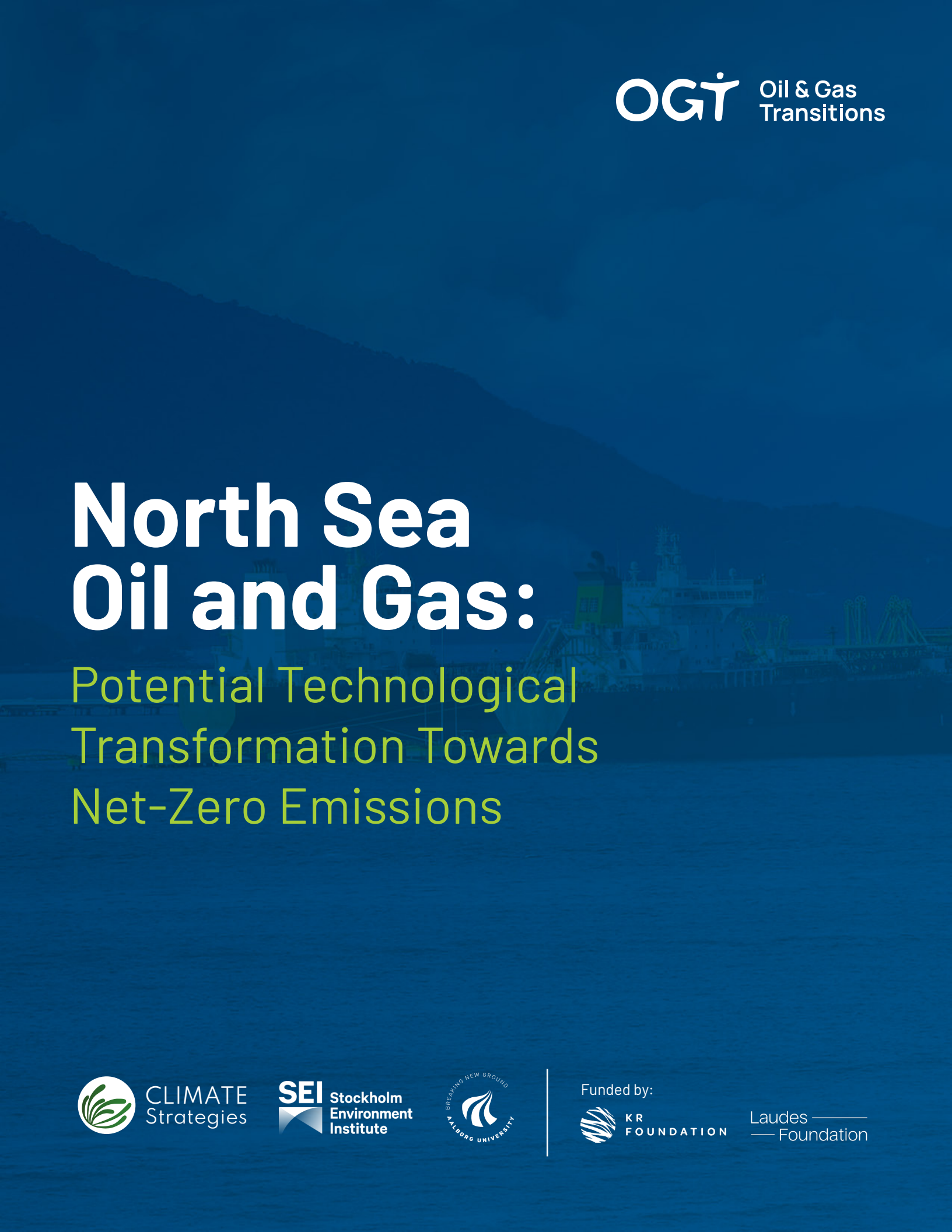

Oil & Gas Transitions

North Sea Oil and Gas:

Potential Technological Transformation Towards Net-Zero Emissions

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About this report

This report was written by Aalborg University as part of the Oil and Gas Transitions (OGT) programme, which is co-led by Climate Strategies (CS) and the Stockholm Environment Institute (SEI). OGT is an evidence-based programme which aims to generate evidence and co-produced pathways for policy action to accelerate oil and gas just transitions in the UK/Scotland, Denmark and Norway. The report aims to identify barriers and opportunities for the technological transition of the oil and gas sector in the North Sea, particularly in Denmark, by focusing on two case studies: 'carbon capture and storage in offshore oil and gas reservoirs' and 'offshore oil and gas platforms as energy island hubs'. The findings will serve as inputs for the co-production of just transition pathways and international blueprints for oil and gas transitions in upcoming stages of the programme. The statements herein do not directly represent the views of CS, SEI, the funders of the programme or other members of the OGT consortium.

For more information visit: www.oilandgastransitions.org.

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Executive Summary

Denmark, Norway and the United Kingdom have been extracting oil and gas from the North Sea since the 1970s. Historically this has had a major impact on their economy and on the welfare of their society. The innovation brought about by new technologies has been key for the success of producing oil and gas in the North Sea. But as the energy sector of the region enters a new era that involves gradually abandoning fossil fuels to meet the objectives of the Paris Agreement, offshore oil and gas' technological innovations face the critical juncture of determining whether they can be transferred to another industry. The just transition that has already been initiated in the North Sea requires phasing out oil and gas and large investments in the low-carbon economy. In such a context, the technology transition in the industry can become key.

This report aims to map the most important stakeholders and technologies involved in the North Sea offshore oil and gas industry. As the technological transition in the sector can take place in many forms and sizes, this report focuses on two different case studies where it can play a role in the future North Sea energy systems:

- Carbon capture and storage in offshore oil and gas reservoirs
- Offshore oil and gas platforms as energy island hubs in the North Sea

Carbon capture and storage in offshore oil and gas fields features in greenhouse gas emissions reduction strategies in all three countries. Several projects have already been initiated in Europe, and billions of USD in investments have been announced by the EU, Denmark, Norway and the United Kingdom. Many of the projects intend to use depleted oil and gas reservoirs and to repurpose platforms and infrastructure to store CO2 offshore, with the oil and gas operators as partners.

The use of offshore oil and gas platforms as energy hubs follows the same technology transition logic. Offshore platforms, in particular, could become part of the future distribution network as energy hubs, together with the artificial energy island announced by the Danish government. Other pilot projects are investigating whether it will be feasible to reuse the platforms and related infrastructure for Power-to-X production in the future.

The two case studies show that repurposing offshore oil and gas platforms and infrastructure can be considered as part of the just transition to a low-carbon economy. However, to fully understand the extent of the industry's technology transition, from the infrastructure to the workforce, further analysis is needed into the legislative, financial and political considerations that will determine just and feasible pathway scenarios for the phasing out of offshore oil and gas production in the North Sea.

1. Introduction

Technology plays a vital role in providing a reliable energy supply that supports modern society. History shows that oil and gas production in the North Sea has also had an apparent transformational effect promoting innovative new technologies, especially as it becomes increasingly challenging to access reserves[1]. New technologies in the offshore oil and gas industry continue to be developed, as they must provide commercially viable solutions to explore deeper waters and maintain high production levels from matured reservoirs[2].

However, a new era is opening for offshore oil and gas in the North Sea, as national climate strategies focus on transitioning towards renewable energy to meet the goals of the Paris Agreement. In 1982, Wood Mackenzie & Co. predicted that the United Kingdom's North Sea oil and gas production would run out between 2012 and 2026. As current trends are already moving beyond that trajectory, the sector faces the critical junction of determining whether its technology innovations can be transferred to other industries[3].

This report looks at the technologies deployed in the offshore oil and gas sector that can be adapted or reused in other industries located in the North Sea. Therefore, it will disregard the solutions transferred to other regions[4]. The transformation discussed in the report is in line with the 'just transition' principles, which aim to guarantee social justice by securing workers' rights and livelihoods in the shift towards low-carbon economies[4].

The North Sea oil and gas industry has been a major contributor to European economic growth since the 1970s, but as the Paris Agreement was adopted in 2015, the sector is looking into an uncertain future, with significant changes to transition to a lower greenhouse gas (GHG) emission world. As the third-largest producing country of oil and gas in the North Sea (behind Norway and the UK), the Danish government in January 2020 decided to cancel the 8th tender for new licenses and became one of the first oil-producing countries to set an end date for oil extraction in 2050. However, there is still the possibility for Denmark to release new exploration and extraction licenses until 2050 in the form of speculative applications known as "mini rounds"[5]. This solution can come into play if oil and gas operators find it valuable. The discovery of the Svane field in 2002, potentially the biggest gas field ever found in the Danish North Sea, has opened the debate. But this is a high-pressure-high-temperature (HPHT) field, difficult to extract from. It was therefore abandoned by DONG Energy in 2012 and Mærsk in 2015 because it was not technically possible to proceed safely and economically[6]. According to the CEO of state-owned oil and gas company Nordsøfonden, Birgitta Jacobsen, the technology has evolved since then, and the project may have become interesting for some operators[6]. But even if they apply for new licenses through mini rounds, granting such permissions will ultimately be a political decision[5].

From an industry point of view, oil and gas companies in the North Sea also look into an expensive future, with major technical and environmental challenges such as matured fields, aging platforms and eventually decommissioning costs. The estimated cost for the decommissioning of the oil and gas sector in the Danish sector of the North Sea is estimated to be in a triple-digit billion order of magnitude (DKK), whereas the leading trade association for the oil and gas industry in the

UK (OGUK) estimate the decommissioning expenditures for the British part at £48.2 billion ($65.4 billion)[7, 8]. At the same time, oil extraction in the region will become more expensive if the technology and the recovery process are not continuously improved[2]. In this respect, the Danish political parties have agreed that stability and predictability are necessary to maintain the industry's activities and investments[9].

Even though ending oil and gas production in the Danish sector of the North Sea is part of the transition towards net-zero, it will only have a limited effect on global GHG emission. Denmark's CO^2 emissions contribute only 1‰ (based on 2017 data) of the global human-caused emissions, even though the amount per capita is still ≈26% higher than the average country[10]. Nevertheless, the move is still important. Danish Climate Minister Dan Jørgensen said after the agreement in 2020:

"Stopping the extraction of oil and gas production from the Danish sector of the North Sea in 2050 will only have an insignificant effect on the climate and the world's total oil production. But it is an important step in the green transition and have great signal value to the world and hopes that the major oil producers will follow in the wake of Denmark."

