MASTER´S THESIS

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Norwegian wind power development in Norway and the UK

Date: 31.08.20 Total number of pages: 107

NORD University

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Forord

Denne masteroppgaven er vårt siste arbeid som studenter ved Nord universitet og markerer slutten på en fin studietid. Det siste semesteret har vært ganske annerledes grunnet COVID-19 og har medført enkelte utfordringer, men vi har allikevel klart å arbeide effektivt og målrettet. Bakgrunnen for å skrive om vindkraft har vært vår interesse for fagfeltet og at temaet har vært aktuelt med et stort mediefokus den siste tiden. Arbeidet har til tider vært krevende, men samtidig svært givende og prosessen har gitt oss ett stort læringsutbytte med økt innsikt i en voksende bransje.

Vi vil gi en stor takk til vår veileder Petter Nore, som har vært til stor hjelp under hele prosessen.

Bodø, 31. august 2020.

Sammendrag

Denne oppgaven omhandler vindkraft og inneholder en sammenligning av landbasert vindkraft, bunnfast havvind og flytende havvind.

Problemstillingens fokus er på hvilken av de tre typene av vindkraft som vil være det beste alternativet for norske selskaper som ønsker å utvikle vindkraft i Norge eller Storbritannia, ved å sammenligne landbasert, bunnfast og flytende havvind. For å gjøre denne sammenligningen har vi benyttet oss av PESTEL, SWOT og Lifecycle-stage analyse.

Fosen prosjektet og dets seks vindparker blir brukt som eksempel for den landbaserte vind industrien, mens Dogger Bank prosjektet utenfor kysten av Yorkshire i England brukes som eksempel på bunnfast havvind og Equinor`s Hywind Scotland brukes som eksempel på flytende havvind siden det er verdens første flytende havvindpark.

Oppgavens konklusjon bygger på økonomiske, miljømessige og sosiale aspekter. Kostnadene (LCOE) av landbasert vind er vesentlig lavere enn både flytende og bunnfast havvind, der flytende havvind er den klart dyreste av de tre.

Når man tar i betraktning sosiale og miljømessige aspekter dannes et annet bilde. Med sin større synlighet og påvirkning på miljøet er landbasert vind kontroversielt og har møtt stor motstand. Disse problemene blir i større grad unngått ved både flytende og bunnfast havvind på grunn av at disse ofte har en beliggenhet et stykke unna friluftsområder og sivilisasjon.

Ved å se på disse tre aspektene har vi konkludert med at det beste alternativet er bunnfast havvind.

Summary

Our thesis addresses Norwegian wind power development and contains a comparison between onshore, fixed offshore and floating offshore wind.

The research question focuses on which of the three approaches that should be the preferred alternative for Norwegian companies looking to develop wind power in Norway and the UK, by comparing and contrasting onshore, floating offshore and fixed offshore wind. For our comparison we have utilized the PESTEL, SWOT and lifecycle-stage analysis.

The Fosen project and its six wind parks is used as an example for the onshore wind industry, while Dogger Bank outside of the Yorkshire coast is used as the fixed offshore example. For floating offshore wind, Equinor`s Hywind Scotland is our example as it is the first floating offshore wind farm of its kind.

Our conclusion is based upon the three pillars of sustainability: Economic, environmental and social aspects. The costs (LCOE) of onshore wind is significantly lower than both floating and fixed offshore, with floating being the costliest alternative of the three.

When considering social and environmental aspects a different picture is formed. Onshore wind with its visibility and environmental impact has been proven to be controversial and met with significant resistance. Both fixed and floating offshore wind manages to avoid many of these controversial aspects due to being located at sea, often away from sight and civilization. By looking into these three aspects we have concluded that the preferred alternative should be fixed offshore wind.

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List of Abbreviations

CFD – Contract for Differences.

DA – Delt Ansvar.

DR - Doctor

KWh – Kilowatt hour.

LCOE – Levelized Cost of Energy.

MW – Megawatt.

NIMBY – Not in My Backyard.

NPV - Net Present Value

NVE – Norges Vassdrags og Energidirektorat.

O&M – Operation & Maintenance.

PESTEL – Political, Economic, Social, Technological, Environmental and Legal.

RO – The Renewable Obligation

ROI – Return on Investment.

SWOT – Strengths, Weaknesses, Opportunities and Threats.

TWh – Terawatt hour

UK – United Kingdom.

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Chapter 1: Introduction

This chapter outlines the background for our thesis (section 1.1), followed up by the purpose behind our thesis and corresponding research question (section 1.2). The significance of our thesis will be found in section 1.3, and the scope, structure and delimitations of this thesis will be presented in section 1.4. Finally, section 1.5 will outline the remaining chapters of our thesis.

1.1 Background

Norway is one of the biggest petroleum exporters in the world, and petroleum has been the backbone of the Norwegian economy since production from the Ekofisk oil field began in 1971[1]. However, Norway has in accordance with the Paris agreement, set out to cut its carbon footprint by diversifying into the renewable energy industry as one of the measures to honor this agreement. Even though most of the electricity production in Norway stems from hydropower[2], this energy source is thought of as having limited growth potential, and Norway has set out to diversify into other renewable energy sources. The increased investments in wind development shows this trend, where the construction of Fosen wind has made Norway the country in Europe with the largest onshore wind farm[3]. Meanwhile, the Norwegian company Equinor is on the forefront of offshore technological development with its Hywind project[4], while currently developing the Dogger Bank project, which will be the world's largest offshore wind farm upon completion.

Norwegian wind power development is not limited to Norwegian territory, as seen from Equinor`s Dogger Bank project outside the coast of Yorkshire, while Hywind is located outside the coast of Scotland. Norwegian wind power developments on both Norwegian and UK territory will therefore be included in this thesis.

[1] Government. (2013, 09. October). Norway`s oil history in 5 minutes. Retrieved from https://www.regjeringen.no/en/topics/energy/oil-and-gas/norways-oil-history-in-5-minutes/id440538/

[2] Government (2016, 11. May) Renewable Energy Production in Norway. Retrieved from https://www.regjeringen.no/en/topics/energy/renewable-energy/renewable-energy-production-in-norway/id2343462/

[3] Statkraft (N.A). Norge. Retrieved (2020, 24. February) from https://www.statkraft.no/om-statkraft/Prosjekter/norge/fosen/

[4] Equinor (N.A) The future of offshore wind is afloat. Retrieved 2020, 14. March. from https://www.equinor.com/no/what-we-do/floating-wind.html

1.2 Purpose and research question

Norway is actively pursuing both onshore and offshore wind power development, which is apparent from the onshore development of Fosen wind, and Equinor's development of Hywind, the world's first operational floating offshore wind farm, and the construction of Dogger Bank, the world's largest offshore bottom fixed wind farm upon completion.

While Norwegian companies operate in these different wind power segments simultaneously, the different alternatives come with its own unique set of challenges and opportunities. It would be interesting to ascertain as to which of these wind power segments that Norwegian companies should devote most of their attention to.

This led to our research question which is to:

Compare and contrast onshore, floating offshore and fixed offshore wind power developments in Norway and the UK, to discover which of these approaches that should be the preferred wind power alternative for Norwegian companies in the future.

1.3 Significance

Our thesis may help to better understand Norwegian wind power development, in relation to which wind power alternative that should be developed in Norway and the UK. Although this thesis is from a Norwegian perspective, and not all findings will be relevant for other countries looking to develop wind power, this thesis may still identify important considerations when choosing which wind power alternative that a country or company should focus on.

1.4 Scope, structure, and delimitations

The scope of this thesis is to conduct an analysis of the general wind industry in Norway and the UK by utilizing a PESTEL analysis, where we will be looking at Political, Economic, Social, Technological, Environmental, and Legal factors that apply for both onshore and offshore wind power developments (Section 5.1). This part of our analysis will provide an overview.

For our industry analysis, we will use a lifecycle-stage framework, that divides the total lifetime of a wind farm into different stages, from project initiative, to the end of the project. This division makes the analysis more transparent, as the differences between onshore, offshore bottom-fixed and offshore floating wind developments are made easier to identify (Section 5.2). This section will provide insight into technical differences between the different wind power segments.

Our Cost analysis will be conducted by utilizing a LCOE analysis for the different wind power segments (Section 5.3). This section identifies the cost-specific differences between the wind power segments.

Finally, our research is focused on an analysis of the Strengths, Weaknesses, Opportunities, and Threats through the use of a SWOT analysis for the Fosen wind, Hywind and Dogger bank projects (Section 5.4). This section will account for all previous findings from the previous analytical sections and enables us to draw a conclusion (Chapter 6.0).

Our thesis is limited to one project for each wind power segment, as we have a wide scope, and therefore find it necessary to limit our thesis within these restrictions. For the offshore wind industry, we are looking at the Hywind and Dogger bank projects.

We are looking at the Hywind Scotland project as it is the first offshore floating wind farm initiative, and the Hywind concept is expected to have a vast growth potential.

Dogger bank will be included in our analysis, as it is the world's largest bottom fixed wind farm upon completion.

For our analysis of onshore wind, we decided to look at Fosen wind, as it is the largest onshore wind park in Europe.

Our thesis consists primarily of secondary data, but we have also conducted interviews with project representatives for the offshore and onshore wind industry for our analysis.

In section 2.3.2 "**Opportunities for further Norwegian offshore floating wind power developments"** and section 2.3.4 "**Opportunities for Further Norwegian offshore bottom-fixed wind power developments**", it will further be explained why offshore Norwegian wind power developments in the UK is included in our thesis.

1.5 Thesis outline

This section outlines the remaining chapters of our thesis.

Chapter 2 relates to our literature review which consists of the background of wind power development and an explanation of the objects we intend to analyze in our thesis.

Chapter 3 will explain the research design used in developing this thesis.

Chapter 4 will give an explanation of our theoretical approach.

Chapter 5 consists of our analyses.

Chapter 6 contains our conclusion.

Chapter 2: Literature Review

In this section we will present the background of wind power development, followed by an explanation of the different objects we will analyze in this thesis. All relevant content in relation to wind power that is not in our analysis will be found in this chapter.

2.1 Background

The history of modern wind power

Modern wind power has been pioneered by the Danish, Dutch and Americans. The modern way of using wind power in a large scale came in the 1980s, with the capacity of turbines increasing from 20 to 2000 kw from the early 1980s to the early 2000s. The competitiveness and reliability increased greatly during this period and the cost per KWh was reduced.

The oil crisis in the 1970s forced several countries to look for alternative sources of energy, thereby, the modern wind industry as we know it today started to develop in the late 1970s - early 1980s. During the same time, there was a heightened debate about the limited natural resources on earth, in addition to the global concern of emissions. This combination, along with increasing technological advancements in wind energy, made large scale wind development a promising outlook: it was environmentally friendly, while also being a renewable source of energy.

Wind turbines

The first modern turbines were created by two widely different initiatives: Large scale national wind programs, and small-scale market-oriented manufacturing. The large-scale national wind programs created huge investments into research & development, that would later make wind turbines more technological advanced.

Meanwhile, the low-scale market-oriented manufacturers made use of know-how in other fields, specifically manufacturers of farming equipment, where proven methods from this field were introduced into the development of wind turbines.

The first small-scale wind energy development initiatives came from the Danish parliament, which granted subsidies in the manufacturing of wind turbines, greatly increasing the profit potential of being a part of this newly created market[5]. Wind energy development is in modern times not viewed as only a decentralized power solution, but rather a renewable energy source that can be applied to a large scale.

Wind power today

Modern wind power is divided into onshore and offshore, where offshore wind power has been given the most attention from a development perspective. According to the IEA (International Energy Agency), offshore wind may become competitive with fossil fuels within the next decade if costs of offshore wind keeps decreasing. Following with the statement that offshore wind is expected to yield total investments of around $840bn over the next two decades[6].

Although offshore wind is expected to be a vital player in the overall energy mix in the future, it still needs to accelerate its growth to reach the goal set in the sustainable development scenario (SDS) of 600Twh. In comparison, the production in 2018 was 67Twh, which shows that offshore wind requires a large growth before it comes close to the requirements in the SDS[7].

Onshore wind is in a similar situation in terms of the need to accelerate growth to reach the goal set in the SDS. However, in the SDS, the goals for onshore wind is set as 3749Twh, compared to the production for 2018 which was 1202Twh[8].

Hydrogen wind power

Wind power has more applications than just pure electricity production. It can also be applied in the production of hydrogen and make one form of renewable energy from another.

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[5] Wizelius, T (2007). Developing Wind Power Projects: Theory and Practice. UK, London: Earthscan. P. 19 – 22.
[6] Financial Times (2019, 24. October). Wind Power has Capacity to Meet World`s Entire Energy Demand. Retrieved from https://www.ft.com/content/7c36dd38-f69b-11e9-a79c-bc9acae3b654
[7] IEA (N.A). Offshore wind power generation in the sustainable development scenario, 2000-2030. Retrieved (2020, 27. May) from https://www.iea.org/fuels-and-technologies/wind
[8] IEA (N.A). Onshore wind power generation in the sustainable development scenario, 2000-2030. Retrieved (2020, 27. May) from https://www.iea.org/fuels-and-technologies/wind

While still in its early stages, hydrogen from wind power production could solve the problems associated with transportation of wind energy over longer distances. The process known as electrolysis, where water is split into hydrogen and oxygen is the cornerstone of this kind of hydrogen production. Hydrogen has many applications and can be used to power fuel cells, turbines, and engines[9].

In Finnmark where the wind conditions are extremely favorable, the EU has established a project to test the combination of wind power and hydrogen production[10].

One of the key aspects of this project is the storage of energy from wind through hydrogen production and proving that the use of mini grids is possible[11].

2.2 Onshore wind development

The advantages of onshore wind farms, compared with offshore installations include lower costs, and easier access to infrastructure and the grid. Costs have in recent years decreased, with LCOE decreasing by 35 % from 2010 to 2018. This decrease in costs is largely driven by technological and manufacturing process improvements. Supply chains becoming more competitive is also an important driver for this[12].

Often onshore wind farms impact local population, wildlife, and nature in general. This has led to controversy and conflict in some cases. The turbines large size can cause the scenery to change radically and trigger protests from local residents.

Turbines have in recent years seen a trend towards becoming larger and rotor diameters have seen a similar trend.

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[9] Paratico, Virginio (2020, 25. February) The Next Chapter of Offshore Wind Energy: W2H2, Wind to Hydrogen. Retrieved from https://www.offshorewind.biz/2020/02/25/the-next-chapter-of-offshore-wind-energy-w2h2-wind-to-hydrogen/

[10] Olsen, Claude (2019, 15. April) Berlevåg to Serve as Base for Major EU Project. Retrieved from https://www.forskningsradet.no/en/EUs-framework-programme/Apply-Horizon2020-funding/tips-fra-noen-som-har-lykkes-i-horisont-2020/berlevag-blir-sentrum-for-stort-eu-prosjekt/

[11] Varanger Kraft (N.A) Produksjonsmetoder. Retrieved (2020, 29. May) from https://www.varanger-kraft.no/hydrogen/

[12] IRENA (2019), Renewable Power Generation Costs in 2018, International Renewable Energy Agency, Abu Dhabi. P. 18. Retrieved from ttps://www.irena.org/-/media/Files/IRENA/Agency/Publication/2019/May/IRENA_Renewable-Power-Generations-Costs-in-2018.pdf

2.2.1 Fosen wind

Photo: Fosen Vind

Fosen Wind was established in 2015 as a joint-venture company by Statkraft (52,1%), Nordic wind power DA(40%) and TrønderEnergi (7,9%), with the purpose of creating, developing and maintaining the six-wind parks: Roan, Storheia, Kvenndalsfjellet, Harbaksfjellet, Geitfjellet and Hitra 2. Statkraft is the developer on behalf of Fosen Vind DA[13]. Nordic wind power DA is a non-Norwegian company established by credit Suisse Energy Infrastructure Partners and is backed by The Swiss power company BKW[14], which indicates that foreign investments is present in Norwegian onshore wind power development.

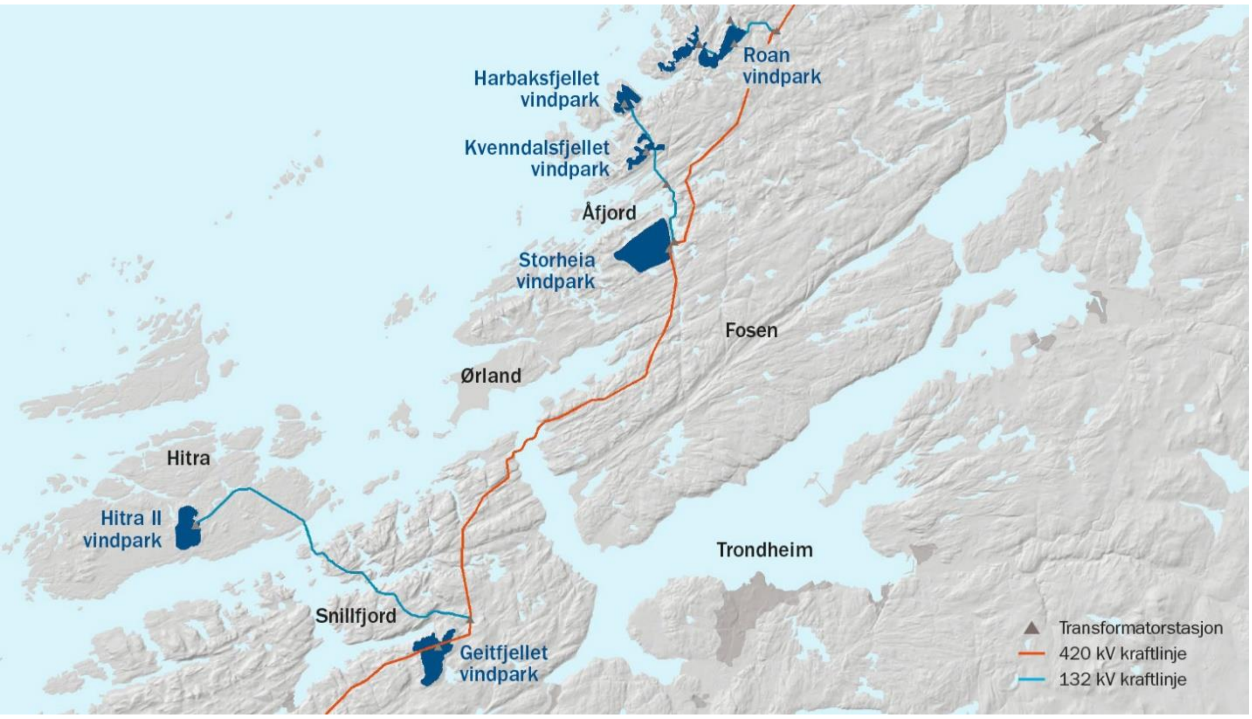
Fosen Wind is a company that is organized as a company with a "Delt ansvar"(shared responsibility), this business organization is not equal to a "limited liability company", instead of stocks, each participants is responsible for their own liability in the company based upon

[13] Fosen Vind (N.A) Om Fosen vind. Retrieved 2020, 17. March. Retrieved from https://www.fosenvind.no/om-fosen-vind/
[14] Rosvold, Knut A: Nordic Wind Power DA i Store norske leksikon på snl.no. Retrieved 30. mai 2020 from https://snl.no/Nordic_Wind_Power_DA

the percentage they own. Fosen Wind DA is similar to a non-Norwegian firm that is characterized as a “joint venture company”[15].

A joint venture company may draw several benefits from this arrangement, some of the advantages are that the risks are shared among the participants, there is a larger knowledge pool to draw competence from and although being temporary, there may be projects in the future where companies may continue to work together on, further leveraging experiences gained. The drawbacks of a joint venture company is that the goals can be vague if there is lack of communication, and because the responsibility is shared among the participants, there might be problems when it comes to taking accountability of the projects potential shortcomings[16].

The six wind parks of Fosen wind



Map: Fosen Vind

Fosen Wind consists of six wind parks. The six parks are: Roan, Storheia, Kvenndalsfjellet, Harbaksfjellet, Geitfjellet and Hitra 2.

[15] Fosen Vind (N.A) Om Fosen Vind. Retrieved 2020, 17. March. from fosenvind.no/om-fosen-vind/
[16] Marsh, Anna (N.A) 12 Advantages and Disadvantages of a Joint Venture. Retrieved 2020, 29. May. from https://businesstown.com/12-advantages-and-disadvantages-of-a-joint-venture/

Roan is the second largest park with a total of 76 turbines with an installed capacity of 255,6 MW, producing 900 GWh. The construction was completed in 2018[17].

