywind Tampen floating offshore wind project in Norway (commissioning in 2022) will partly electrify oil and gas platforms in the Norwegian North Sea. Thus, while both countries are active in domestic and international oil and gas, it is historically and currently more embedded in Norway than in the Netherlands [50,53,71,99]. Consequently, reactions to the most recent decline in demand for oil and gas differed in the two countries. In Norway, the political context favored efforts to sustain oil and gas activity in response to this decline. Moreover, in periods with higher oil prices, the political interest for supporting diversification from oil and gas in Norway was weak. This stands in contrast to the Netherlands, in which the political context, including the diminishing importance of oil and gas, has favored a strategic, albeit it bumpy, long-term diversification strategy. Companies in the Netherlands were therefore more inclined to diversify and pursue new market opportunities. Companies in Norway, on the other hand, did not have the industrial or political confidence, nor incentives, to maintain a diversification strategy [50]. We therefore see that resource flows, leveraged via firm diversification from established sectors to the TIS, differ for the two countries.

5.3. Geographic and TIS-TIS context

While offshore oil and gas clearly played the strongest political and sectoral context role, we also see the relevance of the geographic and TIS-TIS contexts. Geographic proximity to international markets has buoyed the Dutch technological innovation system, as a country already highly integrated and physically close to other European nations. Port infrastructure has brought Dutch competences and ease of access for the manufacturing industry to offshore wind around Europe. Further, as mentioned, the international geographic conditions of the emerging international offshore wind market share similarities to Dutch geographic conditions – specifically a shallow and sandy seabed – thus supporting Dutch innovation system development prior to the emergence of a domestic market.

In regards to TIS-TIS context, we can note the importance of the strong and mature Norwegian hydroelectric innovation system, which already provides relatively cheap and decarbonized electricity for nearly 100% of electricity consumption, including the energy intensive aluminum production industry. This has ensured that offshore wind stayed lower on the political agenda due to fears that electricity costs would rise. In the Netherlands, the natural gas power industry, and particularly the onshore gas industry, maintained cheap electricity prices and stable power production for many years. However, the need for an energy transition as stipulated by the Paris Accord and European law, as well as earthquakes caused by onshore gas extraction, forced the Netherlands to begin to diversify its electricity production. Limited land space also restricted, and continues to restrict, large-scale onshore wind and solar power plants. Therefore, Norway has a competitive relation to an existing technology, while a more complementary relation evolved in the Netherlands. These country specific characteristics also illustrate how the different geographical contexts shaped the different TIS-TIS relations and different political contexts in the two cases. Table 2 summarizes the key context conditions and their influence on the development of the offshore wind innovation system in Norway and the Netherlands.

Table 2
Summary of key context conditions and their influence on the development of the offshore wind innovation system.

	Political	Sectoral	TIS-TIS	Geographical
Norway	• Fluctuating political interest in offshore wind (−) • O&G high on the political agenda (−) • Existing decarbonized electricity (−)	• Offshore oil and gas competencies (+) • Rebound in oil and gas prices (−) • Maritime expertise (+) • Industrial proximity (+)	• Cheap hydroelectric power (−)	• Natural conditions favorable for hydropower (−) • Rich offshore wind resources, but deep waters (±) • Geographic proximity (±)
Netherlands	• Offshore O&G political agenda (+) • Political support for energy transition (+)	• Offshore O&G decline (+) • Maritime expertise (+) • Industrial proximity (+)	• Onshore gas extraction and power production <2014 (−) • Onshore gas extraction >2014 (+)	• Limited land area (+) • Rich offshore wind resources and shallow seabed (+) • Geographic proximity to market (+)

N.B. + indicates positive influence on offshore wind innovation system; – indicates negative; +/− indicates both positive and negative influence.