- Berlingske, 2020[11].

Spurred by Denmark's leadership, expectations are now rising for increased climate ambition in other North Sea countries. Days after Denmark announced 2050 as an end date for oil extraction, Ken Penton, UK climate campaigner at the international NGO Global Witness, said:

"If the UK is to be a real global climate leader, it must follow Denmark's lead by stopping issuing new oil and gas exploration licenses and delivering a managed phase-out of oil and gas extraction"

- The Guardian, 2020[12]

"We are going to need fossil fuels for a very long time moving forward; possibly we are going to need it also after 2050... the baseline for Norway's petroleum policy is that we produce profitable resources. If they are not profitable, we are not going to produce."

- Energy Visions Event[15]

However, to date, the UK has not yet decided to end oil and gas extraction and the 32nd Offshore Licensing Round is still ongoing[13]. At the same time, Norway, the biggest oil and gas producer in the North Sea, intends to continue extraction as long as it is profitable while striving to become a low emission society by 2050[14]. In 2020, Tina Bru, then Minister of Petroleum and Energy, said:

The Norwegian government sees carbon capture and storage (CCS) in the North Sea as a plausible solution. Despite different strategies to meet the goals of the Paris Agreement, former Norwegian Prime Minister Erna Solberg and current Danish Energy and Climate Minister Dan Jørgensen agreed that new technology solutions, such as CCS, Power-to-X (PtX) and bioenergy, could help remain below 1.5°C global warming, the limit set in Pari[15,16]. In line with the just transition principle[4],

Erna Solberg said that these new technology projects will not be successful if they are not adopted at an international level and if countries do not collaborate[11, 15].

From a Danish national perspective, setting an end date for oil production in 2050 gives stakeholders 28 years to adapt. Without disregarding the global climatic changes and the influence oil and gas production still plays in many other countries, following the transition in the North Sea is interesting also because it has the potential to demonstrate the outcome of phasing out a major energy source deriving from fossil fuels. This can inspire other countries and contribute to making the low carbon economy not only more just, but also more likely[4]. The North Sea will thus become an interregional pilot area for this transition, which raises questions such as:

- What are the costs and benefits of the conversion?
- What effect does the declaration of the end date have on the oil and gas recovery in the coming 28 years?
- Can the offshore oil and gas hardware and expertise be reused for other purposes?
- Can the technologies from the oil and gas sector be transferred to other industries?
- Will the transition yield new technological inventions?

This report will not directly answer these questions, but will merely present the technological transformations for the transition from oil and gas to greener activities already being investigated in the North Sea.

The report will also map technologies generally in use by the industry in the area, as well as Danish stakeholders. Based on the mappings, two case studies – on CCS and offshore energy hubs – will offer examples of how offshore oil and gas technologies can be transferred to other industries in the region. Both case studies highlight how parts of the existing technologies from the oil and gas industry can be integrated into future offshore energy systems.

Mapping of key stakeholders in the offshore oil and gas industry

Since offshore oil and gas extraction began in the North Sea in the early 1970s, the industry has grown tremendously. Today, there are more than 8,200 wells and 1,350 offshore installations in the region[17],[18]. Historically the industry has had, and still has, a major impact on the economy and the welfare of society in the relevant countries[19]. This report will focus on key stakeholders in relation to the economy and workforce in the Danish sector of the North Sea. Additional information about Danish stakeholders' visions, framings and expectations about the just transition in the sector can be found in the report:

- "Denmark without Oil and Gas Production: Opportunities and Challenges" [22].
- Key stakeholders involved in the offshore oil and gas industry in the Norwegian and British parts of the North Sea can be found in the reports:
- "Norwegian Oil and Gas Transition: Building bridges towards a carbon-neutral future"[20].
- "The Future is Built on the Past: Just Industrial and Energy Transitions in the UK and Scotland"[21].

A key stakeholder is the Danish state, which generates income from the activities in the North Sea primarily through tax revenues and profits from Nordsøfonden. Revenues come from the hydrocarbon tax (52%) and corporate tax (25%). The state's total revenues from hydrocarbon extraction in the North Sea from 1972 to 2019 amounts to approximately 541 billion DKK ($82.3 billion)[24]. Depending on the calculation method, it is estimated that the Danish state could earn between 88 and 240 billion DKK towards 2050 from oil and gas activities in the North Sea[25].

The Danish Underground Consortium (DUC), which accounts for almost 85% of the Danish oil and gas production in 2020[23],[24], is a joint venture between TotalEnergies (43.2%), Noreco (36.8%) and Nordsøfonden (20%). The companies collaborate to produce oil and gas from the Exclusive Licensing area in the Danish sector of the North Sea, where TotalEnergies is in charge of the exploration and operation of DUC's 15 fields. The offshore oil and gas industry employs 10,000 full-time workers in Denmark[26]. Typically, projects are very large and involve many stakeholders not exclusively from the industry. Therefore, if the indirect jobs are also taken into consideration, the industry has a total of 26,000 full-time staff[26] with a wide expertise, from unskilled personnel to master-level education and PhDs.

The Danish offshore oil and gas industry is already experiencing the consequences of the transition, as the lack of qualified employees becomes a challenge. According to the company Oil Gas Denmark[27], universities are educating fewer graduates than those demanded. Part of the explanation is the uncertainty associated with the future of the industry and its negative publicity. Another reason from universities' point of view is that funding programmes that support research and innovation in oil and gas are sharply declining, so they are adapting with research that can be funded in the future. Key stakeholders involved in the Danish offshore oil and gas industry are shown in Figure 1.

Figure 1: Diagram of key stakeholders involved in the Danish offshore oil and gas industry.

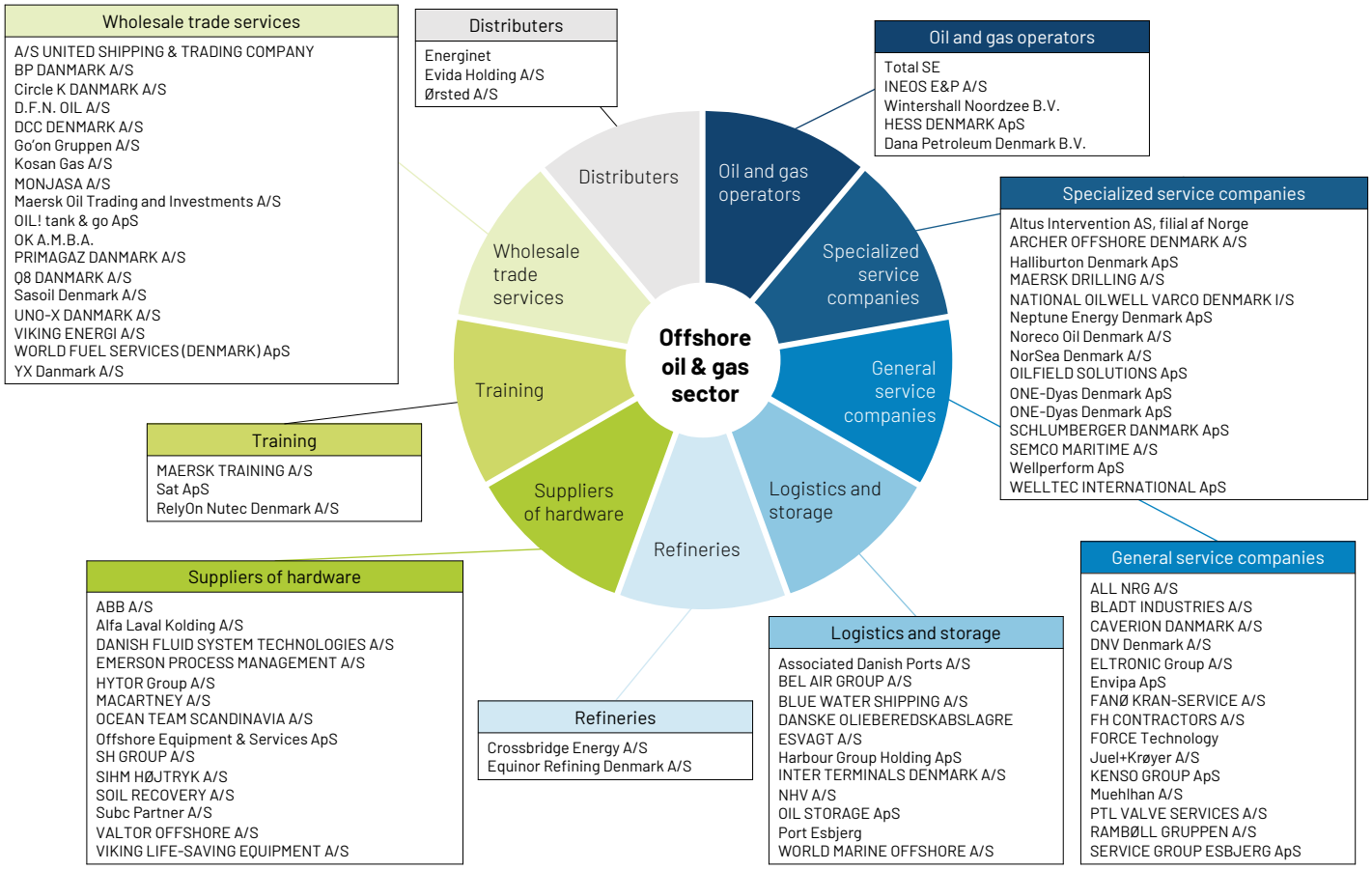
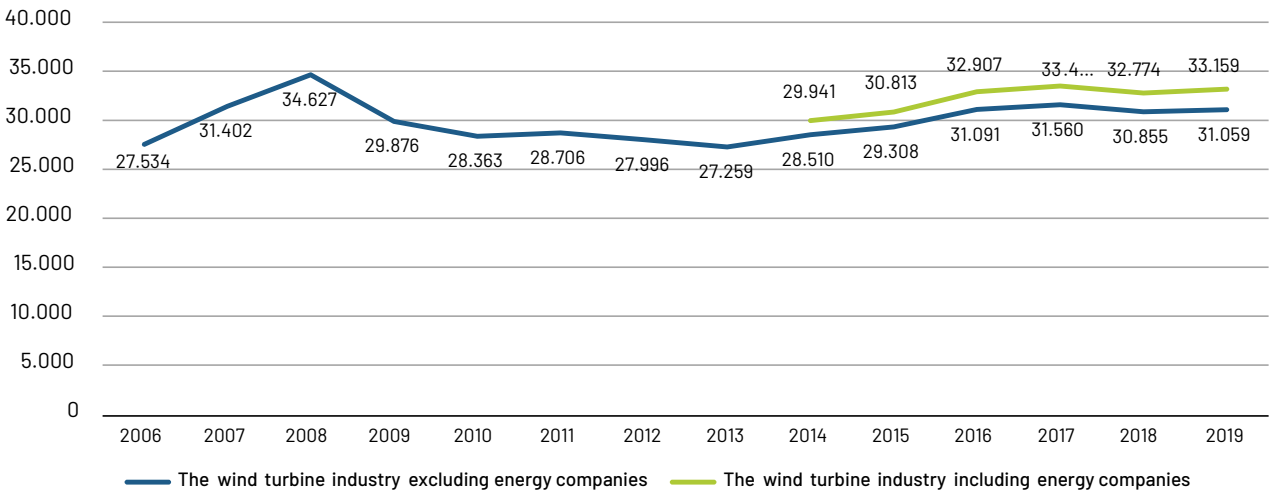