Storheia is the largest of the six parks and consists of 80 turbines that have a capacity of 288 MW, and production of 1000 GWh. When it was completed in 2019 it became the largest wind park in Norway[18].

Kvenndalsfjellet wind park is located in an area of approximately 6 square kilometers and consists of 27 turbines with a capacity of 113,4 MW, and production of 405 GWh. The park will be fully completed in 2020[19].

Harbaksfjellet has a total of 30 turbines with a capacity of 126 MW, and a production of 443 GWh. The park is located on a peninsula facing the ocean and will according to Fosen vind be completed in 2020[20].

Geitfjellet is located just south of Krokstadøra in Snillfjord municipality. The 43 turbines has a capacity of 180,6 MW, and a production of 548 GWh. The park will be completed in 2020[21].

Hitra 2 is located on the island of Hitra. It is an extension of an existing wind park, that was constructed in 2004 and now consists of 26 turbines with a capacity of 93,6 MW, and a production of 290 GWh. Hitra 2 was completed in 2019[22].

Together these six parks have a total capacity of 1057 MW when the final installations will be completed in 2020, with a total production of 3,6 TWh[23].

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[17] Fosen vind (2019, 12. February). Roan Vindpark. Retrieved from https://www.fosenvind.no/vindparkene/roan-vindpark/

[18] Fosen Vind (2019, 12. August). Storheia vindpark. Retrieved from https://www.fosenvind.no/vindparkene/storheia-vindpark/

[19] Fosen Vind (N.A) Kvenndalsfjellet Vindpark. Retrieved 2020, 17. March from https://www.fosenvind.no/vindparkene/kvenndalsfjellet-vindpark/

[20] Fosen Vind (N.A) Harbaksfjellet Vindpark. Retrieved 2020, 17. March from https://www.fosenvind.no/vindparkene/harbaksfjellet-vindpark/

[21] Fosen Vind (N.A). Geitfjellet Vindpark. Retrieved 2020, 17. March from https://www.fosenvind.no/vindparkene/geitfjellet-vindpark/

[22] Fosen Vind (N.A) Hitra 2 Vindpark. Retrieved 2020, 17. March from https://www.fosenvind.no/vindparkene/hitra-2-vindpark/

[23] Fosen Vind (N.A) Om Fosen Vind. Retrieved 2020, 17. March from fosenvind.no/om-fosen-vind/

2.2.2 Further onshore wind power development in Norway

With the newly developed 1057 MW onshore wind power project Fosen Wind, it does not exist a pressing need for further onshore wind power development in Norway. NVE (the Norwegian water resources & energy directorate) has regardless developed a proposal for a national framework for onshore wind power. This proposal consists of 13 areas that are suitable in Norway for further onshore wind power development[24].

Although there are optimal wind resources located in Norway's northern regions, most of the proposed areas are located in the south and in the middle of the country, as there is expected to be less interference with reindeer herders and there exists better infrastructure, like grid connection and roads to support construction and operation of the wind farms[25].

NVE`s proposed 13 areas for future onshore wind power development has been met with strong criticism, and the Norwegian government has decided to abandon this proposal[26]. The opposition consists of mainly two criticisms, The "Not In My Backyard" phenomenon (NIMBY) Where people do not want something that is considered undesirable in their own backyard[27], and the intrusion of the indigenous Sami people`s reindeer herding, as wind power development leads to less room for grazing for reindeers. Reindeer herding is considered an important part in the preservation of the cultural traditions of the Sami people[28].

After the government abandoned the proposed framework for national wind power amidst protests, they have decided to tighten licensing and environmental procedures when it comes to future wind power projects[29]. This will lead to an increased difficulty of getting new projects approved, and may hinder future onshore developments in Norway, which is the opposite of what NVE`s proposal would have accomplished if it were followed.

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[24] CLP Collaborate (N.*A)* Proposal for National framework for onshore wind power. Retrieved 2020, 06. May. from *https://clp.no/en/proposal-national-frame-work-onshore-wind-power/*

[25] CLP Collaborate *(N.A)* Proposal for National framework for onshore wind power. Retrieved 2020, 06. May. from https://clp.no/en/proposal-national-frame-work-onshore-wind-power/

[26] Lee, Andrew (2019, 17. October). Norway Scraps National Wind Power Plan After Protests. Retrieved from https://www.rechargenews.com/wind/norway-scraps-national-wind-power-plan-after-protests/2-1-690827

[27] Kinder, Peter. D. (N.A) Not in MY Backyard Phenomenon. Retrieved 2020, 27. April. From https://www.britannica.com/topic/Not-in-My-Backyard-Phenomenon

[28] Northern Norway (N.A) The Sami: Indigenous People of the North. Retrieved 2020, 23. May. from https://nordnorge.com/en/tema/the-sami-are-the-indigenous-people-of-the-north/

[29] Lee, Andrew (2019, 17. October). Norway Scraps National Wind Power Plan After Protests. Retrieved from https://www.rechargenews.com/wind/norway-scraps-national-wind-power-plan-after-protests/2-1-690827

2.3 Offshore wind development

Offshore wind power are installations set up on water. Offshore wind is divided into fixed and floating. Fixed offshore wind power is when the wind turbines are embedded into the seabed, where floating offshore wind power utilizes anchoring methods to enable the wind turbines to float[30].

The costs of offshore wind power are decreasing but has from a historical perspective usually been higher than onshore wind power. This is mainly due to the costs of infrastructure, power storage and turbines. In recent years, progress in turbine technology along with economies of scale for larger projects, has contributed to decreased costs for offshore wind power development.

The offshore wind industry is currently much smaller than the onshore industry with only 4,5 GW of installations in total worldwide (2018). The majority of installed offshore wind capacity is in China and Europe. The industry is however predicted to grow significantly in the coming years with several new projects[31].

[30] Thompson, Andrew (2015, 14. May) Floating or Fixed? Retrieved from https://www.atkinsglobal.com/en-gb/angles/all-angles/floating-or-fixed

[31] IRENA (2019), Renewable Power Generation Costs in 2018, International Renewable Energy Agency, Abu Dhabi. P.23. Retrieved from ttps://www.irena.org/-/media/Files/IRENA/Agency/Publication/2019/May/IRENA_Renewable-Power-Generations-Costs-in-2018.pdf

2.3.1 Hywind

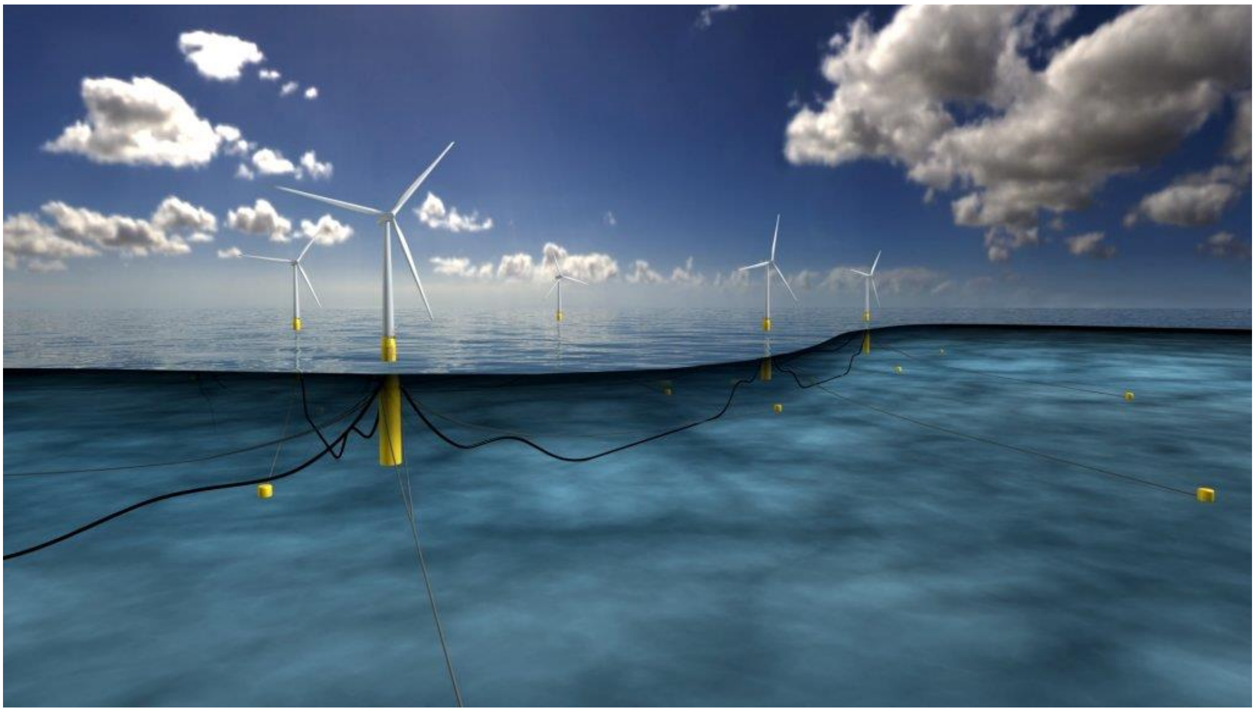

Photo: Equinor

Hywind is an offshore wind turbine design, made for operating in deep waters where the more conventional sea-bed fixed turbines are not appropriate. Instead of being mounted on the bottom of the sea, the wind turbine is designed to float and are anchored in place[32]. Equinor, the developer of Hywind, is a Norwegian multinational energy company where petroleum is the largest business area[33]. Equinor has vast offshore experiences that stems from operating its offshore oil & gas platforms. By combining this experience with new technological solutions in the wind industry has together enabled the company to create and execute the Hywind design.

The concept of operating in deeper water is based upon wind-levels, as the power of the wind is normally stronger in water depths exceeding 60 meters, and the design is thought to be more cost effective, than building large bottom-fixed turbines in deep waters, as bottom fixed wind turbines exceeding 60 meters shows significantly increased costs. **F**urthermore, the lack

[32] Equinor (N.A) How Hywind Works. Retrieved (2020, 04. March) from https://www.equinor.com/en/what-we-do/floating-wind/how-hywind-works.html
[33] Equinor (N.A) Equinor in Brief. Retrieved (2020, 27. March) from https://www.equinor.com/en/about-us.html#equinor-in-brief

of water depth constraints enables wind turbines to be placed almost everywhere where the water depths are over 60 meters, and the most favorable wind conditions can be harnessed[34]. However, floating wind is still in its infancy, and the proposed cost-savings is still not apparent, thereby making less water depth constraints for floating wind the most prominent benefit of this wind power segment.

2.3.2 Opportunities for further Norwegian offshore floating wind power developments

Given Norway`s lack of suitability for offshore bottom fixed wind power development (Section 2.3.4), floating offshore wind is given substantially more attention from a development perspective. This is apparent from the upcoming Hywind Tampen project, where floating offshore wind will give clean energy to power part of the energy need for the oil and gas fields Snorre and Gullfaks. Hywind Tampen is planned to be initiated in 2022 and will have a capacity of 88 MW from 11 turbines[35].

[34] Equinor (N.A) The Future of Offshore Wind is Afloat. Retrieved (2020, 08. March) from https://www.equinor.com/en/what-we-do/floating-wind.html
[35] Equinor (N.A) Hywind Tampen: Verdens Første Fornybare Kraftkilde for Olje- og Gassvirksomhet til Havs. Retrieved (2020, 27. April) from https://www.equinor.com/no/what-we-do/hywind-tampen.html

2.3.3 Dogger bank

Photo: Equinor

Dogger bank is a bottom fixed offshore wind farm located over 130 kilometers from the Yorkshire coast in England. The wind farm is a 50:50 joint venture between SSE Renewables and Equinor. The project was announced in September 2019, and onshore construction commenced on 17th of January 2020, while offshore construction is expected to start in 2021[36].

The Dogger bank area has a water depth ranging from 18m to 63m, making it ideal for bottom fixed wind turbines[37].

The Dogger bank is the remains of the "Doggerlands" which was an area that historically connected Britain and continental Europe (10 000 BC), this area is now submerged under water[38].

Dogger bank consists of three projects initially named Creyke Beck A, Creyke Beck B and Teesside A. The names were later changed to Dogger Bank A, B and C[39].

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[36] Doggerbank (N.A) About the Project. Retrieved (2020, 02. April) from https://doggerbank.com/

[37] Power Technology (N.A) Dogger Bank Creyke Beck Development, North Sea. Retrieved (2020, 08. April) from https://www.power-technology.com/projects/dogger-bank-creyke-beck-development-north-sea

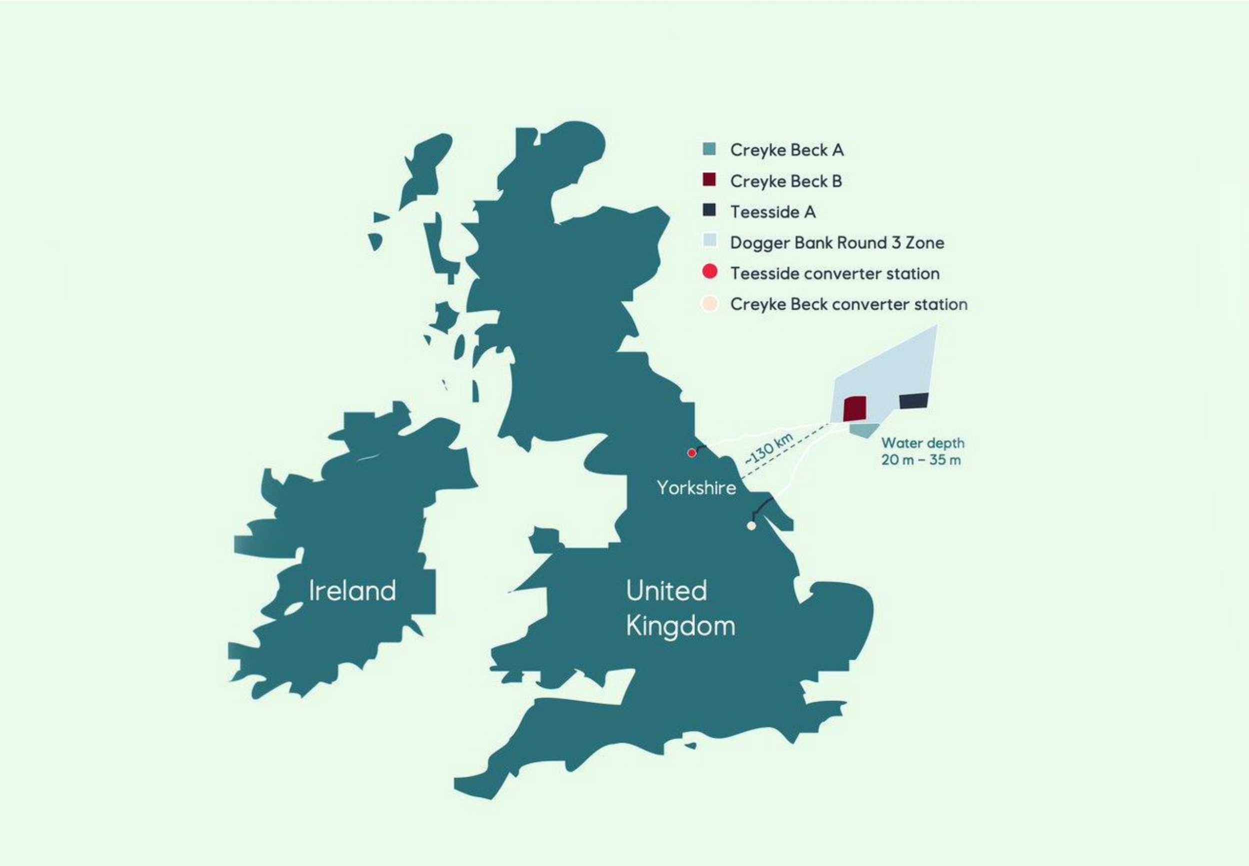
[38] HERITAGEDAILY (2020, 15. May) Doggerland – Europe`s Lost Land. Retrieved from https://www.heritagedaily.com/2018/07/doggerland-europes-lost-land/117925

It is expected that Dogger Bank will provide electricity equal to the consumption of 4,5 million homes and will have an installed capacity of 3.6 GW. Upon completion it will be the world's largest offshore wind farm[40].

Dogger bank will be equipped with what is claimed to be the world's biggest wind turbines: The Haliade-X turbines from GE, which has a rated capacity of 12MW, and an annual generation of 67 GWh[41].

The decision to construct Dogger bank was a combination of the increased profitability of bottom fixed wind turbines and climate change awareness. In order to tackle climate change in accordance with the Paris agreement, co2 emissions needs to be reduced. Each of Dogger banks Haliade-x turbines is expected to offset up to 42 million tons of CO_2, which is equivalent to the annual emission of around 9000 vehicles[42].

The three projects of Dogger bank:



Map: Equinor

[39] reNEWS (2020, 27. February) SSE and Equinor Rename Dogger Bank Triplets. Retrieved from https://renews.biz/58844/sse-and-equinor-rename-dogger-bank-triplets/

[40] Equinor (2019, 20. September) Equinor Wins the Opportunity to Develop the World`s Largest Offshore Wind Farm. Retrieved from https://www.equinor.com/no/news/2019-09-19-doggerbank.html

[41] https://sse.com/whatwedo/ourprojectsandassets/renewables/doggerbank/

[42] NS Energy (N.A) Dogger Bank Wind Farms. Retrieved (2020, 27. 13. April) from https://www.nsenergybusiness.com/projects/dogger-bank-wind-farms/

Dogger bank A consists of a project area of approximately 515 square kilometers and is expected to be online in 2023. Both Dogger bank A and B are located 131 km from the UK mainland[43]

Dogger bank B is the largest of the three with a size of 599 square kilometers and will be online one year after Dogger bank A in 2024[44]

Dogger bank C has a size of 560 km and is located 196 km from the UK mainland. According to plan, Dogger bank C will be online in 2025.

Each of the three projects will have an installed capacity of up to 1.2 GW each[45].
The Dogger Bank project is quoted in CFD prices.
The Contract for Differences (CFD) is a financial instrument, in which an investor will be able to profit from price movements in an asset without owning the underlying asset itself. The CFD is used as it gives access to the asset at a lower cost, than if the asset itself were bought directly. The higher ease of execution of a CFD purchase compared to a direct purchase, is in addition a reason for the use of CFD`s[46].
The CFD prices for each project in Dogger Bank will be: 39,650 GBP for Dogger Bank A, and 41,611 GBP for Dogger Bank B and C in 2012 prices[47].

2.3.4 Opportunities for Further Norwegian offshore bottom-fixed wind power developments

Despite Equinor being a 50% owner of the project, it is not located on Norwegian territory. Norway`s development opportunities of offshore bottom fixed wind farms on its own territory

[43] Dogger Bank (N.A) About the Project. Retrieved (2020, 28. April) from https://doggerbank.com/
[44] Harvey, F. (2015, 17. February). World's biggest offshore wind farm approved for Yorkshire coast. Retrieved from https://www.theguardian.com/environment/2015/feb/17/worlds-biggest-offshore-windfarm-approved-for-yorkshire-coast
[45] Power Technology (N.A) Dogger Bank Creyke Beck Development, North Sea. Retrieved (2020, 08. April) from https://www.power-technology.com/projects/dogger-bank-creyke-beck-development-north-sea
[46] Mitchell, Cory (2020, 10. April) An Introduction to CFDs. Retrieved from https://www.investopedia.com/articles/stocks/09/trade-a-cfd.asp
[47] Equinor. (2019, 20. September). Equinor tildelt mulighet til å bygge verdens største havvindpark. Retrieved from https://www.equinor.com/no/news/2019-09-19-doggerbank.html

is limited, as the there are few areas that possess the necessary water depths (below 60 meters), to support this wind power segment[48].

NVE has a proposal of 15 areas where there is a potential for further offshore wind power development, where 11 of these areas are feasible for bottom fixed wind installations in consideration of water depts. However, in these 11 areas the majority is also suitable for floating wind, and there exists other difficulties than water depts. Varying wind levels and distance from grid connection makes areas otherwise suitable for bottom-fixed wind unfeasible, as the costs becomes too high, while areas with closer distance to a grid connection and optimal wind conditions, do not have optimal water depths.