6. Discussion

The image we derive of the Dutch versus Norwegian offshore wind technological innovation systems is one of differences in targeted system development, a differing interplay of the oil and gas political and sectoral context and distinctions in industrial proximity alignments. We observe that divergent development trajectories in oil and gas have strongly influenced the development of offshore wind in both countries. Hence, the sectoral and political context weighs heavily on these two countries and their respective efforts to diversify and internationalize even while both failed to establish a strong, steady and consistent domestic offshore wind market. While the TIS in both countries are populated by incumbents from related industrial sectors and both have strong basic R&D institutes and (previously) weak market formation policies, the Netherlands was able to more effectively foster a successful offshore wind innovation system.

Our analysis contributes to a more nuanced understanding of the co-evolution of TIS and context, which underscores the critical relevance of understanding the role context plays on the emergence of innovation systems. By tracing and comparing the offshore wind innovation system pathways of two countries with relatively similar starting points, we highlight how context has left a distinctive mark over the past two decades. More specifically, we are also able to distinguish the relative importance of certain context conditions over others. In our case, the oil and gas sectoral and political context conditions have played the largest role on the emergence of the offshore wind innovation system. We see that the same contexts are important in both countries, but that the way in which they evolve and are intertwined differs, and thereby shape differing TIS dynamics.

Notably, and as Bergek et al. (2015) suggest, we demonstrate that many of these context condition boundaries are blurred and strongly overlap [6]. This is most apparent in the interaction between the sectoral and political context in our study. Differing political decisions were made and signals sent to the oil and gas industry over two decades of price fluctuations, establishing grounds for optimism and pessimism. In turn, this suggests that the mutual dependency between established industries and governments evolved differently with different influence on offshore wind innovation system formation.

Finally, we observe that context conditions are not static, which is particularly apparent in the oil and gas context in both countries. Oil and gas price shocks in one country were more anomalies to the norm, whereas in another, they exacerbated a trend. Hence, context, and its effect on TIS, change over time. A key lesson for TIS analysts is therefore to be mindful of the role and effect of the evolution of context conditions.

7. Conclusion

Through a comparative analysis of the emergence of the offshore wind innovation systems in two countries, it becomes possible to draw more general conclusions for countries interested in developing or entering new markets, but are perhaps reticent to invest in expensive home market formation while the technology is still in the development phase. In addition to focusing on the emergence of innovation systems, it is essential to understand, recognize and target fundamental contextual considerations. Sectoral, political, geographic and technological contexts all strongly influence and are influenced by the emergence of an innovation system. However, different countries and innovation systems will be affected in varying ways by different contexts and contexts will interact with each other in different ways. In our case, the sectoral and political contexts played the strongest role in influencing offshore wind development. However, this may not be the case for all technologies in all countries. Therefore, it becomes important to hone in on the most influential context considerations based on the emerging innovation system within a given country's history, embedded institutions, culture and knowledge base. If countries are interested in engaging in new markets, they need to not only focus on the innovation system in isolation, but also to work with and influence the underlying context conditions.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix 1. List of interviews

Interviews in the Netherlands

Actor type	Date of interview	Interviewee's role
Established large enterprise	30.5.18	Head sale's manager
Established large enterprise	5.6.18	R&D manager
Established large enterprise	19.6.18	Commercial manager
Established large enterprise	9.7.18	Business development and acquisition manager for offshore
Established large enterprise	12.7.18	Head of business development
Established large enterprise	5.12.18	Head of offshore wind business unit
Established large enterprise	11.12.18	Business developer
Established large enterprise	27.3.19	Chief commercial officer
Established large enterprise	27.5.19	Former CEO
Established SME	29.6.18	Business manager
Established SME	18.7.18	Manager of renewables
Established SME	25.7.18	Commercial general manager of wind
Established SME	15.11.18	Managing director
Young SME	16.7.18	CEO & founder
Young SME	19.7.18	CEO & founder
Young SME	24.7.18	Project leader
Young SME	23.11.18	Head of offshore wind business unit
Young SME	30.11.18	CEO
Young SME	27.3.19	Co-founder
Startup	16.7.18	General director
Startup	17.7.18	CEO & founder
Startup	26.7.18	CEO & founder
Startup	29.11.18	Head of technical development
Startup	6.12.18	Project developer
Networking organization	7.6.18	Coordinator
Networking organization	25.6.18	Manager/coordinator
Networking organization	20.12.18	Director
Networking organization	20.12.18	Former director
Government agency	24.6.19	Senior advisor
Government agency	4.9.19	Offshore wind project leader
Government agency	11.9.19	Senior advisor for offshore wind