Figure 2: Number of employees in the Danish wind industry[28].

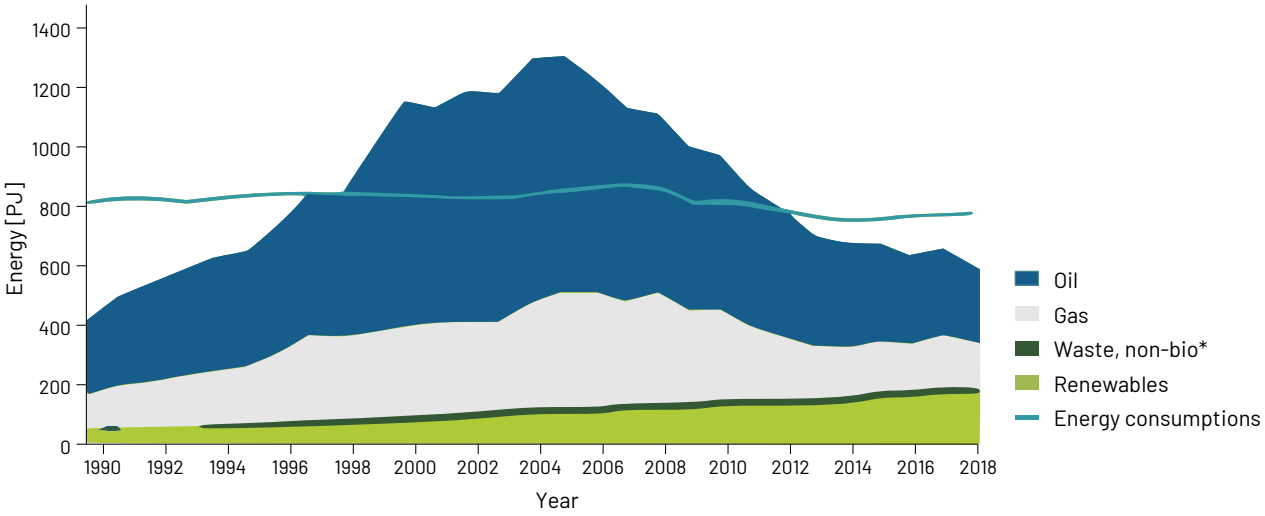


As seen in Figure 1, there are five operators in the Danish sector of the North Sea. All of them are international companies active in other locations too, both in the North Sea and other parts of the world.

Several oil and gas companies are currently re-evaluating their strategic responses to new policies. Most of them are already involved in the green transition through investments in other energy domains while retaining their profitable core[29]. In addition, international oil companies are increasingly seeking ways to improve their economic and reputational resilience, reducing their exposure to climate change and the risk of stranded assets[29]. Together with oil and gas operators, specialized service companies are the stakeholders that will have to re-evaluate and adapt their business strategy the most in the years to come.

Most of the companies in the other categories already operate outside the oil and gas sector. In particular, general service and training companies, as well as hardware suppliers identified in Figure 1, are engaged in several areas of the offshore sector: wind, solar, marine, constructions, transportation, etc.

Figure 3: Denmark's energy production from 1990 to 2018 by different energy sources, measured in petajoule (PJ). Gross energy consumption is shown for comparison[28].



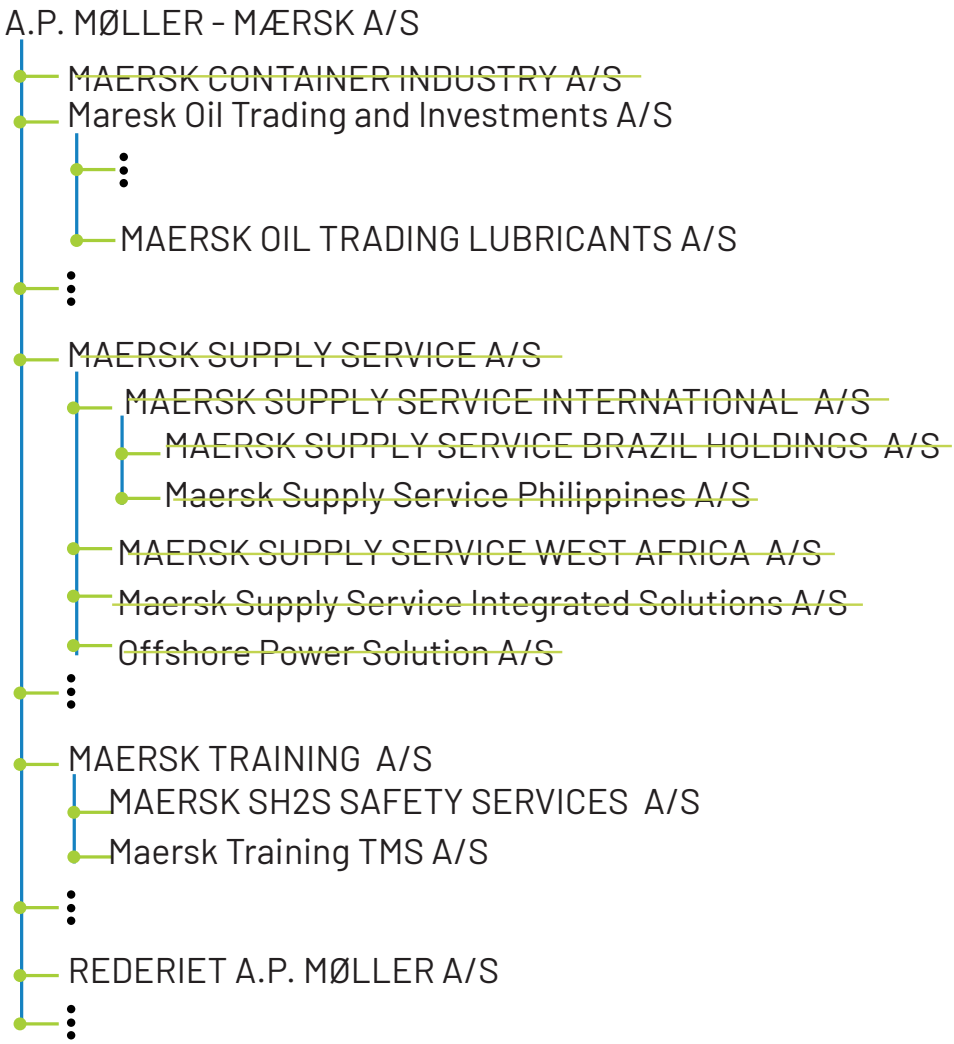
**Indicating the energy content from non-bio domestic waste used for energy production. The energy content from bio-domestic waste is included under Renewables.*

Especially in Denmark, companies providing general services offshore are naturally shifting towards the wind sector, which is steadily growing and approaching the number of employees it had before the global financial crisis in 2008 (Figure 2). Figure 3, on Denmark's yearly energy production from 1990 to 2018, shows oil and gas decreasing and renewables on the rise. These numbers will be largely surpassed in the near future, with the planned establishment of a 2 GW wind farm in the Baltic Sea in the early 2030s and a 10 GW wind farm in the North Sea at a later stage[30]. A study on the socio-economic impacts of offshore wind from 2020 indicates a total labour input potential of around 14,600 full-time equivalents per GW produced[31].

As parent companies also own or control other firms, many of the subsidiaries are listed in the ownership structure by group in Table 4-12 found in the Annex. The tables also show their average number of employees, revenues and gross profit. These lists consist of parent and subsidiary companies only relevant to the Danish offshore

oil and gas industry, as many of the groups are active in several other sectors. For instance, the ownership structure from the A.P. MØLLER - MÆRSK A/S group in Figure 4 consists of 64 companies, but only some of them are engaged in the offshore oil and gas industry.

Figure 4: Ownership structure of the A.P. MØLLER - MÆRSK A/S group. The example shows only part of the 64 different parent and subsidiary companies in the A.P. MØLLER - MÆRSK A/S group involved in the Danish offshore oil and gas industry (red strikethrough).



An ownership structure like that in Figure 4 can complicate the estimation of offshore oil and gas' employees, revenues and gross profit. As an example, Maersk Oil Trading and Investments A/S have no employees, as the staff is directly employed by Rederiet A.P. Møller A/S. The latter employed an average of 2,723 people in 2020. The employees are engaged in shipping activities as well as general administration for A.P. MØLLER - MÆRSK companies. Therefore, estimating the exact number of employees in the different subsidiaries is challenging. The same is true for financial plans, where each subsidiary is an independent entity but can benefit from transferring their profits tax-free to their parent company.