Out of these potential areas, there is one area that is the most promising for bottom fixed wind development in Norway, which is Frøyagrunnene, located 10 km southwest of Bremangerlandet in the Sogn and Fjordane County. The area is optimal based upon the technical characteristics of the site, as the water depts are between 5-60 meters, average wind speeds is estimated at 10 m/s, the zone is close to existing infrastructure, and there are remaining grid capacity , so the wind farm can be connected with a grid close to the site. The optimal technical characteristics of the site will entail that the wind farm constructed in this area will enjoy a low LCOE. However, social and environmental characteristics still exists that makes this area potentially problematic. It is located close to shore, and will therefore be visible, and might lead to a "NIMBY" reaction from residents close to the area. There is also extensive fishing in the area, and vessel traffic needs to change if the wind farm shall be constructed, and the Directorate of Fisheries recommends that this area should not be opened on this basis.

When taking economic, social and environmental considerations into account, there do not exist any area in Norway that is optimal in terms of bottom-fixed wind power development. Rather, development efforts need to weight economical and non-economical metrics against each other, and choose a site that is the most viable, yet not optimal, or decide to keep developing in foreign territories[49].

[48] Midling, A. (2015, 13. November). Norskekysten er krevende for bunnfaste vindmøller til havs. Retrieved from https://forskning.no/alternativ-energi-ntnu-partner/norskekysten-er-krevende-for-bunnfaste-vindmoller-til-havs/459070

[49] NVE (2013, N.A) Offshore Wind Power in Norway. Retrieved (2020, 06. May) from http://publikasjoner.nve.no/diverse/2013/havvindsummary2013.pdf

Chapter 3: Research Design

This chapter outlines the research design used in our thesis. Section 3.1 outlines the main methodology used, section 3.2 and 3.3 relates to data gathering, information regarding our analysis will be found in section 3.5, and limitations of our thesis will be presented in section 3.5.

3.1 Research Design

For the research method a qualitative method was chosen. The basis for this choice was the literature review and careful consideration of the topic and research question. A quantitative approach is deemed too complex to answer our research question, and a qualitative approach is more suitable given our wide topic. To rely on a quantitative approach to compare offshore floating wind, offshore bottom fixed wind and onshore wind is not suitable, as the projects we focus on in these segments has differing purposes and are in different levels of development (Hywind(floating) is based upon a new concept in a developing market, Dogger Bank(fixed) is in a newly developed market, while Fosen wind(onshore) uses modern but traditional methods in a well-developed market). The quantitative comparison we use is not at the core of our analytical work but is rather used to provide support to our analysis and corresponding conclusion. The quantitative comparison is still used as a basis for a strong conclusion in the summary, as we from an economic point of view, point out that onshore wind is the best alternative.

3.2 Data gathering

Our thesis relies mostly on secondary data, which is existing data that has been gathered from articles, journals, websites and books[50].

In our thesis we have also collected primary data from interviews with representatives from the Norwegian onshore and offshore wind industry. These interviews were never meant to be the basis for our assumptions and results, but was rather conducted to provide more insight into the different wind power segments.

[50] University of Toronto Library (2020, 11. May) Definitions & Differences. Retrieved from https://guides.library.utoronto.ca/c.php?g=250546&p=1679414

Due to COVID-19, a reliance on primary data gathered from broader interviews would have proven difficult, and would have significantly hindered our progress in the data collection phase, and would have entailed a prolonging of the overall completion of our thesis.

3.3 Interviews

The primary data gathered in this thesis has come from interviews with industry representatives from the onshore and offshore wind industry, this also include relevant regulatory agencies that influences the Norwegian wind power industry.

Given that some participants wanted to be anonymous, all interviews have been anonymous, and the data gathered from the interviews have only been used in this thesis when secondary sources has backed up the information. Only secondary sources are thereby cited in this thesis.

There have been conducted one interview from each segment: onshore, offshore-bottom fixed, offshore floating and one from a regulating energy agency.

3.4 Analysis

The analysis is conducted in accordance with the analytical methods explained in chapter 4 "Theoretical approach". Section 4.1 gives an in-depth explanation of the process, while section 4.2 lists and explains the different theoretical tools used in this thesis.

3.5 Limitations

Access to primary data

The collection of primary data through interviews is very limited in this thesis, as only four interviews has been conducted. The perspectives and insights we have obtained is also subject to bias, as a representative for an industry cannot be characterized as completely objective and may show a stronger support for their own respective field. The information that has been gathered through interviews has only been used in our thesis when secondary sources has backed up this information.

Access to secondary data

The secondary data that our thesis relies on, has been gathered through public sources, and our analysis and corresponding conclusion does not include information that is privately held.

COVID-19

Due to covid-19 the collection of primary data has been difficult to obtain and is mainly the reason for our limited sample of interviews. Our thesis is on the other hand suitable for a reliance on secondary data given the wide scope of our thesis.

The analysis and corresponding conclusion in our thesis will not include the effects or the expected effects that COVID-19 may have on the differing wind power segments. This is due to the complex and uncertain nature of the pandemic, and it is outside of our field of knowledge. Our thesis will thereby be limited by not taking COVID-19 into account.

Scope of the thesis

Our thesis is limited to one project for each wind power segment. It is therefore no direct comparison between projects in the same segment for Norway and the UK. If included, this would consist of a comparison between onshore wind power development projects in the UK and Norway, as the UK currently has no floating wind projects, while Norway lacks offshore bottom fixed wind developments in their maritime territories.

Chapter 4: Theoretical approach

This chapter relates to our theoretical approach regarding our choice of analytical methodology, choice of analytical tools and corresponding link to our conclusion. Section 4.1 outlines an explanation of our theoretical approach, while section 4.2 explains the different theoretical tools we have used in our analysis.

4.1 Theory explanation

Our thesis is primarily based upon secondary data which is then analyzed in several theoretical frameworks that is interlinked in an overall analysis to give answer to our research question.

The choice of our analytical approach, has been due to the characteristics of our thesis, which is that the stated problem is wide and includes several perspectives, and there exists no single framework that would answer our research question in a satisfactory way. Therefore, several frameworks were needed in order to reach a conclusion that takes all of our perspectives into consideration.

In order to find which of the wind power development alternatives that is optimal for Norwegian companies to focus on. We believe that looking at the strengths, weaknesses, opportunities and threats for each alternative will give a thorough picture as to which approach that is not only optimal now, but that will continue to be the preferred alternative in the future. The process of looking at the Strengths, Weaknesses, Opportunities and Threats is done by using the SWOT framework.

Our analysis is thereby based upon the development of a SWOT analysis for each wind power segment and corresponding project. In order to develop the SWOT analysis in a structured way, we needed two frameworks to base our SWOT analysis on. We decided to use the PESTEL analysis to get a general overview of the factors that are relevant for the Norwegian wind power industry, and to use a life-cycle stage analysis to more specifically identify differences in the strengths , weaknesses, opportunities and threats for the different wind power segments. In addition, we have included a LCOE analysis to supplement our SWOT analysis, as this will make the economic differences between the wind power segments easier to identify.

The PESTEL analysis, the life-cycle stage analysis and the LCOE analysis will be conducted once each and will account for all the wind power segments. The SWOT analysis will be conducted three times, one time for each wind power alternative.

The choice of our frameworks is based upon similar work conducted by Pieter-Jan Vandenbrande. In his thesis, the PESTEL analysis were used to analyze the macro external environment for California, in order to identify the appropriateness of developing an offshore wind power market. In the same thesis, the PESTEL analysis were used to develop the opportunities and threats in a SWOT analysis[51]. Our thesis on the other hand, will also include strengths and weaknesses, and constitutes a full SWOT analysis.

The SWOT analysis has been conducted in a vast variety of fields, and has been especially used in combination with a PESTEL analysis, where the overall findings of the PESTEL analysis has been the basis of identifying the opportunities and threats in the SWOT analysis. The SWOT analysis is primarily used within strategic planning, and the subject of analysis is typically an organization. However, the SWOT analysis can be used for any subject, as long as it fits the goals of the analysis[52]

A SWOT analysis makes a comparison between the various projects clearer and more understandable. We therefore find it suitable to conduct these analytical frameworks in our thesis. Our SWOT analysis will not only consists of the characteristics of the specific wind power segment (Onshore, offshore floating, offshore fixed), but will also include the inherent characteristics of the specific projects that operates within these segments (Fosen wind, Hywind, Dogger bank), as our focus is on Norwegian businesses that operates in these segments.

The report about the life-cycle stages of a wind farm[53] identified critical tasks in the different stages an onshore wind farm goes through from project initiative to project end. Our argument is that this framework can be used for an offshore wind farm as well, in addition, the division of the analysis is naturally segregated in logical sections based upon the different stages a wind farm goes through. The life-cycle stage analysis also considers that the projects we analyze are in different stages.

[51] Vandenbrande,P.J (2017) Opportunities and challenges for a floating offshore wind market in California **http://kth.diva-portal.org/smash/get/diva2:1111166/FULLTEXT01.pdf**
[52] CItoolkit (N.A) Swot Analysis. Retrieved (2020, 03. April) from **https://citoolkit.com/articles/swot-analysis/**
[53] IWEA (2019, March) Life-cycle of an Onshore Wind Farm. Retrieved from **https://www.iwea.com/images/files/iwea-onshore-wind-farm-report.pdf**

By using the life-cycle stage framework of identifying the critical tasks in each stage, it makes us able to better identify the Strengths, Weaknesses, Opportunities and Threats for the different wind power segments, and together with the PESTEL analysis, it will enable us to complete our SWOT analysis.

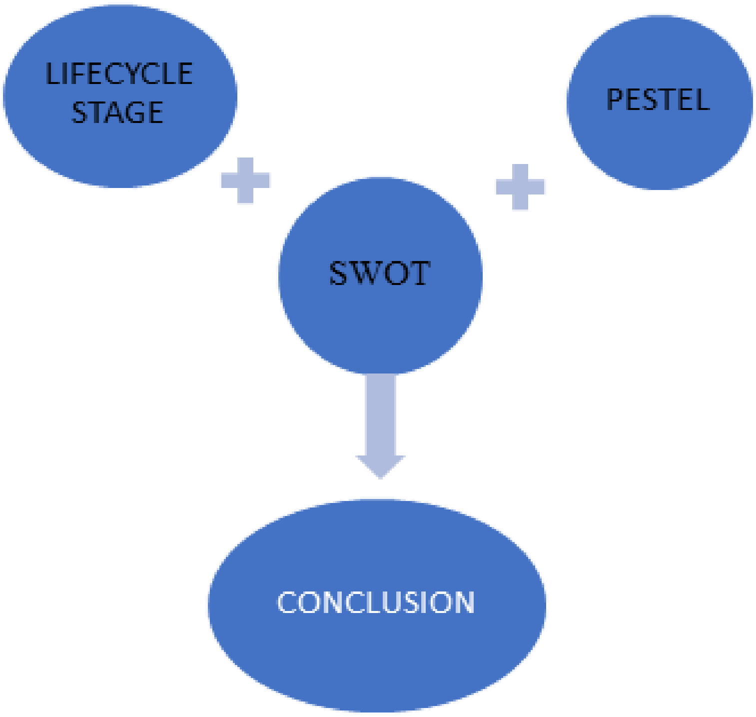


Figure 1; Relationship between the analyses.

As a summing up, the PESTEL and the Life-Cycle Stage analysis will help us to identify the Strengths, Weaknesses, Opportunities and Threats in the SWOT analysis for each wind power segment, and corresponding project. It is from the SWOT analysis that we will primarily draw our conclusion.

Our conclusion will be divided into three perspectives: economic, environmental, and social.

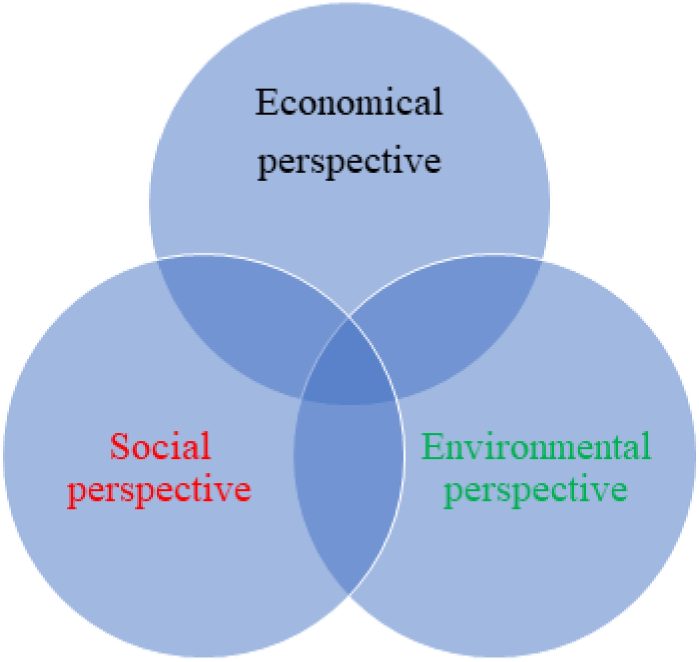


Figure 2; The three pillars of sustainability.

The reason behind choosing these perspectives are that they form the three dimensions of sustainable development[54]. We will try to reach a conclusion as to whether onshore wind, offshore bottom fixed wind or offshore floating wind is the most optimal for Norwegian companies regarding these perspectives.

The economic perspective is with focus on which wind power segment that has the most cost-effective solutions and corresponding LCOE.

The environmental perspective is with focus on the potential damages that each wind power segment causes on the nature, scenery and wildlife surrounding the wind farm.

Lastly, the social perspective is regarding what the contribution will be in terms of health and quality of life.

Each of these perspectives will have their own conclusion followed by an overall conclusion based on all three collectively at the end.

[54] United Nations (N.A) Social Development for Sustainable Development. Retrieved (2020, 28. April) from **https://www.un.org/development/desa/dspd/2030agenda-sdgs.html**

4.2 Theoretical tools

4.2.1 PESTEL analysis

A PESTEL analysis is a framework which is used in marketing and strategic decision making and consists of analyzing the external environment that an organization operates in. PESTEL stands for Political, Economic, Social, Technological, Environmental, and Legal. Depending on the needs for the specific organization, some of the external factors can be dismissed or new ones can be added.

As all organizations operates within a macro environment, the analysis is a useful tool for an organization, as it dictates which boundaries and opportunities that the organization can take advantage off but also can be constrained by.

The elements of the PESTEL Framework;

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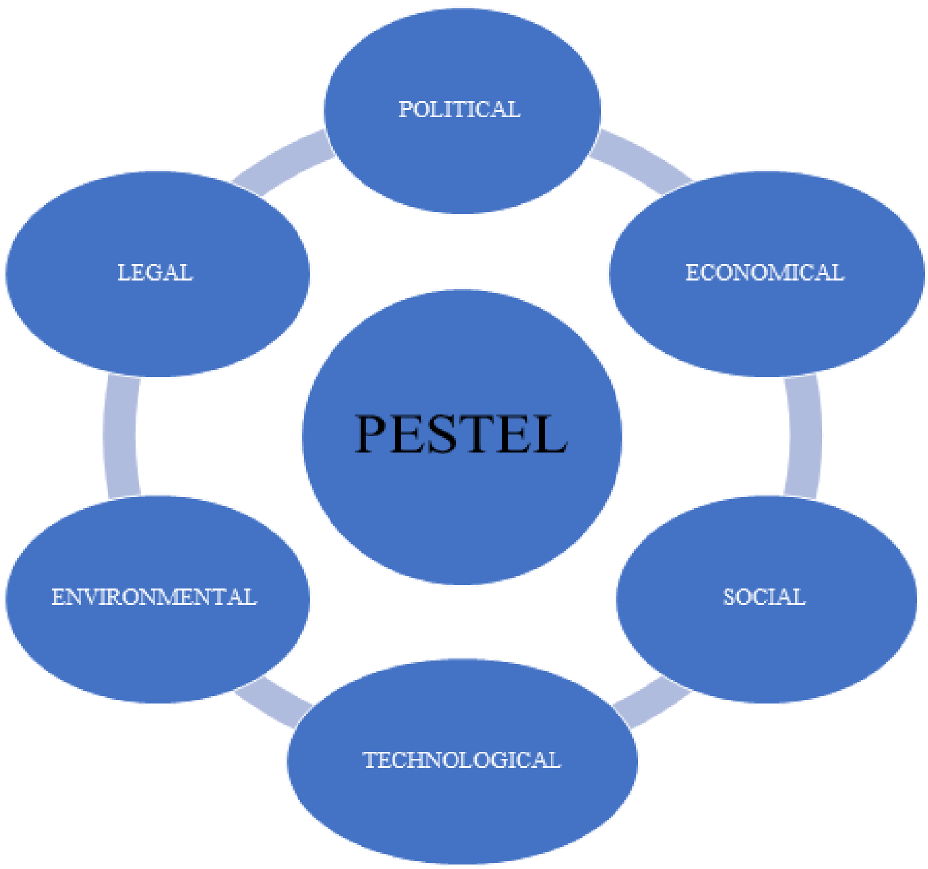

Figure 3; PESTEL Analysis

Political factors

The political factors specify how the government and other regulating agencies affect an organization or an industry through legal and regulatory policies, taxation and tariffs. Depending on the case in question, there may be a need to distinguish between local and central political factors.

Economic factors

The performance of the national economy has a significant effect on the organization and its corresponding ability to generate profit. Economic factors include unemployment rate, economic growth, interest rates, level of inflation, foreign exchange rates and disposable income of consumers and businesses.

Social factors

Analysis of the social environment helps to identify trends in the population, factors include demographic, educational levels, cultural trends and attitude changes for the general public.

Attitude changes has a contributing effect of changes in other factors. Expenditure habits change the economy, opinions can affect governmental policies and laws, environmental awareness can push companies to create cleaner products and cultural trends regarding the benefits against the downsides of technological changes.

High educational levels creates a more skilled workforce, but also creates a more critical population which monitors government and business actions more thoroughly.

Technological factors

Technological factors include the rate of technological developments, innovation and technological trends (level of adoption of certain technologies, like digitalization). These factors are important to consider, as new technological solutions may completely remove the competitiveness of current solutions, making businesses that rely heavily on them obsolete.

Environmental factors

The increased environmental awareness in the general public, has made businesses preoccupied with pollution-level control, local impact assessment on the environment where a business operates, along with creating more efficient production solutions as more and more raw-materials are becoming a scarce resource. An organization, especially one involved in heavy industry where the environmental impact is higher in production, are at an increased risk of being scrutinized and controlled by the government. Projects will also be confronted with initiatives taken from non-governmental organizations (NGO`s), if the environmental impact is deemed too high.

Legal factors

An analysis of the legal factors includes the assessment of what boundaries the organization operates within. Laws and regulations specify what actions a business is able to do, and the most important factors are: employment legislation, product safety, health and safety, and equality laws[55]. It is also important to identify the extent of the legal framework, whether or not it is well developed, or if it`s still in its infancy.

[55] Oxford College of Marketing (N.A) What Is a PESTEL Analysis? Retrieved (2020, 27. March) from https://blog.oxfordcollegeofmarketing.com/2016/06/30/pestel-analysis/

4.2.2 Lifecycle stage analysis

The lifecycle stage analysis is based on the stages that make up a wind farms complete lifecycle from the feasibility stage to decommissioning. Our basis for this analysis is the Irish wind energy associations report "The lifecycle of an onshore wind farm"[56]. The analysis is made up of a total of seven stages that make up the parts of the analysis. Each of these stages will be explained and shown in the figure below:

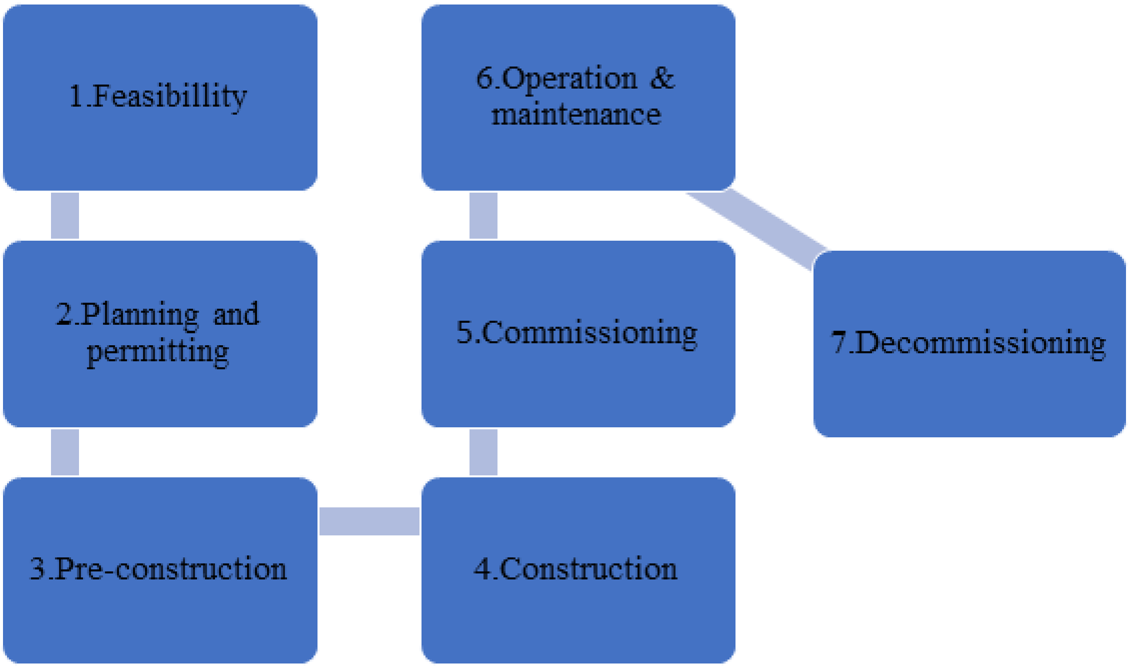

Figure 4; Lifecycle-Stage analysis.