Interviews in Norway

Actor type	Date of interview	Interviewee's role
Established large enterprise	23.10.18	Head of business development
Established large enterprise	08.05.18	Vice president
Established large enterprise	18.10.18	Commercial manager
Established large enterprise	16.10.18	VP renewables
Established large enterprise	13.9.18	Head of renewable energy
Established large enterprise	30.03.19	Chief Commercial Officer
Established large enterprise	04.09.18	Business developer
Subsidiary of large enterprise	25.10.18	Manager
SME	20.08.18	General manager
SME	17.10.18	Head of sales and marketing
SME	16.10.18	Department director
SME	06.09.18	General manager
SME	27.04.18	VP
SME	31.01.18	General manager
SME	26.10.18	Head of renewable energy
SME	24.08.18	Business director
SME	17.10.18	Manager
SME	30.08.18	CEO
SME	22.02.19	Chief Commercial Manager
SME	07.01.19	Head of sales and marketing
SME	22.08.18	General manager
SME	13.08.18	Research Director
SME	25.01.19	General manager
Young SME	07.05.19	Project manager
Young startup	28.08.18	Co-founder
Young startup	24.07.18	Co-founder
Industry association	21.01.19	Industry director
Industry association	01.04.19	Director
Industry association	04.05.18	Director
Lobby organization	17.12.18	Industry contact
Government enterprise	14.08.18	Director Strategy and Business Development