Furthermore, companies in Denmark are divided into different financial classes: A, B, C and D. Class D includes companies listed on the stock exchange and state-owned ones. Class D companies have an obligation to make revenues public, whereas classes A, B, and C can choose to make their revenues publicly available or only publish their gross profit[32].

Even though not all figures are publicly available or are difficult to extrapolate from ownership structures, Table 4-12 gives an extensive overview of key stakeholders' financial performance. However, there are probably other companies that provide general services to the oil and gas industry.

The mapping of stakeholders shows that the transition is already happening. Today, oil and gas operators are not only oil and gas companies but broader energy companies. For instance, Total renamed on 2 June 2021 as Total Energies to reflect its broader goals. Statoil did the same in 2018, when they rebranded as Equinor. Similarly, Danish company DONG Energy (an abbreviation for Danish Oil and Natural Gas) was renamed Ørsted, after the Danish physicist who discovered electromagnetism, Hans Christian Ørsted.

Another visible shift associated with the growth of renewables is in the number of employees. Here the categories most at risk are specialized companies providing services or producing specialized equipment for the oil and gas industry, as it could be problematic for them to sell their products and services to other sectors.

Mapping of offshore oil and gas technologies

The offshore oil and gas industry has built a mature field of research, where scientific and technical innovations have revolutionized production methods, some of which have inspired solutions in other industries, such as dynamic positioning of ships, directional drilling for geothermal heat energy, concrete deep water structure for bridge support, monopile structures for offshore wind turbines[83–85]. Innovation in the industry has been the key driver of increasing profits and economic growth, accessibility and human safety offshore.

The oil crisis in 1973 was the turning point that caused oil and gas extraction in less accessible areas, such as the North Sea, to become profitable[33].

The industry worldwide uses different platform structures and designs depending on their size and water depth. The most common type of production platform is the fixed piled structure, known as the jacket. Other structures are also used in the North Sea. For example, the Troll A platform in the Norwegian sector uses a gravity-based design[35]. Besides full production platforms, smaller (unmanned) satellite installations are also primarily operated remotely or as part of a larger cluster around a central hub platform.

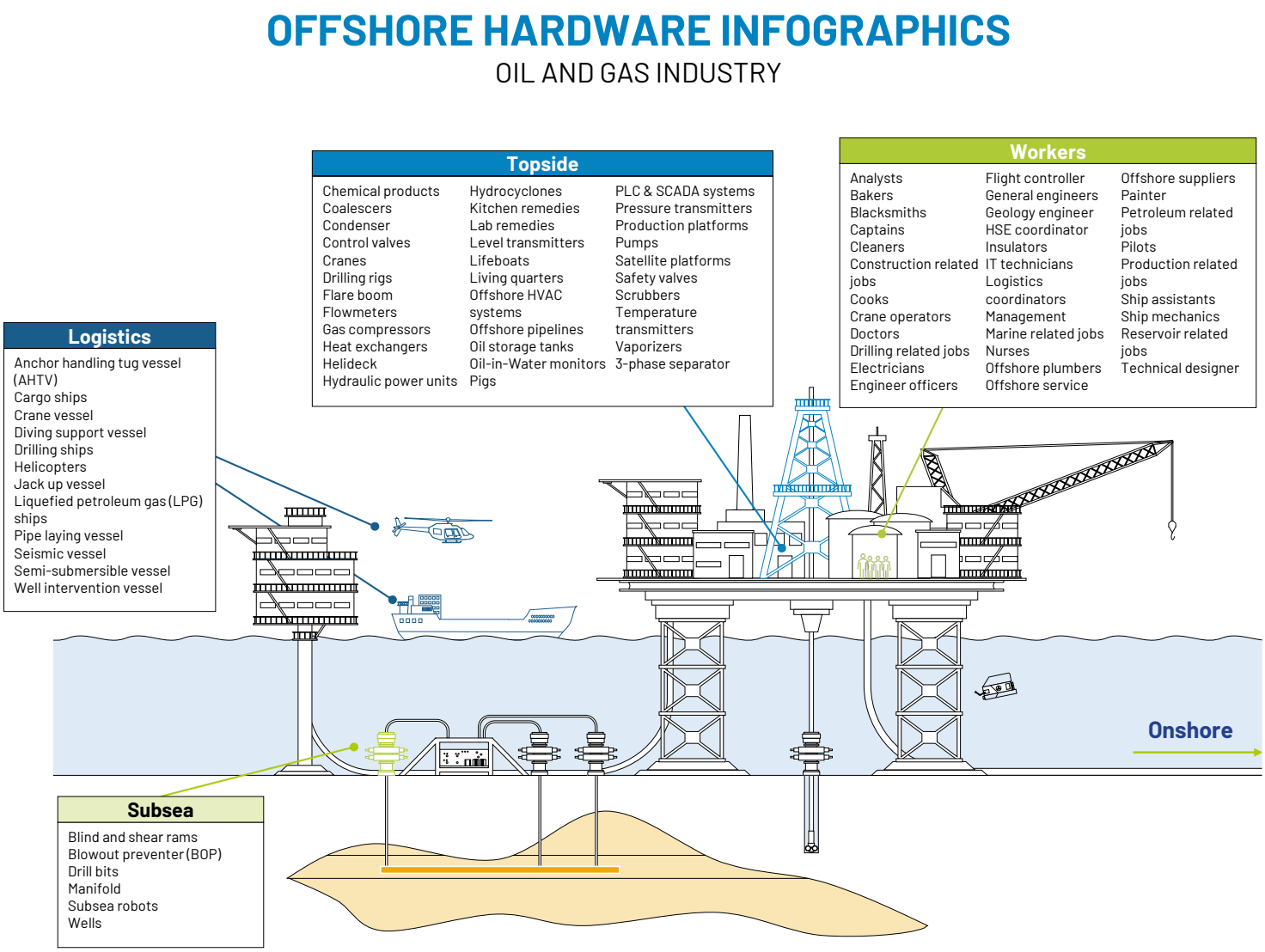
The term technology, however, is an inherently abstract concept that can, to some extent, be difficult to interpret. According to the review study by Wahab et al.[36], technology has been given various definitions in literature and has evolved through history. Newer studies relate the word not only to a product but also to the knowledge of its use, its development and its application[37]. If accepting this definition, technology consists of four elements: technique,

knowledge, organisation and product, and each element cannot remain as an isolated term. If, for instance, technical changes occur (new machines are introduced), the changes will also affect the knowledge, organisational and product elements. Mapping the technologies in the offshore oil and gas industry in the North Sea requires, therefore, highlighting both the hardware and the professional skills of workers.

Many companies producing hardware and providing services in offshore oil and gas are already involved in other industries. In contrast, other more dedicated ones have skills more challenging to transfer.

Figure 5 gives an overview of the hardware and professional roles involved in the offshore oil and gas industry.

Figure 5: Infographic of the hardware and expertise used in the offshore oil and gas industry.



The mapping of the hardware and professional roles related to the offshore oil and gas industry from Figure 5 can be divided into general and dedicated categories, as seen in Table 1.

	General	Dedicated
Hardware	Cargo ships Chemical products Control valves Crane vessel Diving support vessel Flowmeters Heat exchangers Helicopters Kitchen remedies Lab remedies Level transmitters Lifeboats Pigs PLC & SCADA systems Pressure transmitters Pumps Safety valves Seismic vessel Semi-submersible vessel Subsea robots Temperature transmitters	3-phase separators Anchor handling tug vessel (AHTV) Blind and shear rams Blowout preventer (BOP) Coalescers Condenser Cranes Drill bits Drilling rigs Drilling ships Flare boom Gas compressor Helideck Hydraulic power units Hydrocyclones Jack up vessel Liquefied petroleum gas (LPG) ships Living quarters Manifold Offshore HVAC systems Offshore pipelines Oil storage tanks Oil-in-Water monitors Pipe Laying Vessel Production platforms Satellite platforms Scrubbers Vaporizers Well Intervention Vessel Wells
Expertise	Analysts Bakers Blacksmiths Captains Cleaners Constructions jobs** Cooks Crane operators Doctors Electricians Engineer officers Flight controller General engineers* Geology engineer HSE coordinator Insulators IT technicians Logistics coordinators Management Marine jobs** Mechanics Nurses Offshore plumbers Offshore service Offshore suppliers Painter Pilots Ship assistants Ship mechanics Technical designer	Drilling jobs** Oil and gas production jobs** Petroleum jobs** Reservoir jobs**

**Chemical, civil, energy, software, and electrical engineers. **jobs cover technicians, coordinators, leaders, and engineers.*
Table 1: Mapping hardware and expertise listed in Figure 5 into two different categories: general and dedicated.

The general category in Table 1 provides a list of hardware and skills that can be directly transferred to other fields, whereas the dedicated category represents specialized technologies and skills specific to the offshore oil and gas industry. The two case studies on CCS and offshore platforms as energy hubs will highlight how these dedicated technologies, specific to offshore oil and gas, can be transferred to new domains of storing captured CO2 or repurposed to become energy hubs.

Synergies in the offshore O&G and renewables sector: two case studies

In the already initiated just transition, two main trends characterize the North Sea's energy industry. On the one hand, the demand to phase out oil and gas and, on the other hand, the large investments in offshore energy solutions to deliver a low-carbon economy. It is therefore essential to identify synergies between energy sectors and assess possible collaborations. For example, synergies can be found between the oil and gas and the offshore wind sectors, where already integrated systems can maintain workers' expertise.

The synergy between the existing oil and gas facilities and technologies that can be deployed to transition towards a low-carbon offshore energy system is the basis for selecting the two case studies in this report. These involve:

- Using depleted offshore reservoirs for CCS, which is projected to be one of the main solutions for reducing CO2 levels[39].
- Repurposing offshore platforms as energy hubs in connection with the artificial energy islands that will be established in the North Sea[38].

Beyond the selected case studies, other technologies from offshore oil and gas can be used in different sectors. An example is the biofuel sector, in which technologies often correlate with the oil and gas industry or the water and wastewater treatment industry.