1.Feasibility

All projects start with an analysis of the feasibility of the project, or in other words, the ease at which the project is expected to be completed with. The Feasibility stage usually lasts from 2 to 4 months.

[56] IWEA (2019, March) Life-cycle of an Onshore Wind Farm. Retrieved from **https://www.iwea.com/images/files/iwea-onshore-wind-farm-report.pdf**

2. Planning and permitting

This stage comes after the proposed land has been identified for the wind farm and typically lasts for 4-8 years. Planning and permitting typically consists of acquiring the typical permits and commencing planning.

3. Pre-construction

Consists of securing funding for the project and arranging the completion of construction contracts. The length of this stage is usually from 6 to 12 months.

4. Construction

The construction stage usually has some overlap with the pre-construction stage. Its duration varies from project to project, but typically it is from 10 to 14 months.

5. Commissioning

This stage begins when the construction stage nears its completion and typically lasts for 2-4 months. Commissioning involves adjusting, checking and test the equipment involved to make sure it is ready for operation.

6. Operation & maintenance

The longest of the stages and lasts for approximately 20-25 years. During operation, the turbines require regular maintenance and management of several factors.

7. Decommissioning/Repowering

As a wind farm nears the end of its lifecycle there is the option to either decommission or repower. This stage usually has a duration of 6 - 12 months. Decommissioning means that the wind farm will be dismantled, and the site will be restored as closely as possible to its original state.

Repowering involves continued operation of the wind farm. This involves upgrading or replacing wind turbines and blades.

LCOE 4.2.3

LCOE is short for Levelized Cost of Energy. LCOE provides a calculation that can be used to compare and assess energy production, usually in kWh. LCOE is calculated by dividing the net present value of costs over the lifetime of an energy project over the net present value of electricity produced over its lifetime.

$$\text{LCOE} = \frac{\text{NPV of Total Costs Over Lifetime}}{\text{NPV of Electrical Energy Produced Over Lifetime}}$$

Figure 5; LCOE (Corporate finance institute).

The formula behind LCOE can be explained simply as the net present value (NPV) of the total costs including the initial cost of the investment, O&M costs and fuel costs if it is used. The net present value (NPV) of electrical energy produced over lifetime consists of the sum of electricity that is being generated[57].

4.2.4 SWOT analysis

The SWOT analysis is a tool used in strategic planning by analyzing strengths, weaknesses, opportunities and threats. SWOT can be a useful tool when making decisions and identifying what areas that needs to be focused on. Strengths and weaknesses are considered internal factors, while opportunities and threats are external factors[58].

External factors are outside the control of the organization and constitutes either an opportunity that the organization can capitalize on, or a threat which the organization would like to avoid.

Internal factors are inside the control of the organization, and is either a strength which the organization can leverage to exploit an opportunity or avoid a threat, or it can be a weakness, where the organization cannot exploit an opportunity or avoid a threat.

[57] Corporate finance institute. (N.A). Levelized cost of energy (LCOE). Retrieved 15. March 2020 from https://corporatefinanceinstitute.com/resources/knowledge/finance/levelized-cost-of-energy-lcoe/
[58] Brudvik, Marie (N.A) Strategisk Analyse (SWOT – Analyse). Retrieved (2020, 24. March) from https://www.regjeringen.no/globalassets/upload/krd/kampanjer/ry/swot-analyse.pdf

External and internal factors are intertwined as seen from its corresponding connection to each other, and thereby necessitates the analysis to see the internal strength and weaknesses of the organization in relation to the external opportunities and threats[59].

The elements of a SWOT analysis:

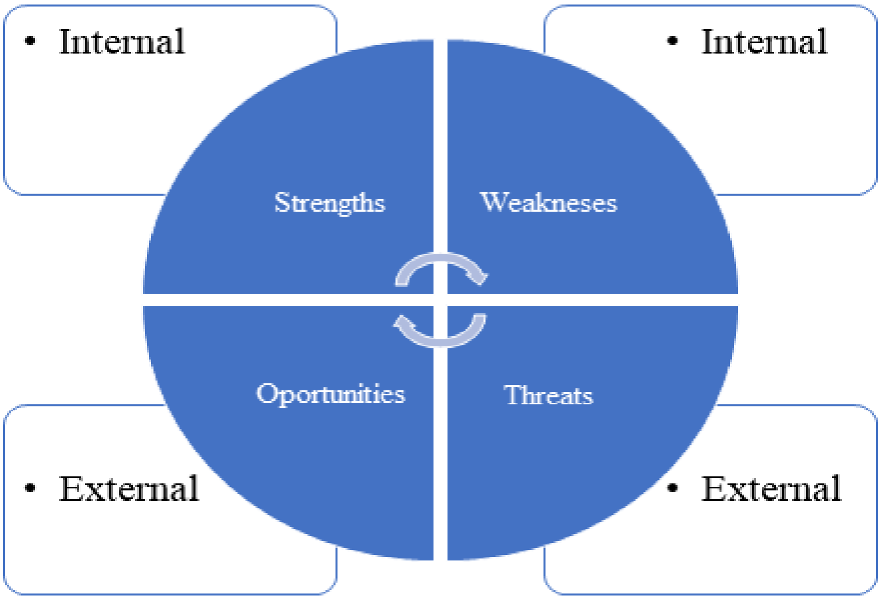

Figure 6; SWOT analysis.

Internal factors:

Strengths consists of internal factors that are positive and contribute in a strengthening way to a company or organization. Examples of elements that can be seen as strengths include a good team or a good product.

Weaknesses consists of negative internal factors that are detracting from the organization's strengths. Examples of weaknesses can be poor organizational structure or a lack of financial capabilities.

[59] Gleeson, Patrick (2019, 11. March) Internal & External Factors That Affect an Organization. Retrieved from https://smallbusiness.chron.com/internal-external-factors-affect-organization-16641.html

External factors:

Opportunities are external factors that could be of an advantage to the organization. Examples include changes in legislation and technological changes.

Threats are external factors that are could be of a disadvantage to an organization. Change in prices and unstable political situations are examples of threats.

By looking into all of these four factors it is possible to get an improved understanding of an organization's competitive abilities and what areas that can be improved.

Chapter 5: Analysis

This chapter contains the analysis's conducted in this thesis. Section 5.1 contains the PESTEL analysis where the general wind power environment is analyzed for Norwegian wind power developers in Norway and the UK. Section 5.2 follows up with a life-cycle stage analysis specifying differences between the different wind power segments. The LCOE analysis with the corresponding cost drivers is found in section 5.3, and the condensed analytical findings from these analysis's is presented and explained in the SWOT analysis in section 5.4.

5.1 PESTEL Analysis

We will investigate the six factors of the PESTEL framework and under each part address what we consider to be the most important underlying aspects for Norwegian wind power developments in Norway and the UK. The analysis is divided into Political, Economic, Social, Technological, Environmental and Legal factors.

5.1.1 Political factors

Energy production is usually characterized as having a substantial level of government involvement. This is because large energy projects often have the government as a partial owner, and the energy security needs of a country are the responsibility of the government, in ensuring a stable balance between supply and demand. This makes governments an active player in the energy markets.

The political climate has therefore a significant effect on renewable energy development, including the development of wind power. Renewable energy production although not a new industry, is still not mature when it comes to profitability and has been dependent on subsidies to function properly, although renewable energy production is becoming more cost competitive, and less dependent on government subsidies[60].

The political factors that will be addressed are the Norwegian electricity certificate act and future political development in Norway. In the UK, the different support schemes for renewable energy will be presented.

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[60] LSE (2018, 14. May). Do Renewable Energy Technologies Need Government Subsidies? Retrieved From http://www.lse.ac.uk/granthaminstitute/explainers/do-renewable-energy-technologies-need-government-subsidies/

The Norwegian Electricity Certificate Act

The Norwegian electricity certificate act is of great importance to the increase and promotion of renewable energy. Therefore, it can be considered largely relevant as a political factor and driver.

The attempt to increase electricity production stemming from renewable sources, made Norway and Sweden engage in a joint electricity certificate scheme in 2012. The scheme involves awarding renewable energy producers one certificate per MWh produced for up to 15 years. The thought is that the scheme will function as a market-driven support, as the certificates will make it more profitable to be involved in renewable energy production, pushing more investments into the industry. Expansions of existing renewable energy plants, and constructions of new plants, may receive electricity certificates if they comply with reporting standards and construction were initiated after 7. September 2009 and before 31. December 2021. In Norway, the scheme will end in April 2036[61].

Despite the green energy certificates keeps awarding producers of renewable energy until 2036, it was decided in April 2016, not to extend the green energy certificate scheme further. Government officials against the extension of the scheme argues that long term investments should be controlled by the market instead, and that the scheme lowers the value of current renewable energy production, as a surplus of electricity is produced, which leads to a decrease in the price of electricity. Norway produced 15twh more of electricity than it consumed in 2015, hurting producers of electricity as prices plummeted to 15-year lows.[62]

The uncertainty involved in the renewable energy industry in Norway, makes producers of renewable energy dependent on clear guidelines from the government, in order to specify that projects will continue to be supported in the future as well.

[61] Energy Facts Norway (2019, 03. January) The Electricity Certificate Marke. Retrieved from https://energifaktanorge.no/en/regulation-of-the-energy-sector/elsertifikater/
[62] Reuters (2016, 15. April) Norway Planning to End Renewable subsidy Scheme by 2021. Retrieved from https://af.reuters.com/article/commoditiesNews/idAFL5N17I2XE

Further development in Norwegian energy politics

The future political developments in energy politics, are important to consider, as it lays the foundation for future energy initiatives and corresponding investments.

The future energy political development was put forth in the "Stortingsmelding" (parliamentary report) from 2016 where the direction to 2030 was explained. Towards the year 2030 the political direction is focused on further development of renewables, environmental focus and ensuring a stable supply of energy. The energy policies will ensure that renewable energy gets used for more purposes than in today's situation.

The government wants a long-term development of profitable wind energy in Norway as well as economic value created from its related industries[63].

The Renewable Obligation and the Contract for difference Schemes in the UK

The Renewable Obligation (RO) was the main support scheme for renewable energy production in the UK. The Scheme came in 2002 and gives the obligation to suppliers of electricity to source a certain proportion of the electricity they provide from renewable sources of energy[64].

In July 2011 however, the government announced that the RO scheme will close to all new generating capacity coming after 31. March 2017[65].

In order for the government to keep promoting the production of renewable energy, the Contracts for Difference (CFD) scheme came in place. The CFD scheme protects developers of renewable energy projects from volatile wholesale prices and protects the customers in periods of high electricity prices[66]. Large scale renewable energy projects come with high upfront costs, and long lifetimes, and the CFD scheme provides some relief to offset the risk associated with these projects, which incentivizes investments.

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[63] Government (2014, 15. April). White Paper On Norway`s Energy Policy: Power for Change. Retrieved from https://www.regjeringen.no/no/aktuelt/stortingsmelding-om-energipolitikken-kraft-til-endring/id2484248/
[64] Ofgem (N.A) About the RO. Retrieved (2020, 30. May) from https://www.ofgem.gov.uk/environmental-programmes/ro/about-ro
[65] Ofgem (N.A) RO Closure. Retrieved (2020, 30. May) from https://www.ofgem.gov.uk/environmental-programmes/ro/about-ro/ro-closure
[66] Gov (2020, 02. March) Contracts for Difference. Retrieved from https://www.gov.uk/government/publications/contracts-for-difference/contract-for-difference

The Support schemes in Norway and the UK for renewable energy, although using different methods, has a similar degree of support function in the promotion of renewable energy.

5.1.2 Economic factors

Economic factors are important to analyze, as they create the foundation from which wind power development may or may not be profitable.

Economic factors we consider to be relevant include the Norwegian electricity market, where we will go into how it is governed, transmitted and how it relates to Norwegian power trading. We will also account for why Norway develops wind power, and economic factors that dictates if the development takes place in Norway or the UK.

The Intermittency Problem of Renewable energy

An important consideration when it comes to renewable energy, is to understand how the market for renewable energy is different from other markets from an economic perspective. In general markets, supply and demand can more easily be managed, by letting the supply stock of a certain product grow when demand is low, and then use this surplus of supply when demand is high.
Renewable energy markets however, faces the intermittency problem, which is that a surplus of electricity will be wasted if demand is to low, and a shortage of electricity will lead to a blackout if demand is too high, because electricity is not easily stored. This coupled with the volatile production of renewable energy, that come from the fact that wind turbines only produces energy when the wind is blowing, makes the market for renewable energy in need for strict regulation, to ensure that demand is met[67].

The Norwegian electricity market

The electricity market in Norway is governed by the "Norwegian energy act"[68], which is based upon having electricity production and trading as market based, while electricity transmission and distribution is strictly regulated and act as a monopoly. By letting electricity

[67] The Greenage (2019, 23. August) Why Is Intermittency a Problem for Renewable Energy? Retrieved from https://www.thegreenage.co.uk/why-is-intermittency-a-problem-for-renewable-energy/
[68] Energy Facts Norway (2017, 04. April) Marked Based Power System. Retrieved from https://energifaktanorge.no/en/norsk-energiforsyning/kraftmarkedet/

prices being dictated by the market, it is thought to naturally ensure reasonable prices and an efficient use of resources in its production. Electricity transmissions and distribution is not subject to competition and are therefore thought of as a natural monopoly. As electricity is not easily stored, there needs to be strict regulations, ensuring that there is an exact balance between generation and consumption.

One of the ways to ensure reasonable prices is through power trading. Power trading is based upon ensuring that power always is consumed in areas where it is valued the most. Norway's involvement in power trading is extensive, which follows from its large electricity production stemming from hydropower. Hydropower is characterized with low reservoir inflows during the winter, and high reservoir inflows during the summer. On the other hand, consumption of power is higher in the winter than during the summer, and without power trading, it would mean low power prices during the summer and high prices during the winter. Power trading ensures that prices are kept more balanced over the year. As the low demand in Norway for power during the summer coupled with high production capacity, allows Norway to export most of its power, and during the winter Norway imports power that is cheaper. Power trading allows Norway access to cheap power in meager times and allows Norwegian electricity prices to be high when there is a surplus in production[69].

Consumption and capacity in Norway

Although 98% of Norway`s electricity consumption comes from its own renewable energy production, where most of this stems from hydropower[70], the majority of Norway's hydropower capacity is already used. It is therefore deemed a necessity to explore other sources of renewable energy, especially wind power, as the Norwegian coastline along with the typography of the land, gives Norway the best wind conditions in all of Europe[71].

However, with the exception of Fosen Wind, the 1057 MW onshore wind project consisting of six wind parks that was completed early 2020, Norwegian wind power developers has

[69] Energy Facts Norway (2017, 04. April) Marked Based Power System. Retrieved from https://energifaktanorge.no/en/norsk-energiforsyning/kraftmarkedet/

[70] Government (2016, 11. May) Renewable Energy Production in Norway. Retrieved from https://www.regjeringen.no/en/topics/energy/renewable-energy/renewable-energy-production-in-norway/id2343462/

[71] Ekra, Siv (2014, 05. May) Wind Power Could Cover Norway`s Energy Needs 20 Times. Retrieved from https://partner.sciencenorway.no/birds-climate-policy-electricity/wind-power-could-cover-norways-energy-needs-20-times/1400766

mostly focused on developments outside of the country. Dogger bank, the 36000 MW offshore bottom fixed wind project that is being constructed outside the coast of Yorkshire, England reflects this. This has in large part been due to the higher electricity prices in England[72], and the lack of suitability to construct bottom fixed wind turbines on Norwegian territory[73].

Equinor`s 30 MW offshore floating wind farm "Hywind Scotland", that is located 25 kilometers outside of Peterhead, Scotland, also reflects the inclination to develop offshore wind power outside of Norwegian territory[74].

Floating wind is however expected to be developed on Norwegian territory, as the lack of water dept constraints for floating wind enables Norwegian wind power developers to circumvent the issues of the lack of suitable water depts on Norwegian territory. The upcoming Hywind project, Hywind Tampen is to be constructed in the Tampen area in the North Sea.[75]

Profitability of the different wind power segments will be addressed in the LCOE analysis (Section 5.3).

5.1.3 Social factors

Norway is an egalitarian culture where consensus driven decisions are on the forefront of priorities, and where the personal opinions of its population are considerable weighted in public debate, business decisions and government actions. The social factors that will be discussed is seen in relation to stakeholder interests for Norwegian wind power developments in Norway and the UK.

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[72] Ekra, Siv (2014, 05. May) Wind Power Could Cover Norway`s Energy Needs 20 Times. Retrieved from https://partner.sciencenorway.no/birds-climate-policy-electricity/wind-power-could-cover-norways-energy-needs-20-times/1400766

[73] Norway Today (2020, 18. February) Statkraft Says No to Offshore Wind. Retrieved from https://norwaytoday.info/finance/statkraft-says-no-to-offshore-wind/

[74] Hill, Joshua S (2018, 16. February) Hywind Scotland, World`s First Floating Wind Farm, Performing Better Than Expected. Retrieved from https://cleantechnica.com/2018/02/16/hywind-scotland-worlds-first-floating-wind-farm-performing-better-expected/

[75] NS Energy (N.A) Hywind Tampen Project Details. Retrieved (2020, 27. April) from https://www.nsenergybusiness.com/projects/hywind-tampen-floating-wind-farm/

Political participation

Norway has a well-educated workforce and has one of the world's highest percentage of people that have attained higher educational levels[76]. Having a highly educated population, along with Norwegians willingness to discuss and participate in political matters[77], makes a critical population which monitors business actions and businesses needs to be able to identify which opinions that can affect the business.

Stakeholder interests

The main interest group in any project is the shareholders which has a vested interest in the project's success by being a partial owner and is primarily interested in the "return on investment" (ROI). However, stakeholders which is all the different groups that are interested in the project, including shareholders, is not only occupied with the economic metrics of the project[78].

In the case of business decisions, metrics other than profit maximization, are weighted extensively in Norway. A business decision that aids the overall society in other ways of generation income is highly favored and pose both and opportunity and a threat to Norwegian wind power developments. Wind energy is environmentally friendly and helps create additional jobs which is highly favored, but wind energy is still met with several concerns.

Three main concerns arise from a stakeholder perspective in Norway, the NIMBY phenomenon, conflicting interest with the Sami people, and local employment effects.

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[76] Moore, Melanie (N.A) Norway Summary. Retrieved (2020, 24. April) from https://education.stateuniversity.com/pages/1130/Norway-SUMMARY.html

[77] Smith, Alexander (2017, 22. February) Norway is the "world`s best democracy" – We asked its people why. Retrieved from https://www.nbcnews.com/storyline/trumps-address-to-congress/norway-world-s-best-democracy-we-asked-its-people-why-n720151

[78] Landau, Peter (2019, 31. January) Stakeholder VS Shareholder: How They`re Different & Why It Matters. Retrieved from https://www.projectmanager.com/blog/stakeholder-vs-shareholder

NIMBY

The NIMBY phenomenon is present in Norwegian culture, although there is a support for wind power in general. Despite Norway being an oil-based economy, Norwegians are in particular interest of moving away from fossil fuels in favor of renewable sources of energy. Thereby it can be said that the opposition of wind power, is mostly related to the "NIMBY" phenomenon, rather than a direct opposition to wind power in general.