References

[1] 4C Offshore Ltd. Global market overview report – december 2018. Lowestoft; 2018.
[2] NORWEP. Annual global offshore wind market report 2020-2024. 2019. https://doi.org/10.3726/978-3-0351-0281-9/2. Oslo.
[3] Hollandse RVO. Kust. The Hague: Where Wind & Water Works; 2017.
[4] Hekkert MP, Suurs RAA, Negro SO, Kuhlmann S, Smits REHM. Functions of innovation systems: a new approach for analysing technological change. Technol Forecast Soc Change 2007;74:413–32. https://doi.org/10.1016/j.techfore.2006.03.002.
[5] Suurs RAA, Hekkert MP, Kieboom S, Smits REHM. Understanding the formative stage of technological innovation system development: the case of natural gas as an automotive fuel. Energy Pol 2010;38:419–31. https://doi.org/10.1016/j.enpol.2009.09.032.
[6] Bergek A, Hekkert MP, Jacobsson S, Markard J, Sandén BA, Truffer B. Technological innovation systems in contexts: conceptualizing contextual structures and interaction dynamics. Environ Innov Soc Transit 2015;16:51–64. https://doi.org/10.1016/j.eist.2015.07.003.
[7] Mäkitie T, Andersen AD, Hanson J, Normann HE, Thune TM. Established sectors expediting clean technology industries? The Norwegian oil and gas sector's influence on offshore wind power. J Clean Prod 2018;177:813–23. https://doi.org/10.1016/j.jclepro.2017.12.209.
[8] De Oliveira LGS, Negro SO. Contextual structures and interaction dynamics in the Brazilian biogas innovation system. Renew Sustain Energy Rev 2019;107:462–81. https://doi.org/10.1016/j.rser.2019.02.030.
[9] Wieczorek AJ, Hekkert MP, Coenen L, Harmsen R. Broadening the national focus in technological innovation system analysis: the case of offshore wind. Environ Innov Soc Transit 2015;14:128–48. https://doi.org/10.1016/j.eist.2014.09.001.
[10] RVO. Offshore wind energy in The Netherlands: the roadmap from 1,000 to 4,500 MW offshore wind capacity. 2015. Utrecht.
[11] 4C Offshore Ltd. Global market overview report – october 2018. Lowestoft; 2018. https://doi.org/10.1017/CBO9781107415324.004.
[12] EnergiNorge. Veikart for Grønn Konkurransekraft i norsk fornybarnaering mot 2050. 2017.
[13] Normann HE, Hanson J. The role of domestic markets in international technological innovation systems. Ind Innovat 2018;25:482–504. https://doi.org/10.1080/13662716.2017.1310651.
[14] 4C Offshore Ltd. 4COffshore windfarms database 2018.12.04. Lowestoft; 2018.
[15] Hanson J, Normann HE, Aspelund A, Steen M, Afewerki S, Bjørgum Ø, et al. Conditions for growth in the Norwegian offshore wind industry. International market developments, Norwegian firm characteristics and strategies, and policies for industry development. Oslo: Centre for sustainable energy studies (CenSES); 2019.
[16] Norge Eksportkreditt. Kartlegging av den norskbaserte fornybarnæringen. 2019. Oslo.
[17] 4C Offshore Ltd. 4COffshore windfarms database. 2019. 04.02 2019.
[18] Carlsson B, Stankiewicz R. On the nature, function and composition of technological systems. J Evol Econ 1991;1:93–118. https://doi.org/10.1007/BF01224915.
[19] Carlsson B, Jacobsson S, Holmén M, Rickne A. Innovation systems: analytical and methodological issues. Res Pol 2002;31:233–45. https://doi.org/10.1016/S0048-7333(01)00138-X.
[20] Bergek A, Jacobsson S, Carlsson B, Lindmark S, Rickne A. Analyzing the functional dynamics of technological innovation systems: a scheme of analysis. Res Pol 2008;37:407–29. https://doi.org/10.1016/j.respol.2007.12.003.
[21] Wieczorek AJ, Hekkert MP. Systemic instruments for systemic innovation problems: a framework for policy makers and innovation scholars. Sci Publ Pol 2012;39:74–87. https://doi.org/10.1093/scipol/scr008.
[22] Suurs RAA. Motors of Sustainable Innovation. Towards a theory on the dynamics of technological innovation systems. 2009. Utrecht.
[23] Markard J, Hekkert MP, Jacobsson S. The technological innovation systems framework: response to six criticisms. Environ Innov Soc Transit 2015;16:76–86. https://doi.org/10.1016/j.eist.2015.07.006.
[24] Köhler J, Raven R, Walrave B. Advancing the analysis of technological innovation systems dynamics: introduction to the special issue. Technol Forecast Soc Change 2020;158. https://doi.org/10.1016/j.techfore.2020.120040.
[25] Hanson J. Established industries as foundations for emerging technological innovation systems: the case of solar photovoltaics in Norway. Environ Innov Soc Transit 2017. https://doi.org/10.1016/j.eist.2017.06.001.
[26] Andersen AD, Gulbrandsen M. The innovation and industry dynamics of technology phase-out in sustainability transitions: insights from diversifying petroleum technology suppliers in Norway. Energy Res Soc Sci 2020;64:101447. https://doi.org/10.1016/j.erss.2020.101447.
[27] Hansen GH, Steen M. Offshore oil and gas firms' involvement in offshore wind: technological frames and undercurrents. Environ Innov Soc Transit 2015;17:1–14. https://doi.org/10.1016/j.eist.2015.05.001.
[28] Rogge KS, Johnstone P. Exploring the role of phase-out policies for low-carbon energy transitions: the case of the German Energiewende. Energy Res Soc Sci 2017;33:128–37. https://doi.org/10.1016/j.erss.2017.10.004.
[29] Frangenheim A, Trippl M, Chlebna C. Beyond the single path view: interpath dynamics in regional contexts. Econ Geogr 2020;96:31–51. https://doi.org/10.1080/00130095.2019.1685378.
[30] Steen M, Weaver T. Incumbents' diversification and cross-sectorial energy industry dynamics. Res Pol 2017;46:1071–86. https://doi.org/10.1016/j.respol.2017.04.001.
[31] Meadowcroft J. Engaging with the politics of sustainability transitions. Environ Innov Soc Transit 2011;1:70–5.