The CCS and the energy hub case studies have been highlighted for two reasons:

1. Their potentials are already described in literature and are considered in the climate policies of North Sea countries to drastically reduce their carbon footprint in the coming decades. For example, on 21 September 2020, Norway launched the CCS Longship project for a total investment of 25.1 billion NOK ($2.9 billion)[40]. Denmark also launched CCS projects, e.g., the Greensand project worth 197 million DKK ($30 million), the Bifrost project for 75 million DKK ($14.5 million), the InnoMission project worth 200 million DKK ($30.6 million), while an additional 16 billion DKK ($2.45 billion) will be released from 2024 over 20 years partly in support of CCUS[16],[82]. As for the UK, the government has announced a £1 billion ($1.34 billion) CCUS infrastructure fund and several projects have already been initiated (see Table 3)[41]. Lastly, the EU Innovation Fund announced an investment of over €1.1 billion ($1.25 billion) on 16 November 2021 to develop seven large-scale projects, of which four supporting CCS[42].

2. The potential to establish a synergy between the phasing out of offshore oil and gas and the addition of fossil-free energy systems. Denmark has made the political decision to create two energy islands primarily for energy production from wind farms. One will be an already existing island, Bornholm, in the Baltic Sea, while the other will be built artificially in the North Sea. The projects are estimated to cost 210.2 billion DKK ($32.2 billion) and should be completed in 2033[43]. This project does not in itself constitute a synergy with the offshore oil and gas industry, but the offshore platforms could become part of the future energy distribution, together with the energy island, as energy hubs.

Case Study 1: Carbon capture and storage in offshore oil and gas reservoirs

Carbon storage is, according to the UN's Intergovernmental Panel on Climate Changes (IPCC), a crucial tool to deal with climate changes. It will be difficult to meet the Paris Agreement's objective to stay within 1.5°C global warming without carbon storage, the IPCC says[44],[45]. In 2021, the EU agreed to reduce CO2 emissions by 55% by 2030 compared to 1990 levels[46]. Some European countries, such as Denmark and UK, have adopted more ambitious targets (see Table 2).

Table 2: EU, Denmark, Norway, and UK's current GHG emission reductions over 1990 levels, and their targets in 2030 and 2050.

	Current status (2019) [47]	2030 target	2050 target
EU[46]	25.9%	55%	net-zero emissions
Denmark[48]	37.6%	70%	net-zero emissions
Norway[49]	2.2%	50-55%	90-95%
UK[50]	43.2%	68%	net-zero emissions

The UK government has also decided to set an additional sub-goal of 78% GHG emissions reduction by 2035. Norway is following the EU ambition and aims to reduce emissions by 50-55% in 2030 compared to 1990, with a longer-term 90-95% target by 2050[49].

All three North Sea countries envisage a role for carbon storage in their GHG emissions reduction strategies. Carbon storage can be achieved with afforestation of forest areas, agricultural soil storage, oceans and deep oceans absorption, and deep underground geological formations[51].

In relation to the technologies for the transition away from offshore oil and gas, the focus of this case study is on deep underground geological formations. CCS technologies are considered to have enormous potential and at least the same importance as renewable energy to reach climate goals[51]. However, CCS does not have the same economic and employment effects as renewables and is mostly associated with costs: CO_2 capture, transport, storage, capital and operating costs[52].

CO_2 cannot just be pumped deep underground everywhere; a suitable geological formation must be present to retain CO_2. It is estimated that worldwide there are reservoirs for geological storage of CO_2 with sufficient capacity to significantly contribute to limiting climate change[39]. Depleted natural gas and oil fields are considered ideal for carbon storage, not least as the reservoirs' properties, including formations and fluid flow characteristics, are well known due to previous exploration and years of activity[53], [54]. Furthermore, the reservoirs have already proven that they can retain gases for thousands of years without significant leakage[2]. In addition, the production rates from the extraction period of the reservoir can give a reasonable first estimate of the amount of CO_2 that can be stored[54].

CO_2 storage in depleted or depleting oil and gas reservoirs is not a new technology. Injection and storage of CO_2 into oil reservoirs have been carried out safely and effectively by the oil and gas industry for more than 45 years, for enhanced recovery or explicitly for geological storage[55]. Knowledge of CO_2 injection from the sector has shown that there are no technical barriers preventing the implementation of carbon storage[52]. The main challenge to CCS

deployment is, however, commercial given the costs as mentioned previously[56]. Other questions often addressed to this technology are related to the risk of leakage and its environmental impact, to the impurities of the captured CO_2, reactions with the reservoir, public acceptance (onshore storage), storage capacity, type of formation, and injectivity rate [52], [53], [57-60].

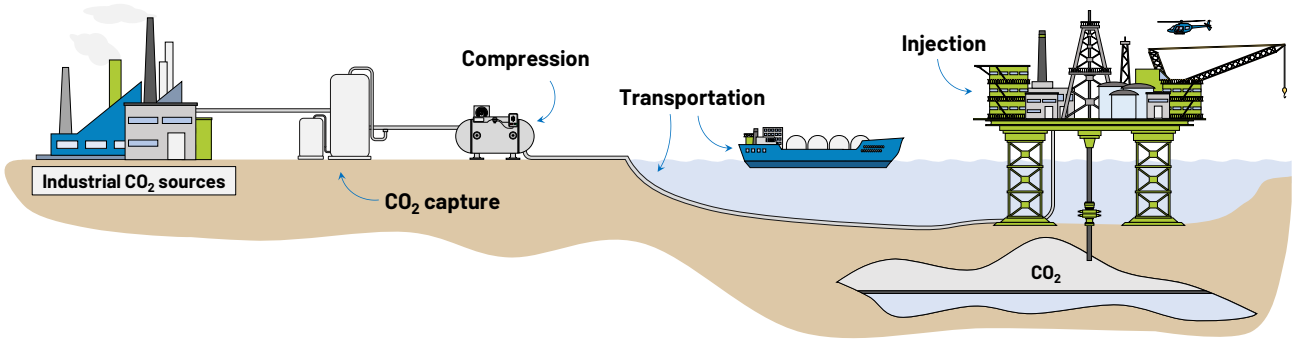
The development of CCS projects in the North Sea requires expanding the transport and storage infrastructure. The oil and gas industry has the knowledge and infrastructure for CO_2 transportation (pipelines), storage (wells, reservoirs know-how) and additional hardware. It can thus facilitate the deployment of this technology[59].

Oil and gas operators can potentially benefit from further oil and gas recovery by injecting CO_2 into reservoirs to transition from being a production reservoir to becoming a storage site[2]. An already well-known practice already exists in the oil and gas industry, known as enhanced oil recovery (EOR)[61], but this may face criticism as it would prolong oil extraction and continue CO_2 emissions. Therefore, the economic feasibility of CCS is either dependent on high CO_2 taxes and prices and governmental support, or on the ability to sell the captured CO_2 in the future for the production of synthetic fuels by PtX systems[62]. The process of capturing CO_2 at the source and transporting it for storage in geological formations offshore is described in Figure 6. A key element for a meaningful deployment of CCS is that the energy used in the process must come from low-carbon energy sources to have the highest outcome of the CO_2 emission ratio (kg per CO_2 injected vs. kg per CO_2 released in the process of storing CO_2).

Figure 6: The carbon capture storage process in reusing the depleted oil and gas reservoirs for geological CO_2 sequestration"

CO2 capture: The composition and purity of the CO_2 depend on the collection process and significantly impact all the subsequent stages of the CCS process. The presence of only a few percentages of water (H_2O), hydrogen sulfide (H_2S), sulfur oxide (SO_x), nitric oxide (NO_x), nitrogen (N_2), and oxygen (O_2) can affect the physical and chemical properties of CO_2, and thus impact the receiving reservoir [57], [60]. The presence of the impurities in the CCS process should therefore be treated with care.

Injection: When CO_2 arrives at an offshore platform, it is injected under pressure into the reservoir. The pump pressure must be sufficiently high in relation to overcome the internal pressure in the reservoir. Different wells can be connected to the same reservoir. The number of wells necessary depends highly on the amount of CO_2 to be stored, the CO_2 injection rate, the pump operational specifications, the reservoir's permeability, and its physical and chemical structure. As the main purpose of storage of CO_2 is to store it for many years, the reservoir's properties are crucial to protect. Too high injection pressure can unintentionally damage the reservoir's caprock.



Compression: The CO_2 gas is compressed into a liquid, whereby the CO_2 volume is reduced significantly. When CO_2 is captured from the industrial CO_2 sources, the highly concentrated CO_2 is dehumidified and compressed before transportation and injection for storage. Dehumidification is necessary to prevent corrosion in the CCS process and the formation of scales under the high pressure that can physically plug the equipment [58].

Transportation: CO_2 can be transported either by ship or through pipelines. Transporting CO_2 by ship is done by Liquefied petroleum gas (LPG) ships. The most modern LPG ships can load more than 200,000 m^3 of CO_2 [57], [63]. Although, transporting CO_2 by ship does not supply the injection process at a constant rate, which puts a load on storage capacity onshore and offshore. Today, pipelines are used to transport large quantities of natural gas and oil in the oil and gas industry, which can be repurposed for the use of CO_2. The use of pipelines will be much cheaper in operational cost than transport by ship enables a continuous supply of CO_2 from the collection point to the storage site [57], [63]. Although for sources far away from storage sites, transport by ship could be more economically feasible [57], [63].

Suppose the existing offshore oil and gas pipeline infrastructure is considered to be used for CCS in the future. In that case, further investigations are needed to determine whether it is fit to transport CO_2. If reservoirs are repurposed for CCS, offshore platforms can also offer practical solutions, as they are designed to house workers and provide a wide range of professional needs for life there. The equipment owned by oil and gas operators, however, could also become a liability. If future CCS projects choose another path, e.g., deep saline formations or onshore reservoirs, offshore oil and gas operators may have to decommission the entire facilities with enormous costs. Therefore, oil and gas companies are already showing their interest in investing in CCS projects in the North Sea and becoming part of the just transition. The Global CCS Institute, an international think tank aiming to accelerate the deployment of the technology, mentions in its 2021 report that 35 CCS projects are currently under development in Europe. Most are using the North Sea for storage, and many of the involved partners in the projects are companies from the oil and gas industry[39].