This resistance makes wind power that is visible in populated areas potentially problematic. Although Norway has a significantly smaller population density compared to other European countries, and therefore it would indicate that that less people will be visually affected by wind power development, it has still faced significant opposition from residents affected by wind power development. This can be seen in relation to that the outdoor environment in Norway is used heavily by hikers and other groups that can regard wind turbines as a negative addition.

This problem is solved by constructing offshore, where it will in most cases be out of sight from inhabitants. The NIMBY phenomenon is therefore primarily a problem in relation to onshore wind power development, although there can be problems for offshore wind farms if they are visible from shore.

The NIMBY phenomenon is not present in the UK when it comes to Dogger bank, as it is located over 130 kilometers from the Yorkshire coast in England[79].

The indigenous Sami people in Norway

The indigenous people of Norway: The Sami, has a strong standing on cultural preservation. The Sami people`s traditional livelihood includes fishing, livestock farming, hunting and most notably in this context: Reindeer herding. Today, around 2600 Sami have a livelihood based upon reindeer herding[80]. As seen previously from "further onshore development in Norway" in Section 2.2.2, NVE`s proposal for further onshore wind power development in Norway was declined, where one of the reasons where the negative effects that onshore wind power development has on the reindeer herders. In terms of not conflicting with Reindeer herders, offshore wind development is preferred over onshore wind development.

[79] Doggerbank (N.A) About the Project. Retrieved (2020, 02. April) from https://doggerbank.com/
[80] Northern Norway (N.A) The Sami: Indigenous People of the North. Retrieved (2020, 23. May) from https://nordnorge.com/en/tema/the-sami-are-the-indigenous-people-of-the-north/

Local employment effects

From a Norwegian perspective, onshore wind power development (Fosen Wind) is preferable when considering employment opportunities, as it is located on Norwegian soil. Wind power developments on Norwegian territory will lead to more employment for Norwegians than if the development takes place outside the country. In terms of employment, onshore wind power development is preferred over offshore wind power development, which currently takes place outside the UK coast.

Employment effects is fairly overlooked, as it has not been used as a proponent argument for further developments of onshore wind in Norway. Onshore wind power development shows similar promotion of employment effects as general industrial development, but is has not been discussion in relation to the lost employment effects that comes from developing wind power abroad.

5.1.4 Technological factors

Wind power is becoming more of a reliable alternative to energy production, turbines are larger and more efficient and processes in relation to infrastructure are becoming more cost effective, all of which is a result of technological development. It is therefore important to consider the technological developments that are relevant to Norwegian wind power initiatives, and identify the inherent differences between onshore, bottom-fixed offshore and floating offshore wind power development regarding solutions and problems from a technological perspective.

Onshore

Onshore installation has seen a development in the technology related to turbines. This has led to an increase in efficiency and reduced costs associated with construction. Large onshore installations such as Fosen have the advantage of having access to the latest in onshore technology.

Floating offshore

Floating offshore wind has been a more explored solution in recent years. It makes producing wind power at depths greater than 60 meters possible. This technology opens up many previously unused areas for wind power production, where the wind conditions often are more favorable[81].

Within floating offshore Equinor has utilized many components from their experience with offshore oil and gas production.

This includes the anchoring system that consists of cables which hold the turbine in place by being connected to the bottom of the sea.

Equinor´s movement-based sensors monitor the wind and movements in order to adjust the turbine blades, reduce the load on the anchor points, limit tower movements and secure optimal energy production.

Floating offshore has the advantage of being able to complete the installation on land and then subsequently towing the complete turbine out. This greatly reduces the risks that can be associated with offshore assembly.

Fixed offshore

Fixed offshore has been the most utilized offshore solution, but it is limited by sea depth and because of this might not access the greatest wind conditions that often are found at greater depths. The maximum suitable depth that fixed offshore can be applied to is up to approximately 60 meters. Approximately 80 percent of the world's wind resources are found at depths greater than this[82].

As previously mentioned, the mounting and assembly of the fixed offshore installations has to be carried out at sea as opposed to floating where a large portion of it can be carried out at land before being transported to location.

Bottom fixed being the more proven of the two offshore wind alternatives, can be considered a safer technology, and therefore making both planning and execution an easier and more predictable task.

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[81] Equinor (N.A) The Future of Offshore Wind is Afloat. Retrieved (2020, 24. March) from https://www.equinor.com/no/what-we-do/floating-wind.html
[82] The Explorer (N.A) Harnessing Offshore Wind in Deep Waters. Retrieved (2020, 24. March) from https://www.theexplorer.no/solutions/hywind--harnessing-offshore-wind-in-deep-waters/

The trends for further development can be difficult to predict, but one could argue that future wind power instalments will be driven by new technologies and lower costs associated with those solutions[83].

In-depth analysis regarding technology and processes will be found in the “life-cycle-stage” analysis (Section 5.2).

5.1.5 Environmental factors

The global focus towards the potential environmental hazards that comes with industrial production, has made the awareness of climate change and green energy focus increasingly important. It is therefore necessary to go through the potential environmental benefits along with the environmental challenges facing Norwegian wind power development in Norway and the UK and identify potential differences between onshore and offshore wind power development.

Indications of Norway`s phasing out of petroleum exploration

Norway is one of the leading countries when it comes to climate change awareness and a protection of local environments. Despite being one of the biggest petroleum exporters in the world, and although not completely official yet, the Norwegian government chose not to exploit the vast oil reserves in Lofoten`s Islands, and to all intents and purposes, this area will be closed for the oil industry[84]. Not exploiting the vast oil reserves that is believed to be in the Lofoten`s islands, shows a strong support of the shift towards more environmentally friendly energy sources.

[83] IEA (N.A) Tracking Clean Energy Progress: Offshore Wind. Retrieved (2020, 27. April) from https://www.iea.org/fuels-and-technologies/wind
[84] Soldati, Camilla (2019, 30. April) Norway says no to oil explorations in the Lofoten Islands. Retrieved from https://www.lifegate.com/norway-lofoten-oil-ban

The environmental impacts of wind power

Wind power is one of the energy sources that has the lowest impacts on the general environment, as it creates a significant reduction of carbon emissions and has no pollution in the air. Wind power is therefore a positive component of tackling climate change[85].

Wind power development has on the other hand a negative environmental impact locally where wind farms are established. Onshore wind farms degrade the local environment and puts pressure on species that lives in the vicinity of the wind farm.

Although wind power generation itself creates no carbon emissions, there are however carbon emissions from other activities involved in wind power development like the production of materials, material transport, maintenance, construction, assembly and dismantlement[86].

For offshore wind power development, the effects on marine life is not fully understood. There are however been made studies and discussions in relation to the potential threat that Offshore wind has on marine life. The most focused area has been the effects that offshore wind has on marine mammals and seabirds, as these species are more protected through laws. The two most substantial threats that has been focused on, are the pile driving method and increased vessel traffic[87].

For offshore bottom fixed wind turbines, the most common technique for mounting the wind turbine to the seabed is known as pile driving. The pile driving method is associated with substantial noise pollution, and the noise emitted might cause hearing damage to surrounding marine life and cause marine life to be spread away from the area to avoid the noise. Mounting a single turbine to the seabed requires thousands of hammer strikes before it is secured in place, and sound can travel long distances underwater, which may interfere with marine life far away from the vicinity of the wind farm[88].

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[85] AWEA (N.A) Wind`s Environmental Record. Retrieved (2020, 28 April) from https://www.awea.org/wind-101/benefits-of-wind/environmental-benefits

[86] Union of Concerned Scientists (2013, 05. March) Environmental Impacts of Wind Power. Retrieved from https://www.ucsusa.org/resources/environmental-impacts-wind-power

[87] Bailey, H. Brookes, K. Thompson, P. (2014, 14. September) Assessing Environmental Impacts of Offshore Wind Farms: Lessons Learned and Recommendations for the Future. Retrieved from https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4172316/

[88] Bailey, H. Brookes, K. Thompson, P. (2014, 14. September) Assessing Environmental Impacts of Offshore Wind Farms: Lessons Learned and Recommendations for the Future. Retrieved from https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4172316/

Furthermore, the vessels that are brought to the offshore wind farm sites in relation to construction or surveillance might also pose a threat off collision and interferences with marine mammals.

The perceived importance of understanding the impact that offshore wind farms has on marine life is not limited to the local vicinity of the wind farms. Although the direct changes that may occur will happen locally where the wind turbines are constructed and operates, the main focus is still how this local change may affect the overall environment for marine life that far extends from the wind farms. Each marine species is interlinked in a food web, where the disturbance of one part may have significant impact on the overall web, and given its complexity, it can be hard to predict how severe these changes can be[89].

Decommissioning

At the end of a wind farms lifecycle, the wind farm may be decommissioned. Decommissioning involves the decision to not repowering the wind farm and decide to stop operating. Typically, it is expected that the constructor and operator of the wind farm, is to restore the site as closely to its previous state before the construction started when decommissioning the site. However, given that decommissioning is given little attention from an environmental standpoint, there exist little legislation and therefore there are substantial uncertainty in how decommissioning may impact the environment. Furthermore, the decommissioning needs is unique for each wind farm, as weather conditions, type of equipment and characteristics of the site of the wind farm, makes it hard to establish a single methodology of how a wind farm shall be decommissioned[90] .

There exists no single legislation that governs what is to happen to the materials and parts that are left after the decommissioning. Sometimes the materials are recycled back into the business.

[89] NIVA (2011, 08. November) Marine Food Webs. Retrieved from https://niwa.co.nz/coasts-and-oceans/research-projects/marine-food-webs
[90] McMillan,D, Topham, E. (2016).Sustainable Decomissioning of an Offshore wind farm. Retrieved from https://www.sciencedirect.com/science/article/pii/S0960148116309430

5.1.6 Legal factors

The legal factors that are relevant for the wind power industry is worth addressing, as it puts the framework for how onshore and offshore wind power development must be carried out to be within these limits, and changes in this framework may create massive changes in the industries. Strict regulatory boundaries may put pressure on an industry, but loose regulation can also be a threat, as new laws that conflicts with current developments can significantly hinder progress in wind power development initiatives.

There are several legal factors worth addressing in relation to both onshore and offshore wind power in Norway and the UK. In this part, relevant factors and laws will be addressed and investigated in order to give an overview. Differences in legal frameworks between offshore and onshore operations is also an aspect that we will consider.

Offshore regulation

For offshore wind it can be relevant to look at the regulations of the offshore petroleum operations outside the coast of Norway, as it has many similarities to offshore wind. There are however few relevant laws that are directly linked to the offshore wind industry, as it currently has a weak regulatory framework.
As offshore wind continues to grow, a good legal framework will become increasingly important. According to the paper and project proposal at the university of Bergen "Governing offshore wind: Legal challenges, market opportunities and policy perspectives", the regulatory aspects for offshore wind are still lagging behind, much due to the complexity of energy regulation[91].

The legal framework concerning offshore wind includes UNs law of the sea. The United Nations established this law to regulate international waters.
The United Nations Law of the sea concerns freedom of navigation, territorial boundaries, economic zones and other aspects.

[91] Anchustegui,I .(2019.21. August). Governing Offshore Wind:Legal challenges, market opportunities and policy perspectives. Retrieved from https://www.uib.no/sites/w3.uib.no/files/attachments/governing_offshore_wind_21.08.2019_for_websites_version_002.pdf

The main goal of this law is to secure the use of the world's seas and oceans for humanity's best interest, with focus on cooperation between countries. This is more likely if there is a shared regulatory framework, that will reduce the change of conflicts.
Among the significant factors for wind farms, is the exclusive 200 nautical mile economic zone that gives any nation the rights over these areas in proximity to their coast[92].
The exclusive economic zone and the territorial sea are the areas that are the most researched and according to the previously mentioned project at the University of Bergen ***there currently exists a vacuum regarding offshore wind regulation.***

The comparison between offshore wind and offshore oil and gas licensing can be used as they have quite a few similarities. This includes the maritime environment that they are operating in and the infrastructure being used.
However, the two industries have substantial differences in their activities, and therefore applying the same licensing and regulation would perhaps not be the best solution. Oil and gas production exploits and uses the resources from the sea in a completely different way than wind power, as wind is a renewable source of energy.

Onshore regulation in Norway

For onshore regulation we have chosen to look into "Energiloven" and "Plan og bygningsloven".
For regulation and governing of energy in Norway, "Energiloven" or "the law of energy" is one of the essential cornerstones and we therefore have included it in this section.
Energiloven is a law for Norwegian onshore energy from January 1991.
It relates to production, transformation, sale, transfer, distribution and use of energy. The law however does not apply to Norwegian offshore territories[93].
Energiloven is a collective work of rules that previously was spread out over a number of separate laws[94].

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[92] United Nations. (N.A). Oceans and the law of the sea. Retrieved 20.April 2020 from https://www.un.org/en/sections/issues-depth/oceans-and-law-sea/index.html

[93]Lovdata.(1990.29. June). Lov om produksjon, omforming, overføring, omsetning, fordeling og bruk av energi m.m. (energiloven). Retrieved from https://lovdata.no/dokument/NL/lov/1990-06-29-50
[94] Landsamanslutninga av Vassdragskommunar. (N.A) Energiloven. Retrieved 25.May 2020 from https://lvk.no/energiloven

Another relevant law concerning onshore wind is "plan og bygningsloven". Plan og bygningsloven concerns construction, regulation and use of Norway's land areas.
The law applies to all activities concerning both state and local municipalities[95].
Since onshore wind development also often includes substantial amounts of infrastructure, plan og bygningsloven can also be considered relevant[96].

In general terms Norway has a strong focus on safety and legal rights of employees. Most industries are heavily unionized, giving employees a lot of power. Safety is one of the top concerns. It is therefore important for project developers to clarify how to respond to potential threats in the future, and especially in consideration of how this will affect its workers.

5.2 Wind farm life-cycle stages

This industry analysis will be structured after the different life-cycle stages that a wind farm goes through, and the inherent differences between offshore bottom fixed, offshore floating and onshore wind farms will be identified and explained. This will then serve as an important input to the SWOT analysis (Section 5.3).
There exist several overlaps between the different stages, and the different tasks may go over several stages. The tasks that gets the most attention in the different stages will vary between projects, and outside of regulations, it is mostly up to the developers. The feasibility stage, planning and permitting stage, and the pre-construction stage will have extensive overlaps.

5.2.1 Feasibility analysis

The first phase in any project is to conduct a feasibility report, this can either be done using an established framework or be done in a more informal manner. A feasibility study is the conduction of a report that assesses the level of feasibility, or in other words, the ease or convenience of completing the specific project[97].

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[95] Lovdata. (2008, 27. June). Lov om planlegging og byggesaksbehandling (Plan-og Bygningsloven). Retrieved from https://lovdata.no/dokument/NL/lov/2008-06-27-71
[96] Energi Norge. (2013, August). Rettslige rammer for ytelser til vertskommuner ved prosjektering, utbygging og drift av vindparker. Retrieved from https://www.energinorge.no/contentassets/3296a98b551240f5bce2d9443dcc78ae/veileder-ytelser-til-vertskommuner-fra-vindkraftselskaper.pdf

[97] Kenton, Will (2019, 11. August). Feasibility Study. Retrieved From https://www.investopedia.com/terms/f/feasibility-study.asp

The feasibility phase consists of a wide range of tasks that each require specialized knowledge, it is therefore common that several parties are involved. Typical tasks that is involved in the feasibility phase is:

Mapping of available land and the ownership of land

An integral part of a successful wind power project is to be able to identify and claim an optimal site to construct the wind farm, as wind conditions obviously is the most important factor in terms of optimizing the energy production from the site. The land or site, whether it is onshore or offshore, is under a certain country's territory, or are under an international jurisdiction (floating offshore wind might be located far out at sea in international waters), and the project developers needs to map out how to get access to the site, and what laws and processes that needs to be respected in this pursuit.

Wind speed assessment

The average wind speed of different proposed areas will be identified. The measurement of the average wind speed in an area where the wind farm is proposed to be built, is a crucial activity as wind is a highly variable resource. Wind speeds vary extensively, from strong winds, followed by periods of calm winds, seasonal patterns, and climatic influences, makes current wind conditions a highly unreliable observation, as it is unlikely it will be representative for future wind conditions[98].

Identify the level of community acceptance

Community acceptance will be analyzed briefly or extensively, depending on the expected reactions that a new wind power development initiative will receive. There is limited data to be gathered around this in the initial stage, as the project is still to be announced. The exception is when there already exists wind farms in the vicinity, and the new project may benefit from the experience that was gained in terms of how the previous project was meet by the community.

Grid infrastructure assessment

The electricity generated from a wind farm needs to be distributed and will therefore need to be connected to a grid. Conducting a grid infrastructure assessment is a crucial step in wind

[98] Wind empowerment. (N.A). Wind Recource assessment-the basics. Retrieved 15. March 2020 from http://windempowerment.org/wind-resource-assessment-the-basics/

power development, as the lack of a proper grid connection will make the entire project obsolete.

Construction access

Assessment of the availability of existing public roads, or if new roads needs to be established to get construction access to the site. For offshore wind farms this task will be occupied with an analysis of distance from shore, and the availability of vessels and equipment that can be transported to the site.

Ground conditions

Ground conditions relates to the inherent characteristics of the site where the wind farm is supposed to be built. For offshore wind farms this will be water depth and seabed conditions, for onshore wind the terrain of the land and type of land will be identified[99].

5.2.2 Planning and Permitting

After the feasibility analysis is conducted, and the proposed land have been identified for the wind farm, the project goes over into the planning and permitting stage. Here all the necessary permits will be acquired, and planning commences. Typical tasks will be:

Lease options for the site

In the feasibility assessment, mapping of the ownership of the site where the wind farm is proposed to be built have been identified, and now the project developers needs to investigate lease options for the site. It is typical that the lease contract will last twice as long as the expected lifetime of the wind farm, as wind farms has an expected lifetime of 20-25 years, the lease contract will usually be 40-50 years. The longer lease time is arranged in case the project developer wishes to repower the wind farm, or in case of decommissioning, the project developers has time to dismantle the wind farm without pressing time constraints[100].

Community engagement

Wind power development, and onshore wind power development in particular, has shown that local communities can pose one of the biggest threats towards future projects. Positive long

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[99] Renewables first. (N.A). Windpower feasibility study. Retrieved 15. April 2020 from https://www.renewablesfirst.co.uk/windpower/windpower-feasibility-study/

[100] Canadian wind energy association. (N.A). Wind farm lifecycle. Retrieved 20. March 2020 from https://canwea.ca/communities/planning-a-wind-farm/

term relationship building is therefore a high priority for wind power development initiatives, as it both maps out the local concerns, and increases the chance of less criticism, as the development shows it takes all interested parties into consideration. It also shows developers how to best implement the project in advance, which avoids problems down the road, as it is hard and costly to make major changes later in the construction process. Community engagement involves local residents and local authorities, and both of these parties should be actively involved in the whole process from project proposal, until decommissioning/repowering of the wind farm. It is mainly in this stage that the developers make a community engagement plan that they will stick to throughout the project[101].

Environmental impact assessment of the site

The environmental impact assessment at this stage will include environmental surveys and studies. How extensive this task will be is dependent on the specific concerns that is raised around the environmental protection of this specific site. In some geographical locations certain species that are legally protected might exist and as the wind farm project needs to be in accordance with rules and regulations, there needs to be conducted a report in regards to the likelihood of interference with these species, and how severe the interference might be[102].

On-site wind speed monitoring

The proposed site is expected to have good wind conditions, but in order to make predictions of what wind turbines will actually produce over its lifetime, on-site wind speed monitoring equipment will be dispatched to the site. The wind speed data that is gathered will be used to calculate the average, maximum and the standard deviation of the wind speed, and the longer the monitoring period is, the more reliable the data will be[103].