[32] Raven R, Kern F, Verhees B, Smith A. Niche construction and empowerment through socio-political work. A meta-analysis of six low-carbon technology cases. Environ Innov Soc Transit 2016;18:164–80. https://doi.org/10.1016/j.eist.2015.02.002.
[33] Burstein P, Linton A. The impact of political parties, interest groups, and social movement organizations on public policy: some recent evidence and theoretical concerns. Soc Forces 2002;81:380–408. https://doi.org/10.1353/sof.2003.0004.
[34] Daugbjerg C, Marsh D. Explaining policy outcomes: integrating the policy network approach with macro-level and micro-level analysis. In: Marsh D, editor. Comp. Policy networks. Buckingham: Open University Press; 1998. p. 52–71.
[35] Carlsson B. Internationalization of innovation systems: a survey of the literature. Res Pol 2006;35:56–67. https://doi.org/10.1016/j.respol.2005.08.003.
[36] Coenen L, Benneworth P, Truffer B. Toward a spatial perspective on sustainability transitions. Res Pol 2012;41:968–79. https://doi.org/10.1016/j.respol.2012.02.014.
[37] Lundvall BÅ, Johnson B, Andersen ES, Dalum B. National systems of production, innovation and competence building. Res Pol 2002;31:213–31. https://doi.org/0048-7333/02/$ –.
[38] Huenteler J, Schmidt TS, Ossenbrink J, Hoffmann VH. Technology life-cycles in the energy sector - technological characteristics and the role of deployment for innovation. Technol Forecast Soc Change 2016;104:102–21. https://doi.org/10.1016/j.techfore.2015.09.022.
[39] Wieczorek AJ, Negro SO, Harmsen R, Heimeriks G, Luo L, Hekkert MP. A review of the European offshore wind innovation system. Renew Sustain Energy Rev 2013;26:294–306. https://doi.org/10.1016/j.rser.2013.05.045.
[40] Van der Loos HZA, Negro SO, Hekkert MP. International markets and technological innovation systems: the case of offshore wind. Environ Innov Soc Transit 2020;34:121–38. https://doi.org/10.1016/j.eist.2019.12.006.
[41] Rohe S. The regional facet of a global innovation system: exploring the spatiality of resource formation in the value chain for onshore wind energy. Environ Innov Soc Transit 2020. https://doi.org/10.1016/j.eist.2020.02.002.
[42] Binz C, Truffer B. Global Innovation Systems—a conceptual framework for innovation dynamics in transnational contexts. Res Pol 2017;46:1284–98. https://doi.org/10.1016/j.respol.2017.05.012.
[43] Markard J, Hoffmann VH. Analysis of complementarities: framework and examples from the energy transition. Technol Forecast Soc Change 2016;111:63–75. https://doi.org/10.1016/j.techfore.2016.06.008.
[44] Andersen AD, Markard J. Multi-technology interaction in socio-technical transitions: how recent dynamics in HVDC technology can inform transition theories. Technol Forecast Soc Change 2020;151:119802. https://doi.org/10.1016/j.techfore.2019.119802.
[45] Van der Loos HZA, Negro SO, Hekkert MP. Low-carbon lock-in? Exploring transformative innovation policy and offshore wind energy pathways in The Netherlands. Energy Res Soc Sci 2020;69. https://doi.org/10.1016/j.erss.2020.101640.
[46] Baker L, Newell P, Phillips J. The political economy of energy transitions: the case of South Africa. New Polit Econ 2014;19:791–818. https://doi.org/10.1080/13563467.2013.849674.
[47] Kern F, Markard J. Analysing energy transitions: combining insights from transition studies and international political economy. In: Van de Graaf T, Sovacool BK, Ghosh A, Kern F, Klare MT, editors. Palgrave handb. Int. Polit. Econ. Energy. London: Palgrave Macmillan UK; 2016. p. 291–318.