A partial rebuild of platforms is likely needed for the transition. For some, it will be enough to renovate or remove the top. Topside replacement is not an unnatural solution in the oil and gas industry. In recent years several of the Tyra platforms owned by TotalEnergies in the Danish sector of the North Sea have been redeveloped by building new topsides and jackets at a total price of 21 billion DKK ($3.2 billion)[64]. Suppose the replacement of the topside section is enough to extend the life of the platform. In that case, the construction of the new topside takes place onshore, like in the Tyra Future project, and costs can be significantly reduced[64].

The EU projects at an advanced development stage highlighted in the Global CCS Institute report can be seen in Table 3:

Table 3: Carbon Capture and Storage projects in development around Europe[39].

			Transport		Storage	
Project	**Location**	**Capacity (Mtpa)**	**Pipeline**	**Ship**	**Deep saline formations**	**Depleted oil and gas reservoirs**
HyNet North West	UK – Northwest of England and North Wales	4.5 -10	√	√		√
South Wales Cluster	UK – Southern part of Wales	9.0	√	√	√	
Net Zero Teesside	UK – Teesside	0.8 - 6.0	√		√	
Humber Zero	UK – Humber	Up to 8.0	√	√	√	
Zero Carbon Humber	UK – Humber	Up to 18.3	√		√	
Acorn	UK – Northeast of Scotland	5.0 – 10.0	√		√	
Longship	Norway – Oslo, and Brevik	1.5 – 5.0	√	√	√	
Antwerp@C	Belgium – Antwerp	9.0	√	√	√	√
Porthos	The Netherlands – Rotterdam	2.0 – 5.0	√			√
Greensand	Denmark – Danish part of the North Sea	3.5	√	√		√
C4 Copenhagen	Denmark – Copenhagen	3.0	√		√	
Ravenna Hub	Italy – Ravenna	Up to 4.0	√			√

Many of these European CCS projects aim to use North Sea reservoirs, whether they are deep saline formations or depleted oil and gas formations. Some of the projects do not focus on storage sites but on the transportation of CO_2. As an example, Wales does not have the opportunity to store CO_2 due to the lack of suitable geological formations close to the shore[65]. Therefore, the project in Wales looks at different options, such as shipping or a connection into the HyNet North West project for CO_2 storage[65]. Another example is the Antwerp@C project in Belgium. Belgium does not have suitable geological strata so it needs to collaborate with other countries, either by transporting CO_2 across the border to Rotterdam by pipelines or by shipping it[66].

Besides the Ravenna Hub and the C4 Copenhagen project, all other projects in Table 3 focus on using formations in the North Sea. In most of them, the stakeholders are oil and gas companies located in the area. For example, Equinor, Shell and TotalEnergies are the leads in the Northern Light project, a subproject of the Longship project in Norway[67]. Similarly, the Greensand project in Denmark is a CO_2 storage consortium formed by INEOS and Wintershall Dea. The same applies in the UK where, for instance, Equinor is involved in the Zero Carbon Humber project and Eni in the HyNet North West project.

Offshore CCS in the North Sea is already part of the transition and, based on the number of projects announced, the CCS industry will only become more prominent in the future[39]. Through CCS, oil and gas operators will try to maintain their presence in the North Sea energy systems after the end life of oil and gas. In this regard, stakeholders supporting oil and gas operators have a great interest in maintaining cooperation. An example is the Danish company Welltec, which develops and produces advanced specialized equipment for the oil and gas industry. Welltec has close to 800 employees worldwide and annual revenues in 2020 of $222 million, with parts of the production in Denmark[68]. The company is, together with INEOS and Wintershall Dea, part of the Greensand project. Welltec's CEO Peter Hansen sees great potential in being part of the transition and managing the complicated process of storing captured CO_2:

"It is important for Welltec to take an active role to deliver solutions to CCS projects globally. We have uniquely positioned technologies with a strong track record within oil and gas, providing advanced solutions designed to operate under challenging subsurface conditions. We are already engaged in various CO2 projects and high temperature geothermal applications, we absolutely have a key role to play in CCS too".

- Welltec's CEO Peter Hansen[69]

The case study shows that the synergy between the phase out of offshore oil and gas and the development of renewable energy systems could become a natural transition for stakeholders with a focus on CCS. The main challenge is whether CCS can become commercially feasible through high CO_2 taxes and prices, governmental support, public acceptance or by selling the captured CO_2 in the future, e.g., for producing synthetic fuels by PtX systems. Another prospect for oil and gas operators is whether the transfer to CCS projects could reduce the decommissioning costs of already existing infrastructure and platforms. Legislative, financial and political considerations will have to be addressed for this purpose[70].

Case Study 2: Offshore oil and gas platforms as energy island hubs in the North Sea

Electricity plays a key role in energy conversion away from fossil fuels. Large investments in low-carbon electricity production combined with the electrification of end-use sectors are expected to deliver a sharp decline in global CO_2 emissions[71]. However, the incremental increase of electricity production will require large investments in grid development and a complex energy management system. This is due to the fact that with current technology, electricity cannot be stored on the scale needed and therefore has to be converted to other forms of energy.

In light of that, the Danish parliament agreed on 22 June 2020 to build the world's first artificial energy island in the North Sea and a similar energy hub on a natural island, Bornholm, in the Baltic Sea[48]. In the first phase of the project, the artificial energy island in the North Sea should be connected to a 3 GW offshore wind farm, with the possibility of expansion in the future to 10 GW[43].

The artificial energy island is estimated to have a construction cost of 210.2 billion DKK ($32,2 billion), the largest construction project in Danish history by far[43]. The first phase is expected to be operational in 2033 with a capacity of 3 GW, which will be able to cover approximately the electricity consumption of 2,500,000 - 3,000,000 European households[38],[72].

The artificial energy island will function as a hub between several large offshore wind farms and associated transmission lines to Jutland's west coast in Denmark and the neighbouring countries in the North Sea (Norway, UK, Germany, Belgium and The Netherlands)[38]. The CEO of Danske Rederier, Anner H. Steffensen, said that the energy island project can support approximately 42,000 jobs[74], many of which must be employees from the oil and gas industry with the right qualifications and competencies.[73]

Due to the relatively early stage of the energy island project, there are many unresolved issues. The potential of using the island to serve other purposes, such as the conversion of electricity to other energy sources (PtX) in the future, is still under discussion. Nor has the design of the island been determined. Several design solutions have been presented, one of which can be seen in Figure 7.

Figure 7: An illustration of how the world's first artificial energy island could potentially look like[38].

The Danish government is not alone in the idea of connecting the electricity grid in the North Sea to a power hub. In 2017, TenneT Netherlands, TenneT Germany and the Danish Energinet at the Seas Energy Forum in Brussels set up a consortium focusing on the transnational and cross-sectoral approach in the North Sea. The hub-and-spoke concept by the consortium supports governments and policymakers in their decision-making process on realising the potential of the green energy market in the North Sea transnationally[30].

The company Neptune Energy in the Netherlands follows another approach. As parts of the North Sea offshore oil and gas assets are approaching the end of life and face decommissioning in the coming decade, they become available for repurposing. Therefore, the company, together with partners, is expected by early 2023 to startup the first offshore PtX plant in the world on a satellite platform (platform PL-Q13a-PA) through the PosHYdon project[30],[75]. The project further demands that the production of hydrogen, by splitting it from the desalinated seawater with electrolyzes, come from wind energy[30],[75],[76]. That requires the platform to be electrified to produce hydrogen fossil-free, while today offshore platforms are powered by large gas turbines and pumps using gas without connection to the electricity grid.

Electrifying offshore platforms while they are still in operation for oil and gas extraction also benefits CO_2 emissions reductions[77]. It is estimated from the baseline projection that the total discharge from the North Sea offshore oil and gas platforms in Denmark will be 1.0 million tonnes of CO_2 per year in 2030[77]. By partially electrifying the platforms, it is estimated that it will be possible to reduce emissions by 0.2-0.6 million tonnes of CO_2 per year[78]. However, the potential could further increase, depending on the dimension of the offshore wind farms, the electricity demand and whether a cable is established directly on the shore or via the future energy island[77]. If electricity is drawn from the onshore electricity grid, the entire platform's energy consumption can be covered when wind farms cannot fulfil the demand.

Currently, about 22 GW of offshore wind is installed across Europe, of which 77% is located in the North Sea[79]. The offshore wind capacity is expected to reach 76 GW in 2030, over a three-fold increment in the next decade[79]. Future wind farms will be located further out to sea not to deplete the coastal locations[38] and will be positioned closer to the offshore platforms, thus increasing the potential to establish a synergy with the oil and gas industry.

Denmark is not the only country investigating the possibility of electrifying offshore platforms in the North Sea. Several Norwegian companies have the same ambition, and the Norwegian government has already approved the electrification of three of them[80], [81].

Electrification of offshore platforms in practice does not directly affect the transition of the oil and gas industry and does not in itself point to a fossil-free future. However, it can be a prudent transitional solution to reduce CO_2 emissions while the platforms are still in operation, as is happening in Norway[49]. Furthermore, it also incentivises the solution of reusing the platforms after they have served their purpose in the oil and gas regime, reducing the capital cost of implementing CCS or PtX topside[43]. In addition, the depleted offshore oil and reservoirs could potentially be used to store the X-product. The gross area available on the platform, however, constrains the maximum capacity that can be installed of the technology selected, such as a PtX system.

The electrification of the platforms gives oil and gas companies opportunities to lower their CO_2 footprint and leverage existing offshore infrastructure for billions of dollars[75]. Currently, the offshore pilot projects, such as the energy island project in Denmark and the PosHYdon project in the Netherlands, are still in an early stage[43],[30],[75]. It will probably take years before conclusions can be drawn about whether a project like PosHYdon can be done financially[75]. Jacobs[75]. even estimates that we may not know it until this decade ends. Furthermore, as the PosHydon project aims to gain experience in including hydrogen in an integrated offshore environment, it is yet to be investigated how and to which degree the existing offshore oil and gas workforce and technologies can be adapted into this type of application[76].