Grid-connection application

In order for the wind farm to distribute its electricity production, it needs to be connected to a grid, and the developer of the wind farm needs to apply for this grid connection. Finding the appropriate grid connection is usually a time consuming endeavor, depending on grid

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[101] Department of energy and climate change. (2014). Community engagement for offshore wind developments. Retrieved from https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/364244/FINAL_-_Community_engagement_guidance_-06-10-14.pdf

[102] Western Balkans environmental program. (2010). Guidelines on the environmental impact assessment for wind farms. Retrieved from https://www.unece.org/fileadmin/DAM/env/eia/documents/EIAguides/Serbia_EIA_windfarms_Jun10_en.pdf

[103] Wind Logger. (2014, 13. August). Introduction to wind speed monitoring for wind turbines. Retrieved from https://www.windlogger.com/blogs/news/5116392-introduction-to-wind-speed-monitoring-for-wind-turbines

capacity, whether or not the wind farm has to contribute to investments into the grid, or whether or not they have to wait for a new grid to be constructed[104].

New technology and more investments into grid networks might make the process easier, but there have been several challenges in the past relating to insufficient grid capacity compared to how much grid capacity the wind industry needs. This might be a problem in the future, if grid capacity develops slower than wind power development[105], as electricity production will be wasted due to lack of storage capabilities in accordance with the "intermittency problem", previously discussed in section; **5.1.2 The Intermittency Problem of Renewable energy.**

The ministry of petroleum and energy (MoPe) is the managing entity for the licensing of Norwegian wind power. The average time between licensing applications are submitted to NVE, and a final decision are made in MoPe is 3.7 years. NVE used 2.1 years and MoPe used 1.6 years. New proposed projects can then expect to spend 3.7 years from permits are applicated until they are finally approved[106].

Offshore wind farms are in especial need of addressing how the wind farm will be connected to a grid. It is currently a challenging field which carry extensive costs, and this corresponds to an equal opportunity of decreasing costs. Transmission of electricity over long distances require innovative solutions[107].
The Dogger bank project was decided to be connected to the UK grid[108], Fosen wind would be connected to Norway`s own grid connection supplier Statnett[109], and Hywind Scotland was decided to be connected to Grange substation in Peterhead, Scotland[110].

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[104] Statnett. (2018, 27. November). The steps in the grid connection process. Retrieved from https://www.statnett.no/en/for-stakeholders-in-the-power-industry/the-grid-connection-process/the-steps-in-the-grid-connection-process/
[105] Power Technology. (2012, 27. June). Wasted wind energy: solving the problem of bad grid connections. Retrieved from https://www.power-technology.com/features/featurewasted-wind-energy-grid-connections-turbines/
[106] Blindheim, Bernt (2015, 23. May) Gone With the Wind? The Norwegian Licensing Process for Wind Power: Does it Support Investments and the Realization of Political Goals? Retrieved from URL: dx.doi.org/10.5278/ijsepm.2015.5.3
[107] Sintef. (N.A). Grid connection. Retrieved 10. April 2020 from https://www.sintef.no/en/grid-connection/
[108] SSE and Equinor. (2019, 30. October). Aibel and ABB to deliver power grid solution to Dogger Bank wind farms. Retrieved from https://doggerbank.com/downloads/Dogger-Bank-Aibel-and-ABB.pdf
[109] Statnett. (2019). Executive summary grid development plan. Retrieved from https://www.statnett.no/globalassets/for-aktorer-i-kraftsystemet/planer-og-analyser/nup-og-ksu/grid-development-plan-2019.pdf

5.2.3 Pre-construction

After the project has secured planning permissions, permissions to use the land where the wind farm is to be constructed, and has received an offer to who the electricity it produces will be sold to, the project moves into the pre-construction stage.
During this stage the project needs to secure funding for the actual construction and arrange and complete construction contracts. As the planning and permission stage takes several years, all work done in this stage will be reviewed, and necessary changes made.

Turbine contracts

The most prominent element of a wind farms capacity to produce energy relates to its choice of turbine and corresponding turbine provider. The global market for wind turbine manufacturing is in rapid growth, and the largest players in this market are: Ge Renewable Energy, Envision, Goldwind, Ming Yang, Nordex, Senvion, Siemens Gamesa Renewable Energy, Suzlon Energy, United Power, Enercon and Vestas Wind Systems[111].

The choice of manufacturer is based upon what type of turbine that is to be built: onshore, offshore bottom-fixed or offshore floating, how much capacity the developer wish to have in each turbine, if the supplier are able to deliver within the desired timeframe, wind conditions (stronger winds require more robust turbines) and corresponding size of the overall project (larger projects may still be viable with smaller turbines)[112].
Generally, a wind power developer purchases from the most established supplier, however, the wind turbine industry is characterized as bigger is better, and new projects typically chooses the supplier that can provide the latest technology, and the largest most efficient turbines that can be delivered at an acceptable cost.

[110]Equinor. (N.A). The development of Hywind Scotland pilot park. Retrieved 22. April 2020 from http://marine.gov.scot/sites/default/files/hywind_scotland_pilot_park_-_cost_efficiency_and_low_risk_solutions.pdf
[111] Wind Power Monthly. (N.A). Turbine manufacturers. Retrieved 14. April 2020 from https://www.windpowermonthly.com/turbine-manufacturers
[112]Windustry (N.A). Turbine selection and purchase. Retrieved 15. April 2020 from http://www.windustry.org/community_wind_toolbox_15_turbine_selection_and_purchase

Turbines and the technology associated with it has been through an evolution in the last years. A wind turbine varies in size that typically is between around 3,6 MW for onshore turbines[113] (Fosen) and up to 12 MW for offshore wind turbines (Dogger Bank)[114]. Smaller offshore turbines are however more common, and Equinor`s Hywind Scotland utilizes 6 MW turbines for its floating offshore wind park.
For the onshore segment, the supplier for Fosen wind is Vestas wind systems, which has a global installed wind capacity of 115 GW, making it the largest wind turbine manufacturer in the world when it comes to total installed capacity[115].

For the offshore bottom-fixed wind segment, the supplier for the Dogger Bank project is GE Renewables, which will equip the project with its Haliade-X wind turbines, that has a capacity of 12 MW each, making it the largest wind turbine in the world. GE Renewable energy has a total installed capacity of 400 GW of renewable energy worldwide[116].

For the offshore floating wind segment, Equinor has several suppliers for the different components that makes up the wind turbines in the Hywind design[117]. Hywind Scotland has a total number of 5 turbines, that has a capacity of 6 MW each[118].

5.2.4 Construction

Construction comes after the pre-construction stage, although there might be some overlap in certain cases. The duration of this stage can vary depending on the size of the project, but it is typically between 10-14 months. Although not the most time-consuming stage it requires the most financially out of all the stages. Construction could be finished at a rapid pace, but grid connection usually takes a long time compared to other construction activities, and the construction process is usually scheduled to coincide with the grid connection.

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113 Fosen Vind. (N.A).Vindturbinene. Retrieved 14. March 2020 from https://www.fosenvind.no/utbyggingen/vindturbinene/
114General Electric (N.A) Haliade-X 12 MW offshore wind turbine platform. Retrieved 10. April 2020 from https://www.ge.com/renewableenergy/wind-energy/offshore-wind/haliade-x-offshore-turbine
115 Vestas. (N.A) Wind. It means the world to us. Retrieved 30. May 2020 from https://www.vestas.com/
116 McPhee, D. (2019, 1. October). Worlds largest turbines to be used a Dogger Bank wind farm. Retrieved from https://www.energyvoice.com/otherenergy/208842/worlds-largest-turbines-to-be-used-at-dogger-bank-wind-farm/
117 Equinor (N.A) Suppliers Make Hywind Possible. Retrieved (2020, 25. April) From https://www.equinor.com/en/what-we-do/floating-wind/suppliers-make-hywind-possible.html
118 Equinor (N.A) Statoil to Build the World`s First Floating Wind Farm: Hywind Scotland. Retrieved (2020, 25. April) From https://www.equinor.com/en/news/hywindscotland.html

Furthermore, modern wind power projects are getting larger in scale, where several wind farms are constructed simultaneously, which typically increases construction time.

The completion of all the wind farms under the Fosen wind project was four years, construction commenced in 2016 and the completion of construction was early 2020. However, some of the wind farms did not start construction until 2018, which explains the long duration of the construction for the entire project.
Typically, the roads and infrastructure are constructed first, then followed by the foundations for the turbines, followed by areas to mount the cranes, substation construction and mounting the turbines.
When the wind farm gets near its completion, the commissioning stage can begin.

5.2.5 Commissioning

The commissioning stage begins as the construction stage gets close to completion and has a duration of 2- 4 months. It mainly consists of adjusting, checking and testing all of the equipment involved in order to ensure that everything is working as it should. Exactly how long time the commissioning stage will take varies and is dependent on how large and complex the project is.
First the substation and grid connections get commissioned, followed by the actual turbines. One turbine usually takes about one week to be commissioned and this process is often carried out on several turbines at the same time. Grid compliance testing is also conducted at the same stage.

5.2.6 Operation & maintenance

When the project has been fully commissioned, the Operation & Maintenance (O&M) stage begins. The duration of the O&M stage makes up the largest part of all the stages at approximately 20 - 25 years in total. During the O&M stage the wind farm is producing electricity to the grid and to the consumer. Operating a wind farm requires a continually management of maintenance, security and finance in order to secure successful operation. O&M can also make up a large amount of the total costs, in some cases as much as 30 percent of the total costs of a wind farm.

The turbines are continually monitored during operation to make sure everything is running efficiently and up to required performance standards. If any irregularities are detected, maintenance crews will be dispatched to deal with the problems. Thus, making the downtime caused by maintenance or other irregularities as short as possible[119].

Maintenance

Routine maintenance is usually carried out between two and four times per year, but this can vary depending on the type of turbines used. The amount of time that the maintenance will require is variable depending on what needs to be done, but typically it is around 40 hours a year for a modern turbine. The maintenance crew will usually be made up of two people per 20 to 30 turbines. Smaller wind farms usually do not have their own maintenance crew, but rather use outside help when conducting the necessary maintenance tasks. Unscheduled maintenance can also happen due to various reasons, such as component failure or other unforeseen causes[120].

Access to maintenance differs greatly when onshore and offshore are compared. Onshore wind turbines have the advantage of usually being accessible by road while the offshore equivalent requires access by ship.

5.2.7 Decommissioning/repowering

A wind farm has a typical lifespan of between 20 to 25 years, and when the wind farm reaches this age there is an option between decommissioning or repowering the wind farm. Decommissioning involves the decision to not repowering the wind farm, and decide to stop operating. Decommissioning of a wind farm entails the opposite of the construction, as the wind farm is dismantled.

Repowering entails the decision to keep operation the wind farm, the wind turbines will be upgraded or replaced with new turbines. There is a distinction between full repowering and refurbishment. Refurbishment entails upgrading and fixing existing wind turbines, while full repowering entails completely switching the turbines.

[119] Bakken Sperstad, I. (N.A). Offshore wind operation and maintenance. Retrieved from https://www.sintef.no/en/offshore-wind-operation-and-maintenance/

[120] Wind energy the facts. (N.A). Commissioning, operation and maintenance. Retrieved 15. March 2020 from https://www.wind-energy-the-facts.org/commissioning-operation-and-maintenance.html

Refurbishment has been a problem in the past, mostly because the planning of the wind farms haven`t included the end stage decommissioning/repowering thoroughly enough. Problems with refurbishing have been lack of spare parts, and outdated technology[121].

There is however a case for full repowering. There are several arguments that points in the direction of repowering over decommissioning, as the capital investments in infrastructure will continue to be leveraged as they will still be in use, rather than being dismantled. Furthermore, there have been extensive monitoring of wind conditions on the site, meaning that the data is more reliable, as not only have there been monitoring before the wind farm was built, but data has been collected over the lifetime of the wind farm as well, meaning that future projections will be more reliable. The developers do not need to spend time, capital and the inherent risk of developing a new site if they choose to repower the already existing wind farm[122].

As Fosen Wind and Hywind Scotland has recently been constructed and is operational and Dogger Bank is under construction,, there exist little focus on how these farms will be decommissioned, or if they will be repowered when they outlive their initial usefulness.

[121] Canadian Wind Energy Association. (N.A). Decommissioning/repowering a wind farm. Retrieved 10. April 2020 from https://canwea.ca/communities/planning-a-wind-farm/
[122] Canadian Wind Energy Association. (N.A). Decommissioning/repowering a wind farm. Retrieved 10. April 2020 from https://canwea.ca/communities/decommissioningrepowering-wind-farm/

5.3 LCOE

Levelized cost of energy (LCOE) is a method for comparison of energy production. LCOE takes the NPV of total costs over the project's lifetime divided by the NPV of electric energy that has been produced[123].

We have compared the LCOE of floating offshore, fixed offshore and onshore wind using our table below:

Wind segment	Floating offshore	Fixed offshore	Onshore
LCOE	118-264 Øre/Kwh	146 Øre/KWh	32 Øre/KWh
Grid connection cost	28-63 Øre/KWh	22-44 Øre/KWh	3-4 Øre/KWh
Grid connection cost percentage of LCOE	24%	15-30%	9-14%

Table 1; LCOE for onshore, fixed offshore and floating offshore wind. See appendix A.

The LCOE for the onshore wind segment is for Norwegian onshore wind power in 2019. Offshore fixed and floating LCOE are global industry averages for 2015 and 2014 respectively. The LCOE numbers are from different sources and from different years. This is due to the limited amount of information available.

As seen in the table onshore wind represents the lowest LCOE with fixed offshore being significantly higher and floating offshore the most costly solution.

NVE has in their published data of costs in the energy sector an LCOE estimate for onshore wind of 32 Øre/KWh in 2019. This is predicted to decrease substantially to 21 Øre/KWh in 2040[124].

Fixed offshore LCOE are over three times as high as onshore with a LCOE of 146 Øre/KWh, representing a large leap in costs[125].

The LCOE for floating offshore is given in an interval from best to worst case scenario, based on the findings in Bjerkseth, Myhr, Nygaard and Ågotnes findings[126]

[123] Corporate finance institute. (N.A). Levelized cost of energy (LCOE). Retrieved 15. March 2020 from https://corporatefinanceinstitute.com/resources/knowledge/finance/levelized-cost-of-energy-lcoe/

[124] Norges Vassdrag og Energidirektorat. (2019, 11. June). Kostnader i energisektoren. Retrieved from https://www.nve.no/energiforsyning/energiforsyningsdata/kostnader-i-energisektoren

[125] Ebenhoch, R, Marathe, S, Matha, D, Molins, C, Munozc, P. (2015) Comparative levelized cost of energy P.12 Retrieved from https://www.sintef.no/globalassets/project/eera-deepwind-2015/presentations/f/f_matha_univ-stuttgart.pdf

Grid connection cost

As seen from table 1, the grid connection costs for onshore wind is between 3 and 4 Øre/KWh, and the corresponding grid connection costs for offshore fixed wind is between 22-44 Øre/KWh, while offshore floating wind has a grid connection cost between 28-63 Øre/KWh. Offshore wind is far more expensive than onshore in general, but grid connection costs stand for a significant part of the higher cost for offshore wind.

The percentage of grid connection cost of total LCOE in table 1 shows that grid connection stand for 9-14% of LCOE cost for Onshore wind, 15-30% of LCOE for offshore fixed wind and 24% of LCOE for offshore floating wind. Grid connection for offshore wind thereby also stand for a higher percentage of total LCOE cost than for onshore wind. See appendix A.

Cost drivers

Site conditions

For offshore wind, the further out at sea the wind farm is located, the more expensive the foundation of the wind farm becomes. This holds true for both Bottom-fixed wind and floating wind. Bottom-fixed wind located at greater depths necessitates taller wind turbines and creates more expensive transportation to site in relation to construction and maintenance.

The need for alternating methods when the area of the wind farm is not homogenous, drives up costs, as new designs and methods needs to be implemented, which is both time consuming and necessitates more equipment and expertise.

Floating wind is in its infancy when compared to bottom-fixed wind, and therefore relies on new methods that are expensive to implement, especially when compared to the low power generation currently seen from floating wind initiatives, making the costs of the foundation very high in relation to the costs of the turbines that produces the energy.
Onshore wind is also site-specific in terms of costs, but these costs is mostly associated with maintenance of wind farms that have suboptimal road infrastructure, making each maintenance visit more time consuming and might necessitate specialized equipment.

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[126] Bjerkseter, C, Myhr, A, Nygaard, T, Ågotnes, A. (2014). https://reader.elsevier.com/reader/sd/pii/S0960148114000469?token=BD850CDADF24F837F1645D4B21847FE7272014A1380B03E02E8606C16EF1DA84B1A645F7831AE7D54920CC22540954FE

However, most onshore wind farms have ideal sites in terms of keeping costs down, giving them a distinct advantage over offshore wind, where ideal sites are both harder to identify and also necessitates site specific equipment, which drives up costs[127].

Supply chain evolution

The wind energy supply chain can be roughly divided into four parts: Raw materials, component manufacturing, Project development and Operation and maintenance.
As the market for wind energy are getting more mature, the effect on the supply chain has led to a reduction in costs by more collaboration between the different parts in the supply chain, along with an increased volume of orders has led to increased investments into design, processes and manufacturing in order to manage larger orders, thereby reaping the benefits of economies of scale[128].
The least mature segment is floating offshore wind, and this wind power segment is characterized by lacking a commercial scale, in which processes can be more standardized and suppliers of infrastructure and components of the wind turbines are better able to manufacture in a large scale, which reduces costs. Equinor`s Hywind Scotland project is also characterized as being mostly an “in-house” development, where Equinor are using technologies and solutions that stems from its extensive experience and know-how in operating its offshore oil & gas fields, where the costs reduction must be seen in relation to Equinor`s own supply chain, which is outside the scope of this thesis.

However, offshore floating wind has the potential of reducing costs in relation to onshore assembly, which bottom-fixed wind do not enjoy the benefit off. More onshore assembly reduces costs, as there are less constraints in relation to weather conditions, and there is less need of specialized offshore equipment and more simplified transportation to site, as whole components can be transported at once[129].

[127]CATAPULT - Offshore renewable energy. (N.A). Retrieved 25. March 2020 from https://guidetoanoffshorewindfarm.com/wind-farm-costs
[128]Jha, V. (2017, 1. May). Building supply chain efficiency in solar and wind energy. Retrieved from https://www.ictsd.org/sites/default/files/research/building_supply_chain_efficiency_in_solar_and_wind_energy_digital.pdf
[129] Jha, V. (2017, 1. May). Building supply chain efficiency in solar and wind energy. Retrieved from https://www.ictsd.org/sites/default/files/research/building_supply_chain_efficiency_in_solar_and_wind_energy_digital.pdf

Highly specialized vessels is a huge constraint for the offshore wind industry, as it is both expensive as it requires the vessels to be customized according to the need of the installation or maintenance activities that is to be performed, and these vessels are in short supply compared to the expected needs that offshore wind farms will have in the future.

Technological development

The largest factor in regard to cost reduction, has been technological development, especially wind turbine technology. The wind turbine is the producing part of the overall wind farm, and technological development has had a rapid growth[130], increasing the capacity of wind turbines from a meager 2 MW 20 years ago, to GE renewable`s Haliade X-turbine with 12 MW capacity that is being constructed for the Dogger Bank project[131].

An increase in MW capacity, reduces the costs per MW, in accordance with the principles of economies of scale[132].

The MW capacity increase comes from an increased turbine efficiency and an increase in the size of the turbine. Larger turbines are also able to reach further up where winds are stronger, increasing the production of energy.

Cost of financing

The most typical way of driving down financing costs, is to reduce the perceived risk associated with the wind power project. Therefore, there are distinct differences in the financing structure between onshore wind, offshore-bottom fixed wind and offshore floating wind, where the perceived risks are very different. Onshore wind power development enjoys a good track record compared to offshore, where the methods and return on investments(although not necessarily optimal) can be analyzed over a longer period, giving lenders more reassurance, as there are more data to draw a conclusion from. Onshore wind power development is also more standardized, making similarly sized projects more identical when looking away from turbine capacity (which is a result from new technology), decreasing the uncertainty involved with a new onshore wind farm.

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[130] CATAPULT - Offshore renewable energy. (N.A). Retrieved 25. March 2020 from https://guidetoanoffshorewindfarm.com/wind-farm-costs

[131]General Electric. (2019, 1. October). GE renewable energy Haliade X turbines to be used by Dogger Bank wind farms. Retrieved from https://www.genewsroom.com/press-releases/ge-renewable-energy-haliade-x-turbines-be-used-dogger-bank-wind-farms

[132] Kenton, W. (2019, 20. May). Economies of scale. Retrieved from https://www.investopedia.com/terms/e/economiesofscale.asp

Offshore-bottom fixed wind is becoming more mature and has proven it can be a viable wind power alternative. That being said, this wind power segment comes with site specific challenges, meaning that, a new offshore-bottom fixed wind farm might have a distinctly different cost structure than similar projects, as the increased complexity of these wind farms makes early prediction of costs hard to ascertain, making the perceived risk higher, along with a corresponding increase in financing costs.