[48] Fagerberg J, Mowery DC, Verspagen B. The evolution of Norway's national innovation system. Sci Publ Pol 2009;36:431–44. https://doi.org/10.3152/030234209x460944.
[49] Mäkitie T, Normann HE, Thune TM, Sraml Gonzalez J. The green flings: Norwegian oil and gas industry's engagement in offshore wind power. Energy Pol 2019;127:269–79. https://doi.org/10.1016/j.enpol.2018.12.015.
[50] Ernst & Young. Dutch oilfield services analysis. 2018. 2019.
[51] Weijermars R, Luthi SM. Dutch natural gas strategy: historic perspective and challenges ahead. Neth J Geosci 2011;90:3–14. https://doi.org/10.1017/s0016774600000627.
[52] Poulsen T, Lema R. Is the supply chain ready for the green transformation? The case of offshore wind logistics. Renew Sustain Energy Rev 2017;73:758–71. https://doi.org/10.1016/j.rser.2017.01.181.
[53] ABN AMRO. The Dutch Oil & Gas Service Industry: bad times signal good times ahead?. 2018. https://doi.org/10.1016/0160-4120(91)90153-h.
[54] Normann HE, Hanson J. Exploiting global renewable energy growth: opportunities and challenges for internationalisation in the Norwegian offshore wind and solar energy industries. 2015. https://doi.org/10.13140/RG.2.1.3972.1041. Oslo.
[55] Normann HE. The role of politics in sustainable transitions: the rise and decline of offshore wind in Norway. Environ Innov Soc Transit 2015;15. https://doi.org/10.1016/j.eist.2014.11.002.
[56] Norwegian Petroleum. Employment in the petroleum industry. 2019.
[57] Normann HE. Policy networks in energy transitions: the cases of carbon capture and storage and offshore wind in Norway. Technol Forecast Soc Change 2017;118. https://doi.org/10.1016/j.techfore.2017.02.004.
[58] Sprenger M. Ja til Havsul I. Tek Ukebl 2009.
[59] Steen M, Hansen GH. Barriers to path creation: the case of offshore wind power in Norway. Econ Geogr 2018;94:188–210. https://doi.org/10.1080/00130095.2017.1416953.
[60] Hanson J, Kasa S, Wicken O. Politikk for den store transformasjonen [Policies for the great transformation]. In: Hanson J, Kasa S, Wicken O, editors. Energirikdommens Parad. Innovasjon som klimapolitikk og næringsutvikling. Oslo: Universitetsforlaget; 2011.
[61] Karstad P, Tomasgard A, Bachynski EE, Bjorgum O, Bolstad H, Granado P, et al. Havvind - en industriell mulighet. Trondheim; 2019.
[62] NoordzeeWind. Offshore Windpark Egmond aan Zee n.d. https://www.noordzeewind.nl/nl_nl/over/offshore-windpark-egmond-aan-zee.html (accessed September 24, 2019).
[63] Vattenfall. Egmond aan zee. 2019. https://powerplants.vattenfall.com/en/egmond-aan-zee#/. [Accessed 24 September 2019].
[64] Eecen PJ. Wind energy research in The Netherlands. In: Rao KR, editor. Energy power gener. Handb. Establ. Emerg. Technol. ASME Press; 2011.
[65] WWEA. World wind energy association - Netherlands country profile. 2018. Bonn.
[66] Ministry of Economic Affairs. Investeren in energie. Keuzes voor de toekomst. Energierapport 2002. 2002. The Hague.
[67] Agterbosch S, Vermeulen W, Glasbergen P. Implementation of wind energy in The Netherlands: the importance of the social-institutional setting. Energy Pol 2004;32:2049–66. https://doi.org/10.1016/S0301-4215(03)00180-0.
[68] Verhees B, Raven R, Kern F, Smith A. The role of policy in shielding, nurturing and enabling offshore wind in The Netherlands (1973-2013). Renew Sustain Energy Rev 2015;47:816–29. https://doi.org/10.1016/j.rser.2015.02.036.