Conclusion

The North Sea area is in transition. While oil and gas production is declining, the offshore wind industry is growing. The production of oil and gas in the Danish sector of the North Sea faces an early end of life, before petroleum reservoirs from which oil may be economically recovered are depleted. Oil and gas stakeholders strive to be part of a just transition and look for opportunities where parts of their existing technologies can integrate into the future offshore energy system. The two case studies presented in the report highlighted some of the potential synergies. The investigations show that the oil and gas industry in the North Sea has great potential to be part of a just transition. In the meantime, electrifying offshore platforms can be a prudent solution to reduce the CO2 emissions while these are still in operation. Furthermore, connecting offshore platforms to the electrical grid may incentivize the technology transition after their end of life, e.g., with CCS or as energy hubs.

Based on the two case studies, stakeholders from the oil and gas industry are already involved in many of the projects, indicating that the companies aim to maintain their presence in the North Sea energy industry in the future.

The report also focused on how the oil and gas industry hardware can become part of the transition, as platforms approach the end of life and decommissioning in the coming decade. The two case studies show that several projects aim to repurpose offshore platforms and infrastructure in the future.

The extent to which the existing assets of the oil and gas industry will be repurposed is difficult to predict. However, major oil and gas companies could maintain their position in the North Sea through investments in upcoming technologies, such as CCS and PtX, thus becoming part of the future North Sea offshore energy systems. While not addressed in the report, legislative, financial and political factors will have to be considered if existing technologies from the offshore oil and gas industry are to be reused or otherwise transferred into a new fossil-free industry in the North Sea.

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Annex

Oil and gas operators:				
Company	**Employee**	**Revenue' 000,-**	**Gross profit' 000,-**	**Financial year**
Total SE TotalEnergies EP Danmark A/S TotalEnergies EP Algerie Berkine A/S TOTAL E&P ALS A/S TotalEnergies EP Pipelines Danmark A/S TEPKRI Sarsang A/S TotalEnergies Upstream Danmark A/S	1,102 0 0 0 0 364	271,242 USD 376,615 USD 18,844 USD - 44,288 USD 150,594 EUR	5,032 USD 280,382 USD 2,308 USD 4,693 USD 10,548 USD 83,771 EUR	2020-12 2020-12 2020-12 2020-12 2020-12 2020-12
INEOS E&P A/S INEOS E&P GRØNLAND A/S INEOS E&P (Petroleum Denmark) ApS INEOS E&P DK A/S	210 0 0 0	1,182,106 DKK - - 13,110 DKK	852,706 DKK -284 DKK -27,304 DKK 15,163 DKK	2019-12 2019-12 2019-12 2019-12
Wintershall Noordzee B.V.	0	-	-	2020-04
HESS DENMARK ApS	95	88,283 USD	-266,903 USD	2020-12
Dana Petroleum Denmark B.V.	0	-	-	2020-12

Table 4: A list of each five operators in the Danish offshore oil and gas industry and their ownership structure. The lists include information on revenue, gross profit, and the number of employees for each company.

Training:				
Company	**Employee**	**Revenue' 000,-**	**Gross profit' 000,-**	**Financial year**
MAERSK TRAINING A/S MAERSK H2S SAFETY SERVICES A/S	96 62	- -	50,090 DKK 56,936 DKK	2020-12 2020-12
Sat ApS	3	-	1,710 DKK	2019-12
RelyOn Nutec Denmark A/S	51	-	34,917 DKK	2019-12

Table 5: A list of each private training company in relation to the offshore industry and their ownership structure. The lists include information on revenue, gross profit, and the number of employees for each company.

Refineries:				
Company	**Employee**	**Revenue' 000,-**	**Gross profit' 000,-**	**Financial year**
Crossbridge Energy A/S (A/S Dansk Shell)	259	8,214,500 DKK	-608,000 DKK	2020-12
Equinor Refining Denmark A/S	338	20,588,212 DKK	883,333 DKK	2019-12

Table 6: A list of both refineries in Denmark. The lists include information on revenue, gross profit, and the number of employees for each company.

General service companies:				
Company	**Employee**	**Revenue' 000,-**	**Gross profit' 000,-**	**Financial year**
ALL NRG A/S ALL NRG Oil & Gas A/S	193 195	235,335 DKK -	170,845 DKK 131,169 DKK	2020-04 2020-04
BLADT INDUSTRIES A/S	473	1,956,226 DKK	127,289 DKK	2020-12
CAVERION DANMARK A/S	621	699,898 DKK	307,627 DKK	2020-12
DNV Denmark A/S	175	361,585 DKK	213,027 DKK	2020-12
ELTRONIC Group A/S HE MARINE A/S TS Tech Eltronic Holding ApS TS TECH A/S	28 0 39	- - -	15,651 DKK -31 DKK 25,911 DKK	2020-10 2020-10 2020-10
Envipa ApS	1	-	394 DKK	2020-12
FANØ KRAN-SERVICE A/S	80	-	67,601 DKK	2020-12
FH CONTRACTORS A/S	13	-	8,6391 DKK	2019-12
FORCE Technology	1,077	144,600 EUR	-	2020-12
Juel+Krøyer A/S	27	-	22,317 DKK	2020-05
KENSO GROUP ApS ESBJERG MARITIME SERVICE ApS GLOBAL GRAVITY ApS	38 11	- -	34,971 DKK 22,911 DKK	2020-05 2020-05
Muehlhan A/S	501	464,935 DKK	321,846 DKK	2020-12
PTL VALVE SERVICES A/S	3	-	2,143 DKK	2020-07
RAMBØLL GRUPPEN A/S RAMBØLL DANMARK A/S RAMBOLL OIL & GAS MIDDLE EAST A/S RAMBØLL MANAGEMENT CONSULTING A/S	80 2,678 2 265	202,235 DKK 2,732,637 DKK 487 QAR 308,423 DKK	- 2,264,193 DKK 166 QAR 229,237 DKK	2020-12 2020-12 2020-12 2020-12
SERVICE GROUP ESBJERG ApS	14	-	12,496 DKK	2020-09

Table 7: A detailed list of general service companies in relation to the Danish offshore oil and gas industry and their ownership structure. The lists include information on revenue, gross profit, and the number of employees for each company.

Distributers:				
Company	**Employee**	**Revenue' 000,-**	**Gross profit' 000,-**	**Financial year**
Energinet. Gas Storage Denmark Holding A/S Gas Storage Denmark A/S Energinet Teknik og Anlæg A/S Energinet Forretningsservice A/S Energinet Gas TSO A/S	(1,247) 40 85 320 69	(5,700,000 DKK) 418,360 DKK 224,859 DKK 708,892 DKK 443,357 DKK	- - - - -	 2020-12 2020-12 2020-12 2020-12 2020-12 2020-12
Evida Holding A/S Evida Syd A/S Evida Fyn A/S Evida Nord A/S Evida Service Syd A/S Evida Service Nord A/S	 0 0 0 150 280	680,816 DKK 140,387 DKK 607,494 DKK 448,862 DKK 541,002 DKK	441,586 DKK 93,584 DKK 229,648 DKK 132,359 DKK 206,812 DKK	2020-12 2020-12 2020-12 2020-12 2020-12
Ørsted A/S Ørsted Salg & Service A/S Ørsted Pipelines A/S Danish Offshore Gas Systems A/S Ørsted Services A/S Danish Oil Pipe A/S	6 0 1 1 1,317 1	173,000 DKK 18,709,000 DKK 0 DKK 1,042,052 DKK 2,567,839 DKK 377,441 DKK	173,000 DKK - -25 DKK -13,075 DKK 1,191,121 DKK 56,019 DKK	2019-12 2020-12 2020-12 2020-12 2020-12 2020-12

Table 8: A detailed list of different distributor companies in relation to the Danish offshore oil and gas industry and their ownership structure. The lists include information on revenue, gross profit, and the number of employees for each company.

Logistics and storage:				
Company	**Employee**	**Revenue' 000,-**	**Gross profit' 000,-**	**Financial year**
Associated Danish Ports A/S FREDERICIA HAVN A/S NYBORG HAVN A/S	59 45 8	(5,700,000 DKK) 418,360 DKK 224,859 DKK 708,892 DKK 443,357 DKK	- - - - -	 2020-12 2020-12 2020-12 2020-12 2020-12
BEL AIR GROUP A/S BEL AIR AVIATION A/S BEL AIR AVIATION INVEST A/S BEL AIR BASE A/S	 33 0 0	- - -	25,687 DKK 17,991 DKK 936 DKK	2020-12 2020-12 2020-12
BLUE WATER SHIPPING A/S	842	4,616,134 DKK	548,897 DKK	2020-12
DANSKE OLIEBEREDSKABSLAGRE	20	-	-	
ESVAGT A/S	929	973,813 DKK	704,243 DKK	2020-12
Harbour Group Holding ApS JUTLANDIA TERMINAL A/S COPCO A/S. COPCO TANK TERMINAL A/S Copco Chem A/S	 63 5 0 0	 - - - -	 52,954 DKK 14,954 DKK 5,355 DKK 2,829 DKK	 2020-12 2020-06 2020-06 2020-06
INTER TERMINALS DENMARK A/S	39	46,934 EUR	38,209 EUR	2020-12
NHV A/S	73	354,462 DKK	133,328 DKK	2019-12
OIL STORAGE ApS	0	-	12,846 DKK	2020-12
Port Esbjerg	59	30,540 EUR	24,560 EUR	2019-12
WORLD MARINE OFFSHORE A/S WMO Management A/S WMO Support A/S	21 2 13	- - -	7,671 DKK 5,719 DKK 4,788 DKK	2020-12 2020-12 2020-12

Table 9: Logistics and storage companies in relation to the Danish offshore oil and gas industry.