Offshore floating wind is a new wind power segment which comes with a corresponding lack of reassurance to potential lenders, as the perceived risks of something brand new and innovative are deemed a risky venture. Offshore floating wind is also not yet in a commercial stage, so financing this segment is more viewed as an investment into research and development, rather than a medium to collect a return on investments[133].

[133] CATAPULT - Offshore renewable energy. (N.A). Retrieved 25. March 2020 from https://guidetoanoffshorewindfarm.com/wind-farm-costs

5.4 SWOT analysis

This analysis will be focused on Fosen wind for the onshore wind segment, while Dogger bank and Hywind will serve as examples for the offshore fixed and offshore floating segments respectively. The strengths, weaknesses, opportunities and threats identified for the different projects is also related to the industry they are in. Fosen wind will also include the inherent characteristics of onshore wind development, Dogger bank will include characteristics of offshore bottom fixed wind development and finally, Hywind will include the characteristics of the offshore floating wind development segment.

Onshore Wind:
The Case of Fosen

Fosen wind

Internal	**Strengths** • Large scale project that benefits from economies of scale • Easy access to maintenance • Uses proven technology • Cheap grid connection costs • One of the cheapest renewable energy sources available	**Weaknesses** • Noise Pollution • Local environmental degradation • Negative visual impact • High degree of foreign ownership (over 60%).
External	**Opportunities** • Green shift and focus on renewable energy in media and among local populations. • Norway has many areas and a geography suitable for further onshore wind development. • Provides a basis for further development of a promising new industry in Norway. • Local employment effects	**Threats** • Resistance among local populations can limit the projects. • Changing regulations regarding onshore wind. • Negative media focus on the industry.

Table 2; SWOT analysis of Fosen Wind.

Strengths

Economies of scale

Economies of scale relates to the efficiency gained from production of something in large quantities. Economies of scale makes the production cheaper, as the overall costs are divided by more units, making the production of each unit less expensive[134].

Fosen benefits from this being the largest onshore wind park in Europe with its six wind farms and 277 turbines[135].

Easy access to maintenance.

As Fosen wind is an onshore wind park, it enjoys the benefit of having easy access to maintenance. Furthermore, Fosen wind has a well-established road infrastructure, designed to make maintenance cost-effective and quick to perform. For instance, 70 km of road has been built in relation to the project in Roan, which is one of the wind parks in Fosen[136], even though this led to substantial troubles with environmentalists[137].

Uses proven technology

Compared to offshore wind, onshore wind is well established as a cost-effective way of generating renewable energy and has been well proven[138].

The incremental technological developments has made wind turbines bigger and more efficient, and there exists little confusion as to how to construct them, unlike offshore, where there are numerous designs that haven't been thoroughly proven, and each site is unique, while onshore sites that are picked out are more similar to each other, enabling the same methods to be applied again and again.

Cheap grid connection costs

According to IRENA (See Appendix A), grid connection costs for onshore wind power, accounts for 9-14% of LCOE costs, while the grid connections costs for fixed offshore wind

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[134] Kenton, W. (2019, 20. May). Economies of scale. Retrieved from https://www.investopedia.com/terms/e/economiesofscale.asp

[135] Fosen vind. (N.A). Om fosen vind. Retrieved 10. January 2020 from https://www.fosenvind.no/om-fosen-vind/

[136] Statkraft. (2019, 22 May). Norway's largest wind farm opened. Retrieved from https://www.statkraft.com/media/news/2019/opening-roan/

[137] Oppland, Egil (2016,18. August) Kjemper Mot Vindmøller. Retrieved from https://www.adressa.no/nyheter/sortrondelag/2016/08/18/Kjemper-mot-vindm%C3%B8ller-13203007.ece

[138] International Energy Agency. (N.A). Wind. Retrieved 20. April from https://www.iea.org/fuels-and-technologies/wind

power is 15-30% of LCOE costs, and floating offshore wind power has a grid connection cost of Approximately 24% of LCOE costs. This shows that grid connection for onshore wind is much cheaper than for offshore wind. The more expensive grid connection for offshore wind is related to distance to grid, which necessitates longer cables, increasing the overall costs, while onshore wind power development typically is located closer to a grid.

One of the cheapest renewable energy sources available.

When compared to other renewable energy sources such as biomass, solar and hydro, onshore wind is very low cost, making it highly competitive. The LCOE for onshore wind in Norway is 34.39 Øre per kWh in 2018. A trend of further reduction of costs is predicted to continue[139].

Weaknesses

Noise pollution

Although governmental research has concluded that the noise emitted from onshore wind turbines are comparatively low compared to other industries, wind turbines do make noise and noise pollution is one of the biggest criticisms from local populations where wind parks are established, including Fosen wind[140].

Negative visual impact

The visual impact on the surrounding scenery can in many cases be substantial. It can therefore lead to resistance among the local communities that are affected by the construction process. Areas that are previously untouched by human development can be drastically changed[141].

As part of the increased environmental awareness, the environment also has a strong cultural backing, especially in Norwegian society, where natural landscapes are prioritized, and any changes to it, is met with substantial opposition from environmentalist groups. The “NIMBY” phenomenon where people do not want industry or any other visually obstructions close to

[139] Wind Europe. (2019, 29. March). Wind energy is the cheapest source of electricity generation. Retrieved from https://windeurope.org/policy/topics/economics/

[140]The guardian. (2012, 25. September). Offshore wind energy: what are the pros and cons. Retrieved from https://www.theguardian.com/environment/2012/sep/25/climate-change-windpower

[141]Lindefjeld, V. (2016, 4. February). Vindkraft er unødvendig i Norge. Retrieved from https://www.tu.no/artikler/vindkraft-er-unodvendig-i-norge/276721

their homes is also a strong factor that inhibits a wind farms ability to get approval for further development and operations.

Local environmental impact

As with all industry, the construction of Fosen wind has an environmental impact locally where it operates[142].

Wind power has substantial less impact than most other energy industries, but the impacts are still present.

The threat to birds is the most prevalent concern, as wind turbines poses a threat for collision and a disturbance of their natural habitat. Even though the level of impact that onshore wind farms has on birds are hard to identify, as the impact is very dependent on the specific site, season and whether the birds are migratory or resident, it is still generally thought of being a big potential threat to endangered bird species. However, the mortality rate of birds seem to not be much higher than for other areas where there are tall structures present[143].

Opportunities

Green shift and focus on renewable energy in media and among local populations.

As the focus has shifted gradually towards more environmentally friendly solutions and an increased focus on decreasing greenhouse gas emissions such as CO_2, there has been an increased interest for renewable energy[144].

Norway has many open areas and a geography suitable for further onshore wind development.

Norway has a population density of 14 people per square kilometer[145].

This makes the country ideal to wind industry on a general basis, where untouched landscape amounts to construction opportunities, and the number of people affected for each project will be minimal. Norway also benefits from good wind conditions. NVE has identified 13 new

[142] Patonia, A. (2017). Critical evaluation of the Roan wind farm. Retrieved from http://www.arcticandnorth.ru/upload/iblock/61f/05_Patonia.pdf
[143] Wind energy the facts. (N.A). Onshore impacts. Retrieved 30. March 2020 from https://www.wind-energy-the-facts.org/onshore-impacts.html
[144] Chaudhary, M. (2019, 1. August). Grønt skifte og andre endringer. Retrieved from https://www.ssb.no/natur-og-miljo/artikler-og-publikasjoner/gront-skifte-og-andre-endringer
[145]World population review (N.A). Retrieved March 2019 from https://worldpopulationreview.com/countries/norway-population/

places where further onshore wind development would be suitable, most of them being located in the south and in the middle of the country where there are optimal network opportunities and less interferences with reindeer herders[146].

Local employment effects

Given that Norwegian onshore wind power development takes place in Norway, onshore wind power will benefit from giving the Norwegian population employment opportunities. Because Dogger Bank and Hywind Scotland is located abroad, Fosen wind has the advantage of being on Norwegian soil, which may add the incentive to continue to develop onshore wind, so that Norwegians will further benefit from employment opportunities.

Threats

Resistance among local populations can limit the projects

As seen with Fosen there are several parties that are affected by the project and for some of them this might have negative implications. One example of this is the indigenous Sami people that believe the construction of the wind park will have a negative impact on their reindeer herding[147].

Changing regulations regarding onshore wind.

The regulations and permits regarding wind projects on land can change. The political climate can shift in favor of other renewable energy types and create uncertainty for the onshore wind industry. Unpredictability regarding regulations can therefore be a major threat towards the onshore wind industry[148].

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[146]Karagiannopoulos, L. (2019, 1. April). Norway identifies 13 preferred areas for new wind power development. Retrieved from https://www.reuters.com/article/us-norway-wind/norway-identifies-13-preferred-areas-for-new-wind-power-projects-idUSKCN1RD27H

[147] Naturvernforbundet. (2011, 21. October). Stor motstand mot vindkraftprosjektene. Retrieved from https://naturvernforbundet.no/trondelag/nyheter/stor-motstand-mot-vindkraftprosjektene-article25924-1428.html

[148]Stavanger Aftenblad. (2019, 17. October). Støre: Regjeringens vindkraft håndtering har skapt usikkerhet. Retrieved from https://www.aftenbladet.no/innenriks/i/lAL05y/stre-regjeringens-vindkraft-handtering-har-skapt-usikkerhet

Negative media focus on the industry

The industry can come under negative focus from the media and NGO`s. This negative focus can be harmful and change the perception of wind power. An example of this can be focus on the negative aspects and dangers of wind turbines such as their impact on the environment[149]. Combined with the scrutiny of wind powers financial performance, especially onshore wind power development can be perceived as both damaging to the environment, the economy and also be deemed unnecessary. Oppositions of wind power development points to the arguments that onshore wind power is unreliable[150], damages the environment[151], neglects reindeer herders rights[152],and is unnecessary for Norway[153], as 98% of Norway's electricity need is meet by its own hydropower production[154]. The high degree of foreign ownership in Norwegian onshore wind (over 60%) is also a criticism, as the majority of the profits will not benefit Norway, as it goes to foreign investors.

If the general population starts to share these opinions, it would be very damaging for Fosen wind and other onshore wind power initiatives in the future.

[149] Bolstad, J. (2019, 17. September). Motstanden mot vindkraft på land aukar. Retrieved from https://www.nrk.no/vestland/motstanden-mot-vindkraft-pa-land-aukar-1.14705126

[150] Greenstone, M, Nath, I. (2019, 9. May). Do renewable portfolio standards deliver? Retrieved from https://epic.uchicago.edu/wp-content/uploads/2019/07/Do-Renewable-Portfolio-Standards-Deliver.pdf

[151] Patonia, A. (2017). Critical evaluation of the Roan wind farm. Retrieved from http://www.arcticandnorth.ru/upload/iblock/61f/05_Patonia.pdf

[152] Patonia, A. (2017). Critical evaluation of the Roan wind farm. Retrieved from http://www.arcticandnorth.ru/upload/iblock/61f/05_Patonia.pdf

[153] Lindefjeld, V. (2016, 4. February). Vindkraft er unødvendig i Norge. Retrieved from https://www.tu.no/artikler/vindkraft-er-unodvendig-i-norge/276721

[154] Government (2016, 11. May). Renewable energy production in Norway. Retrieved from https://www.regjeringen.no/en/topics/energy/renewable-energy/renewable-energy-production-in-norway/id2343462/

Internal	**Strengths** • Favorable wind conditions are often found at deeper waters where Hywind operates. • Using technology that is proven from years of offshore oil and gas experience. • Not as disrupting visually as onshore and close to shore wind farms. • Has some cost advantages for installations compared to bottom fixed offshore.	**Weaknesses** • Increased costs compared to onshore and fixed offshore wind. • Expensive and difficult to maintain.
External	**Opportunities** • High growth potential as coastal areas typically have higher energy needs. • Large scale project initiatives that can make Hywind commercially viable. • Can be a new area for offshore oil and gas companies to venture into. • More development opportunities, as more areas are accessible by operating in deep waters. • Can make Norwegian oil & gas platforms more environmentally friendly	**Threats** • Changing regulations and government incentives can make future plans difficult. • Competition from other less costly renewable energy sources. • Floating winds effect on marine life is still not fully understood • Floating wind requires grid connections that is currently lacking in most European harbors

Table 3; SWOT analysis of Hywind Scotland.

Strengths

Favorable wind conditions are often found at deeper waters where Hywind operates.

The best wind conditions are found in deep waters exceeding 60 meters, where the wind is both stronger and wind levels are more consistent. This leads to each turbine generating more electricity, and it is easier to predict electricity generation over time, as the production do not vary to a great extent. Wind generally is also less turbulent over water than on land, so the expected lifetime for an offshore wind turbine is longer, as the turbine suffers less wear and tear[155].

Using technology that is proven from years of offshore oil and gas experience.

Equinor has vast experiences with offshore operations that stems from its operation of its oil and gas platforms. The technological development and know-how from operating in the offshore oil and gas industry has enabled Equinor to use proven technologies in a new industry[156].

Hywind will have a competitive edge over other floating wind initiatives, unless they share Equinor`s experience in operating offshore. Hywind`s competitive edge, also lies in the "first movers advantage", as Hywind Scotland is the first floating wind farm in the world.

Not as disrupting visually as onshore and close to shore wind farms.

The environment is not only a priority when it comes to climate change, protection of species and the ecosystem, but the environment has a strong cultural support. As the natural environment is more and more protected, everything that threatens to alter its appearance comes under heavy scrutiny, especially on Norwegian territory, where people value the protection of nature[157].

The "NIMBY" phenomenon is also avoided, as floating offshore wind is usually located far away from the coast, and is out of sight[158]. Hywind Scotland is located 25 kilometers outside the coast of Peterhead, Scotland[159], while the upcoming project Hywind Tampen will be located approximately 140 kilometers outside the Norwegian coast in the Tampen area[160]

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[155] Equinor. (N.A). The future of offshore wind is afloat. Retrieved 10. March 2020 from https://www.equinor.com/en/what-we-do/floating-wind.html

[156] Equinor. (N.A). About us. Retrieved 3. March 2020 from https://www.equinor.com/en/about-us.html#equinor-in-brief

[157]Krogh-Hanssen, H (2016, 21. September). Take a hike as Norwegians do. Retrieved from https://scandinaviantraveler.com/en/lifestyle/take-a-hike-as-norwegians-do

[158] Lofhouse, J, Bank, R. (2016, 1. August). Wind Power: Not in my backyard! Retrieved from https://medium.com/@stratapolicy/wind-power-not-in-my-backyard-44224e896dab

[159] Hill, Joshua (2018, 16. February) Hywind Scotland, World`s First Floating Wind Farm, Performing Better Than Expected. Retrieved from https://cleantechnica.com/2018/02/16/hywind-scotland-worlds-first-floating-wind-farm-performing-better-expected/

[160] NS Energy (N.A) Hywind Tampen Project Details. Retrieved (2020, 27. April) from https://www.nsenergybusiness.com/projects/hywind-tampen-floating-wind-farm/

Has some cost advantages for installations compared to bottom fixed offshore.

As one of the biggest obstacles for offshore wind is on site construction, which needs to take place in safe weather conditions. On-site assembly in difficult locations leads to increased complexity which drives up costs and is more time consuming. Floating offshore has the advantage off more onshore assembly than bottom fixed wind, which leads to cost reduction and less weather constraints. The different parts can be assembled onshore, and the whole parts can then be transported to the offshore site for completion when weather conditions are appropriate. The on-site construction time will then be shorter as most of the parts are already assembled, which saves time and reduces costs[161].

Weaknesses

Increased costs compared to onshore and fixed offshore wind

The most prominent criticism of floating wind is the costs associated with it. Floating wind has a serious competitive cost disadvantage compared to onshore and fixed offshore wind. This is mainly due to two factors: Firstly, the infrastructure that is needed for the wind turbines to float is much more expensive, than for bottom-fixed wind turbines.

The wind turbine is the profit generating part of the wind farm, and when the infrastructure that supports it becomes more expensive, it becomes more expensive to build and operate, without an increase in production, as the turbines becomes an even smaller part of the overall cost structure.

Secondly, as floating offshore is far from a mature segment, floating offshore wind farms are mainly established to test technology but is not meant to be profitable from current operations[162].

Given the small scale of Hywind Scotland, which do not provide sufficient electricity production to offset the research & development costs. Offshore floating wind lacks both a profitable scale to benefit from economies of scale, and a lack of standardization makes each initiative more expensive. The lack of standardization comes from floating wind being in its early stages and the industry has not yet reached a level of maturity where standardization exists.

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[161] Wind Europe (2018, 1. October). Floating offshore wind energy https://windeurope.org/wp-content/uploads/files/policy/position-papers/Floating-offshore-wind-energy-a-policy-blueprint-for-Europe.pdf

[162] Andersen, O. (2019. 14. October) Equinor: Floating wind farm will hardly turn a profit. Retrieved from https://energywatch.eu/EnergyNews/Renewables/article11684299.ece

Expensive and difficult to maintain

One of the benefits of offshore wind is that it can be placed far out at sea where the best wind conditions are found, which is also one of the biggest downsides from a cost perspective. The further the wind farm is from shore, the more expensive it becomes to maintain it and transport electricity to shore. The most challenging aspect of maintenance is the lifting procedures, as they require heavy machinery that needs to be dispatched to the site. This machinery is scarce, and expensive to transport, making each maintenance visit to the site expensive. Turbines that needs to be maintained or replaced often do not justify the costs associated with it, and therefore maintenance may only be favorable if many lifts are to be performed on several turbines on one visit[163].

Opportunities

High growth potential as coastal areas typically have higher energy needs.

Several of the world's largest cities are located in areas by or near the coast, this means that these areas have high needs for energy and therefore can contribute to growth in offshore wind. This is favorable for offshore wind as it can make the distance of cables shorter and therefore require simpler solutions.

As an example, 39 percent of the US population live in counties that are on the shoreline[164].

Large scale project initiatives that can make Hywind commercially viable.

Hywind Scotland consists of a total of five turbines, while the upcoming Hywind Tampen project will have 11 turbines[165].

This is still a small number compared to larger offshore projects and for Hywind to become commercially viable it is required that large scale initiatives be set in place.

More development opportunities, as more areas are accessible by operating in deep waters.

[163]Conbit. (N.A). Floating offshore wind farms. Retrieved 30. March 2020 from https://conbit.eu/floating-offshore-wind-farms-maintenance/

[164] National ocean service. (2018, 25. June). What percentage of the American population lives near the coast. Retrieved from https://oceanservice.noaa.gov/facts/population.html

[165] Equinor. (2019, 10. October). Investerer I utbygging av Hywind Tampen. Retrieved from https://www.equinor.com/no/news/2019-10-11-hywind-tampen.html

As offshore floating wind farms can be constructed almost anywhere where the water depth exceeds 60 meters, it opens up vast opportunities for new development. Bottom fixed wind farms are constrained by the water depths, greatly narrowing the number of potential sites. Issues regarding fisheries, marine life and the intrusion on other industries are easier to circumvent, as the increased number of potential new sites, makes finding an optimal site that creates the least amount of negative effects more likely. Around 80 percent of the total offshore wind conditions are located in water depths off over 60 meters, wind resources that floating wind can harness[166].

Can be a new area for offshore oil and gas companies to venture into.

Increased climate change awareness has pushed oil & gas companies such as Equinor into decreasing their CO2 emissions, and venture into the renewable energy industry[167].
For oil & gas companies that has offshore experience, they can be inspired by Equinor`s utilization of this experience, to venture into the wind power industry, by developing offshore floating wind farms.

Can make Norwegian oil & gas platforms more environmentally friendly

Oil & gas production and consumption has a huge share of the overall release of climate gasses, and a step into tackling climate change has been to try to reduce the size of this industry. However, the world is expected to be dependent on both the oil & gas revenues, and the reliability this energy source provides for many years to come. There is however still a way to reduce co2 emissions by looking at how oil & gas platforms operates.