[69] DUWIND. Offshore Wind Energy. Ready to power a sustainable Europe. 2001. Delft.
[70] FLOW. FLOW Competitive through cooperation. 2015. Utrecht.
[71] Ruoff M. The future of the Dutch offshore oil and gas infrastructure. 2016. Amsterdam.
[72] Norwegian Petroleum. Aktivitetsnivå på feltene. 2019.
[73] Meld. St. 29. Perspektivmeldingen 2017 [Long-term perspectives on the Norwegian economy 2017] n.d.
[74] Meld. St. 27. Industrien – grønnere, smartere og mer nyskapende [A greener, smarter and more innovative industry] n.d.
[75] Meld. St. 25. Kraft til endring: energipolitikken mot 2030 [Power for change: energy policy towards 2030] n.d.
[76] Norwegian Research Council. Indikatorrapporten 2018 - det norske forsknings- og innovasjonssystemet - statistikk og indikatorer. 2018.
[77] NTB. Equinor får 2,3 milliarder til havvindpark. NTBtekst. 2019.
[78] Solberg E. Prime minister Erna Solberg's speech at the equinor autumn conference in Oslo. 2018. 20 November 2018.
[79] Borchgrevink-Brækhus M. Vil ikke etablere eget statlig selskap for havvind. Sysla Grønn 2019.
[80] Rijksoverheid. Energy agreement for sustainable growth. 2013. The Hague.
[81] Social and Economic Council. The agreement on energy for sustainable growth. 2013. The Hague.
[82] Ministry of Economic Affairs and Climate. Energy Agenda. Towards a low-carbon supply chain. 2017. The Hague.
[83] TKI Wind op Zee. The Netherlands' long-term offshore wind R&D strategy. 2019. Utrecht.
[84] Northern Netherlands Offshore Wind. Background. 2018. https://www.nnow.nl/en/background/. [Accessed 11 November 2019].
[85] Delft B. About buccaneer Delft. 2019. https://buccaneerdelft.com/about-buccaneer-delft/. [Accessed 9 December 2019].
[86] GROW. Twenty for seven. Utrecht: Public Summary; 2016.
[87] DUWIND. TU Delft wind energy institue R&D programme. 2015. Delft.
[88] Kern F, Verhees B, Raven R, Smith A. Empowering sustainable niches: comparing UK and Dutch offshore wind developments. Technol Forecast Soc Change 2015;100:344–55. https://doi.org/10.1016/j.techfore.2015.08.004.
[89] Port of Rotterdam. Generating shared success. Rotterdam Offshore WInd Coalition. Rotterdam: n.d.
[90] Wind Innovators Offshore. Offshore wind Innovators challenge (OWIC) competition brief. 2018. Utrecht.
[91] Van Oord. Press release Consortium excited with winning tender for Borssele V. 2018. Rotterdam.
[92] Ministry of Economic Affairs and Climate. Offshore wind energy roadmap 2030. 2018. The Hague.
[93] Dismukes DE, Upton GB. Economies of scale, learning effects and offshore wind development costs. Renew Energy 2015;83:61–6. https://doi.org/10.1016/j.renene.2015.04.002.
[94] NOWITECH., NOWITECH. Highlights from 2015. Trondheim; 2015.
[95] SINTEF Energi. NOWITECH Norwegian research Centre for offshore wind technology. 2018. Trondheim.
[96] Geels FW, Penna CCR. Societal problems and industry reorientation: elaborating the Dialectic Issue LifeCycle (DILC) model and a case study of car safety in the USA (1900-1995). Res Pol 2015;44:67–82. https://doi.org/10.1016/j.respol.2014.09.006.
[97] RVO. Existing port and manufacturing infrastructure base. Utrecht: n.d.
[98] Seaports Groningen. Follow the energy. Eemshaven: hub in offshore wind logistics. Delzijl; 2018.
[99] Ryggvik H. A short history of the Norwegian oil industry: from protected national champions to internationally competitive multinationals. Bus Hist Rev 2015;89:3–41. https://doi.org/10.1017/S0007680515000045.