Suppliers of hardware:				
Company	**Employee**	**Revenue' 000,-**	**Gross profit' 000,-**	**Financial year**
ABB A/S	376	1,581,592 DKK	340,879 DKK	2020-12
Alfa Laval Kolding A/S	643	1,705,816 DKK	605,768 DKK	2020-12
ALFA LAVAL COPENHAGEN A/S	480	911,067 DKK	89,334 DKK	2020-12
ALFA LAVAL NORDIC A/S	80	503,595 DKK	83,091 DKK	2020-12
ALFA LAVAL NAKSKOV A/S	120	191,528 DKK	41,018 DKK	2020-12
DANISH FLUID SYSTEM TECHNOLOGIES A/S	16	-	18,428 DKK	2020-12
EMERSON PROCESS MANAGEMENT A/S	36	-	35,000 DKK	2020-09
HYTOR Group A/S	19	-	13,046 DKK	2020-12
HYTOR Tools Solutions A/S	20	-	23,128 DKK	2020-12
HYTOR Oil & Gas Solutions A/S	0	-	2,588 DKK	2020-12
HYTOR Fluid Solutions A/S	22	-	5,560 DKK	2020-12
MACARTNEY A/S	174	340,055 DKK	107,077 DKK	2020-09
MacArtney Hydraulics A/S	52	-	22,923 DKK	2020-09
OCEAN TEAM SCANDINAVIA A/S	20	-	18,519 DKK	2020-09
Offshore Equipment & Services ApS	4	-	3,058 DKK	2019-12
SH GROUP A/S	301	430,718 DKK	212,858 DKK	2020-12
SIHM HØJTRYK A/S	15	-	10,404 DKK	2020-09
SOIL RECOVERY A/S	25	-	27,526 DKK	2019-12
Subc Partner A/S	54	-	58,766 DKK	2019-12
VALTOR OFFSHORE A/S	14	-	4,866 DKK	2020-12
VIKING LIFE-SAVING EQUIPMENT A/S	390	1,227,364 DKK	340,654 DKK	2020-12
HydroPen ApS	2	-	5,097 DKK	2020-12

Table 10: A detailed list of hardware suppliers to the Danish offshore oil and gas industry.

Wholesale trade services of solid, liquid and gaseous fuels:				
Company	**Employee**	**Revenue' 000,-**	**Gross profit' 000,-**	**Financial year**
A/S UNITED SHIPPING & TRADING COMPANY	613	231,511 USD	27,508 USD	2020-04
UNI-TANKERS A/S	29	8,945 USD	3,543 USD	2020-04
UNI-TANKERS M/T "JUTLANDIA SWAN" ApS	35	8,273 USD	3,208 USD	2020-04
UNI-TANKERS M/T "SELANDIA SWAN" ApS	35	4,422 USD	3,257 USD	2020-04
UNI-TANKERS M/T "FIONIA SWAN" ApS	35	5,612 USD	2,306 USD	2020-04
UNI-TANKERS M/T "SAMUS SWAN" ApS	29	4,636 USD	2,137 USD	2020-04
UNI-TANKERS M/T "ALSIA SWAN" ApS	19	108,825 USD	2,534 USD	2020-04
UNI-CHARTERING A/S	27	5,392 USD	2,532 USD	2020-04
UNI-TANKERS M/T "LILLO SWAN" ApS	29	4,780 USD	1,899 USD	2020-04
UNI-TANKERS M/T "FENNO SWAN" ApS	27	4,867 USD	1,771 USD	2020-04
UNI-TANKERS M/T "ENDELO SWAN" ApS	35	4,476 USD	3,321 USD	2020-04
UNI-TANKERS M/T "MONA SWAN" ApS	29	4,747 USD	1,810 USD	2020-04
UNI-TANKERS M/T "FEO SWAN" ApS	35	6,881 USD	2,629 USD	2020-04
UNI-TANKERS M/T "TASING SWAN" ApS	27	5,629 USD	2,568 USD	2020-04
UNI-TANKERS M/T "FALSTRIA SWAN" ApS	37	6,896 USD	2,916 USD	2020-04
UNI-TANKERS M/T "ERRIA SWAN" ApS	33	5,958 USD	2,251 USD	2020-04
UNI-TANKERS M/T "LESSOW SWAN" ApS.	35	3,913 USD	2,335 USD	2020-04
UNI-TANKERS M/T "BORINGIA SWAN" ApS	33	5,834 USD	2,077 USD	2020-04
UNI-TANKERS M/T "ANHOUT SWAN" ApS	27	723 USD	421 USD	2020-04
UNI-TANKERS M/T "AMAK SWAN" ApS	0	-	-1 USD	2020-04
UNI-TANKERS M/T "MANDIA SWAN" ApS	1,508	10,946,049 USD	439,532 USD	2020-04
BUNKER HOLDING A/S	19	656,629 USD	13,207 USD	2020-04
KPI OceanConnect A/S	23	851,446 USD	40,611 USD	2020-04
UNIOIL SUPPLY A/S	0	0 DKK	0 DKK	2020-04
UNIOIL CARGO A/S	0	100 DKK	56 DKK	2020-04
USTC ADMINISTRATION ApS	36	717,153 USD	20,195 USD	2020-04
A/S DAN-BUNKERING LTD	16	9,626 USD	107 USD	2020-04
A/S GLOBAL RISK MANAGEMENT LTD. HOLDING	0	-	311 USD	2020-04
BMS United Bunkers S.A. ApS				
BP DANMARK A/S	0	-	-153 DKK	2019-12
BP AVIATION A/S	7	982,652 DKK	29,514 DKK	2019-12
NORDIC LUBRICANTS A/S	7	216,949 DKK	24,896 DKK	2019-12
Circle K DANMARK A/S	1,892	10,819,563 DKK	2,016,787 DKK	2020-04
D.F.N. OIL A/S	3	-	826 USD	2019-12
DCC DENMARK A/S				
DCC ENERGI CENTER A/S	126.	-	122,568 DKK	2020-03
DCC ENERGI DANMARK A/S	0	2,483,845 DKK	136,099 DKK	2020-03
DCC Energi Retail A/S (Shell Express)	0	5,492,925 DKK	101,708 DKK	2020-03
Go'on Gruppen A/S	18	1,032,485 DKK	94,298 DKK	2020-12
Kosan Gas A/S	58	293,378 DKK	157,358 DKK	2020-09
MALIK SUPPLY A/S	15	1,116,182 DKK	26,902 DKK	2020-12
ORSIIVIK ApS	24	-	14,539 DKK	2020-12
G.O. AF 01.10.2006 ApS	3	-	2,888 DKK	2020-12
NORDIC MARINE OIL A/S	31	734,434 DKK	47,617 DKK	2020-12
MONJASA A/S	94	580,052 USD	15,063 USD	2020-12
Maersk Oil Trading and Investments A/S	0	1,501,100 USD	-	2020-12
MAERSK OIL TRADING LUBRICANTS A/S	0	-	1,138 USD	2020-12
OIL! tank & go ApS	6	559,118 DKK	43,844 DKK	2020-12
OK A.M.B.A.	473	6,102,230 DKK	1,446,825 DKK	2020-12
DANOIL EXPLORATION A/S	1	-	-84,859 DKK	2020-12
OK PLUS A/S	19	-	18,922 DKK	2020-12
OK PLUS BUTIKSDRIFT A/S	14	-	5,803 DKK	2020-12

PRIMAGAZ DANMARK A/S	63	-	56,784 DKK	2019-12
Q8 DANMARK A/S	725	3,883,818 DKK	742,804 DKK	2021-02
Sasoil Denmark A/S	0	563,506 DKK	-	2020-10
UNO-X DANMARK A/S	11	3,108,901 DKK	260,738 DKK	2020-12
VIKING ENERGI A/S	13	-	20,594 DKK	2020-12
WORLD FUEL SERVICES (DENMARK) ApS	9	-	8,379 DKK	2019-12
YX Danmark A/S	54	2,521,986 DKK	183,376 DKK	2019-12

Table 11: A detailed list of wholesale trade services of solid, liquid, and gaseous fuels in Denmark and their ownership structure.

Specialized offshore service companies:				
Company	**Employee**	**Revenue' 000,-**	**Gross profit' 000,-**	**Financial year**
Altus Intervention AS, filial af Norge				
ARCHER OFFSHORE DENMARK A/S	1	-	1,919 DKK	2020-12
Halliburton Denmark ApS	81	-	11,295 DKK	2019-12
NATIONAL OILWELL VARCO DENMARK I/S	694	1,146,187 DKK	320,393 DKK	2019-12
Neptune Energy Denmark ApS	0	-	-927 DKK	2020-12
Noreco Oil Denmark A/S	16	480,213 USD	122,664 USD	2020-12
NorSea Denmark A/S	217	-	128,650 DKK	2020-12
OILFIELD SOLUTIONS ApS	11	-	13,178 DKK	2020-12
ONE-Dyas Denmark ApS	0	-	-1,552 DKK	2019-12
PETROGAS DENMARK ApS	0	-	-	2020-12
SCHLUMBERGER DANMARK ApS	90	369,031 DKK	105,787 DKK	2019-12
SEMCO MARITIME A/S	854	997,643 DKK	645,952 DKK	2020-12
The Drilling Company of 1972 A/S	(2,678).	(1,096,000 USD)		2020-12
MAERSK DRILLING A/S	675	94,411 USD.	-	2020-12
MAERSK DRILLING SERVICES A/S	0	277,466 USD.	183,976 USD	2020-12
MAERSK DRILLING DEEPWATER A/S	0	32,801 USD.	12,795 USD	2020-12
MAERSK DRILLING INTERNATIONAL A/S	0	16,617 USD.	-20,595 USD	2020-12
MAERSK INTREPID NORGE A/S	0	34,249 USD.	-3,764 USD	2020-12
MAERSK INTEGRATOR NORGE A/S	0	66,745 USD.	-	2019-12
MAERSK INTERCEPTOR NORGE A/S	0	127,918 USD.	-	2019-12
MAERSK INVINCIBLE NORGE A/S	0	163,051 USD.	-	2019-12
MAERSK DRILLING NORTH SEA A/S	0	8,922 USD.	-	2020-12
Wellperform ApS	14	-	10,135 DKK	2020-12
WELLTEC INTERNATIONAL ApS				
WELLTEC A/S	173	87,912 USD	46,475 USD	2020-12
Welltec Manufacturing Center Completions ApS	46	-	2,867 USD	2020-12

Table 12: A detailed list of different specialized service companies in relation to the Danish offshore oil and gas industry and their ownership structure.

Oil & Gas Transitions

North Sea Oil and Gas:

Potential Technological Transformation Towards Net-Zero Emissions

For more information visit: www.oilandgastransitions.org.

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