Oil & gas platforms are powered by combustion engines which runs on gas, floating offshore wind has the potential to electrify Oil & gas platforms, making the operation more environmentally friendly as less co2 emissions will be released following the removal of the combustion engines[168].

[166] Wind Europe (2018, 1. October). Floating offshore wind energy https://windeurope.org/wp-content/uploads/files/policy/position-papers/Floating-offshore-wind-energy-a-policy-blueprint-for-Europe.pdf
[167] Sætre, E. (2017, 9. Oktober). Statoil: Skal målene fra Parisavtalen nås, må også mye olje og gass forbli i bakken. Retrieved from https://www.aftenposten.no/meninger/kronikk/i/qG9Q1/statoil-skal-maalene-fra-paris-avtalen-naas-maa-ogsaa-mye-olje-og-gass-forbli-i-bakken-eldar-saetre
[168] ABB/ZERO. (N.A). Floating offshore wind. Norway's next offshore boom?. Retrieved 20. April 2020 from https://new.abb.com/docs/librariesprovider50/media/tv1012-br-havvind-notat-til-zerokonferansen---engelsk.pdf?sfvrsn=effbb214_2

Hywind Tampen that is expected to start construction in 2022[169], will power the Norwegian petroleum fields Snorre and Gullfaks with electricity, making combustion engines unnecessary and leads to a decrease of co2 emissions stemming from these fields.

Threats

Changing regulations and government incentives can make future plans difficult.

A predictable framework and governance from governments is essential for such a large-scale project to be successful. Unpredictability regarding rules and regulations can make plans difficult due to the scale and large investments involved. An example of this can be the change in support for offshore wind if one chooses to construct more onshore wind farms instead. As offshore floating wind is still in need for subsidies, a lack of support from the government could make projects economically unviable[170].

Competition from other less costly renewable energy sources.

Offshore floating wind is a costly form of renewable energy production compared to many alternatives.

This can lead to competition from cheaper renewable energy sources. Although offshore floating wind is expected to become less costly, this trend is shared with other renewables, and offshore floating wind, although becoming more viable, can still continue to lag behind as other renewable energy sources continue to reduce their costs[171].

Floating winds effect on marine life is still not fully understood

The effects that floating wind turbines has on marine life is largely unexplored and not yet fully understood.

Although the pile driving method is associated with substantial noise pollution, where the noise emitted is known to cause hearing damage, this is a technique mostly used on fixed offshore.

[169]Mossing J, B. (2020 8. April). Jubel og kritikk for milliardsatsing på havvind. Retrieved from https://www.nrk.no/vestland/utbygging-av-hywind-tampen-er-godkjent-1.14977920

[170] Andersen, O. (2019, 14. October). Equinor: Floating wind farm will hardly turn a profit. Retrieved from https://energywatch.eu/EnergyNews/Renewables/article11684299.ece

[171]CNBC. (2019, 19. September). Renewable energy is now a compelling alternative as it costs less than fossil fuels, says Michael Milken. Retrieved from https://www.cnbc.com/2019/09/19/renewable-energy-is-cost-effective-says-michael-milken.html

As there will be an increasing number of offshore installations in the future, the importance of further knowledge about the consequences on marine life will be more important[172].

It is expected that floating wind poses less of a threat to marine life than bottom fixed wind, as most of the activities that has shown a disturbance is not used for floating wind, as there are less activity related to the seabed. If research finds that floating wind has a large negative impact on marine life, it might put current and future floating wind projects in jeopardy.

Floating wind requires grid connections that is currently lacking in most European harbors.

One of the largest barriers towards floating wind today is the lack of grid connections in most European harbors. In order to convert harbors to be able to handle this, it is necessary to have political support, on regional and national level. The majority of European harbors must invest in major upgrades in order to handle the demands that floating offshore wind will require[173].

[172] University of Maryland, Center for environmental science. (2014, 16. October). Impact of offshore wind farms of marine species. Retrieved from https://www.sciencedaily.com/releases/2014/10/141016123608.htm

[173]Wind Europe (2018, 1. October). Floating offshore wind energy https://windeurope.org/wp-content/uploads/files/policy/position-papers/Floating-offshore-wind-energy-a-policy-blueprint-for-Europe.pdf

Offshore fixed:
Dogger Bank

Internal	**Strengths**	**Weaknesses**
	• Large scale project that can provide synergy effects and benefits from economies of scale. • Benefits from the better wind conditions of offshore wind, while at the same time avoiding the increased costs associated with floating offshore. • Bottom-fixed turbines are currently industry standard for the offshore wind industry, enjoys more standardization and there are less risks associated with new projects as it is a proven concept.	• Not feasible to place in water depths exceeding 60 meters, locations are thereby limited, and the best wind resources will not be harnessed. • Dependent on governmental cooperation.
External	**Opportunities**	**Threats**
	• Potential for fixed offshore growth in many areas outside of the North Sea region.	• Impact of offshore wind farms on marine life is still not fully understood. • Industry might switch to floating wind so heavily, that it hurts future investments in fixed offshore wind farms.

Table 4; SWOT analysis of Dogger Bank.

Strengths

Large scale project that benefits from economies of scale.

Dogger bank is the world's largest offshore wind park with its 3.6 GW total capacity[174]. The scale of the project provides a substantial advantage, making it possible to benefit from a lower unit cost.

Economies of scale is the use of the cost advantages that comes with large scale production, making the cost per unit smaller[175].

[174]Equinor. (2019, 20. September). Equinor tildelt mulighet til å bygge verdens største havvindpark. Retrieved from https://www.equinor.com/no/news/2019-09-19-doggerbank.html
[175] Kenton, W. (2019, 20. May). Economies of scale. Retrieved from https://www.investopedia.com/terms/e/economiesofscale.asp

Benefits from the better wind conditions of offshore wind, while at the same time avoiding the increased costs associated with floating offshore.

Offshore bottom fixed wind enjoys better wind conditions than onshore wind, as the wind is usually stronger and more consistent over water than on land. Offshore turbines enjoy a higher electricity production, and the electricity production do not vary as much as on land, making production predictions over a certain time period more reliable[176].

There is less turbulence over water, which leads to less wear and tear on the turbines and thereby contributing to a longer life span of offshore turbines[177].

Even though the wind conditions don`t rival the wind conditions on deep sea enjoyed by floating wind[178], the costs are much lower, giving the overall beneficial combination of less costs associated with offshore floating wind, and enjoying better wind conditions than onshore wind.

Bottom-fixed turbines are currently industry standard for the offshore wind industry, enjoys more standardization and there are less risks associated with new projects as it is a proven concept.

As the offshore bottom fixed wind segment is mature, it enjoys the added benefits of standardization, making project planning and execution easier, as the process is more proven and relies on previous experiences. Furthermore, it is less uncertainty involved than with floating offshore, as bottom fixed wind has proven it can be profitable as long as it is done at a sufficient scale.

[176]Dreyer, J. (2017, 15. December). The benefits and drawbacks of offshore wind farms. Retrieved from http://large.stanford.edu/courses/2017/ph240/dreyer2/

[177] Danish Wind industry association. (2003, 19. September). Offshore wind conditions. Retrieved from http://xn--drmstrre-64ad.dk/wp-content/wind/miller/windpower%20web/en/tour/wres/offshore.htm

[178]Equinor (N.A) The future of offshore wind is afloat. Retrieved 29.03.20 from https://www.equinor.com/en/what-we-do/floating-wind.html

Weaknesses

Not feasible to place in water depths exceeding 60 meters, locations are thereby limited, and the best wind resources will not be harnessed.

Fixed offshore wind has the disadvantage of not being usable at depths of more than 60 meters. Floating offshore is the only alternative for wind turbines at deeper waters. This limits the potential areas for fixed wind production as only 20 percent of the sea is at depths less than 60 meters[179].

The number of fixed offshore wind farms are increasing around the coast of UK, Germany and Denmark. However, the North Sea where these wind farms are located is not the best representation of how easily a good site for fixed installations can be found. Unlike the North Sea, most oceans rapidly increases in steepness, making bottom fixed wind turbines unfeasible, as the water depths is too high[180].

Dependent on governmental cooperation.

Given the large scale of this project, cooperation with the government is essential for it to be successful. Unpredictability when it comes to rules and regulations can be an obstacle and predictability from the government's side is therefore essential. It can be a disadvantage if regulations change suddenly with little notice beforehand.

Opportunities

Potential for fixed offshore growth in many areas outside of the North Sea region.

Outside of the North Sea region there are many areas where there is great potential for growth. One example of this is Japan, where they are currently looking into constructing more offshore wind farms[181]. Another potential area is New Zealand, where several potential areas have been identified as suitable for fixed offshore wind off the coastline of Taranaki [182]

These new areas can provide great opportunities for the industry and for the countries that utilize this potential.

[179] Equinor (N.A) The Future of Offshore Wind is Afloat. Retrieved (2020, 28. April) from https://www.equinor.com/en/what-we-do/floating-wind.html

[180] Thompson, A (2015, 14. May). Floating of fixed? Retrieved from https://www.atkinsglobal.com/en-gb/angles/all-angles/floating-or-fixed

[181] Safety4sea. (2020, 5. May) Production of first large scale wind project in Japan. Retrieved from https://safety4sea.com/production-of-first-large-scale-offshore-wind-project-in-japan/

[182] The maritime executive. (2020, 4. November). Promising offshore wind potential identified in New Zealand. Retrieved from https://www.maritime-executive.com/article/promising-offshore-wind-potential-identified-in-new-zealand

Threats

Impact of offshore wind parks on marine life is still not fully understood.

As offshore wind is a recent area it is also largely unexplored and many aspects of it are not yet uncovered. This includes the impact that the installation of the fixed turbines has on the surrounding marine life. For offshore bottom fixed wind turbines, the most common technique for mounting the wind turbine to the seabed is known as pile driving. The pile driving method is associated with substantial noise pollution, and the noise emitted might cause hearing damage to surrounding marine life and cause marine life to be spread away from the area to avoid the noise. As each marine species operates in a food web, the change of one species might cause changes to the whole food web, which is complex in nature and therefore difficult to understand. If research finds that offshore bottom fixed turbines cause substantial damage to the environment, it might undermine the whole segment, or at least necessitates major changes in how they should be constructed and operated[183].

Industry might switch to floating wind so heavily, that it hurts future investments in fixed offshore wind farms.

Since floating wind has more potential areas where it can be installed, there is uncertainty to what will be the focus of the wind industry in the coming years. Currently there has been few floating wind farms and the costs are much higher than fixed offshore, but that may change in the future. Access to more favorable wind conditions in many cases can also be a key driver towards floating offshore as a solution. This increased focus on floating offshore might lead to less investment that could potentially hurt fixed offshore investment.

[183]Bailey, Brookes, Thompson (2014) Assessing environmental impacts of offshore wind farms: lessons learned and recommendations for the future. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4172316/

Chapter 6: Conclusion

As our analyses in chapter five uncovered, the differences between the wind power segments are substantial. While floating offshore wind is still on an demonstrational stage without large scale application, fixed offshore and onshore wind have already been applied on a larger scale.

When determining which wind power approach that should be the preferred alternative for Norway in the coming years, our conclusion is divided in regards to the economic, social and environmental perspectives. Lastly, we will give a final conclusion based upon all perspectives.

Economic perspective

The LCOE for fixed offshore wind is over three times higher than for onshore wind projects. Floating offshore wind is at an even higher LCOE than for fixed offshore wind. This is a substantial difference (even when you take into consideration that floating wind is technically and commercially much less developed than the two alternatives).
The trend in recent years, has been a decrease in costs as a result of both economies of scale and technological improvement for all types of wind projects.

In our analysis there have been identified substantial economic differences between onshore, bottom-fixed offshore and floating offshore wind, and the corresponding projects in these segments.
The analysis points out three main reasons for these differences: the maturity of the segments both from a technological and economic perspective, the characteristics of the individual projects within these segments and the inherent characteristics of each segment.

Onshore wind is by far the most economically viable wind power alternative, showing an LCOE of (34,39 Øre/KWh), one third of that for offshore wind. Onshore wind is a mature industry that utilizes proven technological solutions, Fosen wind is deployed on a commercial viable scale of 1057 MW and onshore wind has in addition to this the inherent characteristics of benefiting from easier access to maintenance and better grid-connection applications.

Offshore bottom fixed wind is lagging behind onshore wind, but still shows indications of becoming an economically viable alternative with an LCOE of (148 Øre/KWh) for the fixed offshore industry. Offshore bottom-fixed wind is a developing industry that is becoming more mature, Dogger bank is deployed on a commercially viable scale of 3600 MW upon completion, but the inherent characteristics of the bottom-fixed segment shows challenges in relation to maintenance activities and low cost grid-connection applications.

Offshore floating wind shows no indication of being economically viable in the near future. Offshore floating wind is a newly developed concept, Hywind is not deployed on a commercially viable scale with only 30 MW and the inherent characteristics of the floating wind segment shows high costs in relation to the construction of the foundation of the wind farm and has the same challenges as bottom-fixed wind when it comes to maintenance activities and low cost grid-connection applications

From an economic perspective we argue that onshore wind power development is the best wind power alternative, as this segment has proven it can be economically viable, by producing electricity at highly competitive prices. It is then followed by offshore fixed wind power that is still lagging far behind, but shows a promising trend of cost reductions, and the least viable option is offshore floating wind, where we argue that it will be a long time until floating wind will even be in the discussion in regards to being a cost competitive alternative.

Environmental perspective

The environmental disruptions caused by onshore wind are far larger than those caused by fixed and floating offshore. There are however uncertainties when it comes to how offshore wind farms affect marine life, as this is not yet understood fully. Environmental challenges are not only associated with construction and operation of the wind farms, but also the decommissioning stage has its challenging aspects.

The turbine mounting technique known as pile driving which is used in the offshore bottom-fixed segment has raised questions in relation to the damage it may cause to surrounding marine life, although no conclusive results have been found on the subject, it is still regarded as a cause for concern.

Floating wind can make oil and gas production more environmentally friendly by powering platforms in the North Sea as seen from the Hywind Tampen project, although at a steep extra cost. Its mooring system that connects the floating wind platform to the seabed is assumed to make environmental impacts minimal, but there are still uncertainties associated with how large this impact is due to floating winds limited use. Floating wind do not use the pile driving method associated with bottom-fixed turbines, so it is expected that the environmental disturbance under the construction phase is lower for floating than for fixed.

Onshore wind production has the largest environmental impact of the three, as it degrades the local environment through the construction of infrastructure and turbines.

The most environmentally viable alternative is in our opinion floating wind, followed closely by fixed offshore. We consider onshore wind to be the least preferred option due to its impact on the environment in comparison with the other two alternatives.

Social perspective

In regard to the social perspective, the resistance among local populations has sometimes been substantial when it comes to onshore wind. This is largely due to the negative visual impact it creates and the noise pollution that comes from the industry. Both offshore fixed and floating wind have a smaller impact due to their location at sea often out of sight from populated areas. Even though fixed offshore turbines in some cases can be visible from the shore.

Onshore wind is met with substantial opposition from local communities where onshore wind farms are constructed, and on the basis of the general acceptance of onshore wind farms in Norway, it can be argued that the resistance is based upon the NIMBY phenomenon. As with all industry, there is an alternative way of using the land that is used for wind power, and sometimes there are conflicting interests. The reindeer herders rights to use the land for grazing for their reindeer is also pointed out as an issue with onshore wind farms. The intrusion on the natural landscape with the construction of onshore wind farms leads to less room for grazing, making the livelihood of the Norwegian Sami people less attractive, and is said to be a violation of their rights.

Offshore wind farms are met with much less opposition, as they are out of sight and NIMBY phenomenon is avoided. This holds true for both offshore fixed and offshore floating, although offshore floating, given its ability to be located in deeper waters, is expected to pose even less potential problems, as fixed offshore wind farms may be seen from the coast (if the wind farm is constructed close to land).

Onshore wind is the preferred alternative when it comes to local employment, as Fosen Wind is located on Norwegian soil. Future floating wind initiatives like Hywind Tampen will also be located on Norwegian territory and leads to local employment, although not in a large scale. Bottom fixed wind is not optimal to be constructed in Norway and will therefore lead to less local employment benefits, as it is developed abroad.

The most socially viable alternative is in our opinion offshore floating wind, followed closely by offshore bottom-fixed wind. We consider onshore wind to be the least preferred alternative, given its high degree of resistance from local communities, despite positive employment effects.

Overall conclusion based on the three perspectives

By looking at the economic, environmental and social aspects we have managed to form a rather complete understanding of the various solutions.

Even though floating offshore performs better when considering the environmental and social aspects, we would consider the costs of LCOE to be too high for it to be the overall best solution.

Onshore wind has the lowest LCOE, but the worst environmental and social drawbacks. We will therefore consider fixed offshore to be the preferred wind power alternative for Norwegian companies looking to develop wind power in Norway and the UK, as it has the best balance between economic, environmental and social performance.

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Appendix A

LCOE CALCULATION

Fluctuations in currency can have affected the LCOE values as they have been converted to NOK/Øre. The final LCOE numbers are rounded to whole Øre.

Calculations are made with the Euro/ NOK exchange rate per 27.05.20 at 1 Euro = 10.84 NOK

LCOE floating wind

The range is quoted at 109,3 to 243,4 euro/MWh in 2014.[184] Converting this to Øre/KWh.

Conversion from MWh to KWh:109,3 to 243,4 Euro/MWh/1000= 0,1093 – 0,2434 Euro/Kwh

Conversion from Euro/KWh to Øre/KWh lower range: 0,1093 x 10,84 = 1,1848 NOK x 100 = 118,48 = 118 Øre/KWh

Conversion from Euro/KWh to Øre/KWh upper range: 0,2434 x 10,84 = 2,6385 NOK x 100 = 263,85= 264 Øre/KWh

The LCOE for floating wind ranges from 118 to 264 Øre/KWh.

Grid connection costs for floating wind

Grid connection costs for Offshore floating wind is approximately 24% of LCOE costs.

Grid connection costs lower range: 118 x 0.24 = 28.32 = 28 Øre/KWh

[184] Bjerkseter, C, Myhr, A, Nygaard, Tor, Ågotnes, A. (2013). Levelized cost of energy for offshore floating wind turbines in a life cycle perspective. P. 10 Retrieved from https://reader.elsevier.com/reader/sd/pii/S0960148114000469?token=BD850CDADF24F837F1645D4B21847FE7272014A1380B03E02E8606C16EF1DA84B1A645F7831AE7D54920CC22540954FE

Grid connection costs upper range: 264 x 0.24 =63.36 = 63 Øre/KWH

The grid connection costs for offshore floating wind ranges from 28 to 63 Øre/KWh

LCOE fixed offshore

Quoted at 13.47 Euro cents/KWh in 2015. Converting this to Øre/KWh

Conversion from euro cents/KWh to øre/KWh[185]: 0,1347 euro x 10,84 = 1,46 NOK x 100 = 146 Øre/KWh

The LCOE for fixed offshore wind is 146 Øre/KWh

Grid connection costs for fixed wind

Grid connection costs for offshore floating wind is between 15-30% of LCOE costs[186].

Grid connection costs lower range: 146 x 0.15 = 21.9 = 22 Øre/KWh

Grid connection costs upper range: 146 x 0.30 = 43.8 = 44 Øre/KWh

The grid connection costs for offshore fixed wind ranges from 22 to 44 Øre/KWh

LCOE Onshore

The LCOE for onshore wind in Norway is taken directly from NVEs own data that shows an LCOE of 32 øre/KWh in 2019.[187]

[185]Ebenhoch, R, Marathe, S, Matha, D, Molins, C, Munozc, P. (2015) Comparative levelized cost of energy P.12 Retrieved from https://www.sintef.no/globalassets/project/eera-deepwind-2015/presentations/f/f_matha_univ-stuttgart.pdf

[186] IRENA (2012, June). Wind Power. Retrieved from https://www.irena.org/documentdownloads/publications/re_technologies_cost_analysis-wind_power.pdf

Grid connection costs for onshore wind

Grid connection costs for onshore wind is between 9-14% of LCOE costs.

Grid connection costs lower range: 32 x 0.09 =2.88 = 3 Øre/KWh

Grid connection costs upper range: 32 x 0.14 = 4.48 = 4 Øre/KWh

The grid connection costs for onshore wind ranges from 3 to 4 Øre/KWh.

[187] NVE. (2019.11. June). Kostnader i energisektoren. Retrieved 25 April 2020 from https://www.nve.no/energiforsyning/energiforsyningsdata/kostnader-i-energisektoren