# The likelihood of a Norwegian Pumped-Storage that can support intermittent Power dispatch from Solar and Wind.

*A comparative case study that explores the feasibility of a pumped-storage seen from different Norwegian electricity companies.*

Master thesis in Energy, Environment and Society

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# Summary

For Europe to achieve the targets to decarbonise the energy system, there is a need for a storage technology that can support intermittent power dispatch from solar and wind. Pumped-storage is a mature technology with high efficiency and abilities to store a large amount of energy. It has the capabilities to support intermittency by pumping water up to higher reservoirs and can create additional consumption in surplus periods of intermittent generation. This gives the opportunity to increase the European trade of electricity towards 2050.

This thesis explores the likelihood of pumped-storage to be implemented in the Norwegian hydropower plants. In the power plants, the reservoirs have opportunities to store 85 TWh, which is 50 percent of the European storage capacity. This gives significant opportunities for Norway to support the European energy transition. However, there have been challenges in the implementation of technology in Norway. Therefore, the thesis is constructed around the following thesis statement: *what is the feasibility for implementing a Norwegian pumped-storage, which can support intermittent power dispatch from increasing deployment of solar and wind technologies?* The thesis aims to understand the feasibility seen from different Norwegian utilities since they are the actor most likely to implement the technology

The thesis uses the multi-level perspective, triple embeddedness framework and the re-configuration pathway as a theoretical framework. This is used to understand the likelihood for a pumped-storage to be part of the Norwegian energy system and support intermittency in Europe and Norway. I have used a comparative case to investigate four utilities, which is located in the south of Norway. The utilities were investigated by exploring there perception and conditions needed before the technologies installation is feasible. The thesis has used a mixed method with both qualitative and quantitative data sources from interview, newspapers, webpages, scientific journals and reports

The analysis provides evidence on the likelihood for a Norwegian pumped-storage to occur in the future. It gives evidence on the need for the technology by investigating a scenario towards 2050, where Germany is benefiting from a Norwegian pumped-storage. In addition, it identifies the driver and barriers for realising a future pumped-storage in Norway.

# Preface

This master thesis marks the end of five-years of study at the University of Stavanger. It has been a long and challenging journey with moments of frustration, happiness, failure, and success. It has improved my understanding of the energy system and increased my problem-solving skills by looking on problems from a multi-disciplinary perspective. Moreover, education has provided me with a good knowledge base, which can build on in the future. I'm very grateful for all the help over the two last years.

I will first thank my supervisor of Oluf Langhelle for all the advice with the selection of topic, guides through the different phases and suggestions for improvements. I will also thank Ph.D. candidate Ben Silvester for help in chose of the topic and advise about relevant articles that could be used in the thesis.

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Stavanger, 17 June 2019

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# 1. Introduction

## 1.1 Pumped-storage Hydropower capabilities to support a transition of the energy system

Current and historical emission from anthropocentric greenhouse gases (GHG) is threatening the function of the global society. The main driver for the emissions is the dependency on fossil fuels. (W. Steffen, Grinevald, Crutzen, & McNeill, 2011). To change the trajectory and reduce emissions, the European Union (EU) have adopted a long-term objective by 2050 to decarbonise the energy system by reducing GHG emissions with 80-95% compared with 1990 levels (European Commission, 2011). The ambitions involve an increase in energy efficiency and develop more renewable energy (van Hou, Özdemir, & Koutstaal, 2017). To achieve the target, it might imply electrification of the current global energy system by moving from fossil fuels to a system based on renewable energy. However, the global energy system is dominated by fossil fuels with around 80 percent of total global energy consumption in 2016, while renewables have only 18 percent, with modern renewables (wind, solar and hydropower, etc) only 10 percent (REN21, 2018).

The EU member, Germany have particularly adapted to a long-term strategy to transform the energy system. The objective is to solve problems associated with energy security and climate change (Agora Energiwende, 2015). The strategy involves policies towards increasing the share of renewable energy and make the energy sources "less costly and more competitive compared to other energy sources" (Moe, 2015, p. 142). Policies have increased the attractiveness for German households, farmers, investors, and industry to invest in solar and wind technology. This gave a rapid growth in renewable energy, but solar and wind are intermittent, which gives problems with a power dispatch out of control. In surplus periods there are overproduction and other periods to low supply to meet the needed demand. The problem with intermittency is a barrier for the energy transition since they need to maintain dirty coal as a reserve (Smil, 2016).

To make the German energy system reduce the reliance on fossil fuels. Germany can integrate with the Norwegian energy system (SRU, 2011). Norway gets 95 percent of the energy from hydropower plants, which is clean, flexible, controllable and efficient technology (Boyle, 2012; Gullberg, Ohlhorst, & Schreurs, 2014). Moreover, Norway has experience with the infrastructure needed to connect to another state by being integrated into a Scandinavian market, with knowledge about providing service to intermittent Danish windmills. Therefore, there are opportunities to balance intermittency in Germany. Transmission cables are under construction to Germany and the United Kingdom(UK) and expected to operate in 2021(Statnett, 2019).

European intermittency can be balanced by the integrating to the Norwegian hydropower plants. With an upgrade of the hydropower plants, there is potential to improve the flexibility by being able to pump water to higher reservoirs. The Pumped-storage technology has capabilities to create additional consumption in periods with a surplus of wind and solar. Moreover, pumped-storage is a mature storage technology and have opportunities to provide the energy system with "peaking power, frequency stabilisation, and load balancing" (Killingtveit, 2013, p. 389). In comparison with other storage technologies, the technology has high efficiency, life expectancy and the ability to store a large amount of energy (Harby et al., 2013; Winfield, Shokrzadeh, & Jones, 2018). However, implementation in Norway have been challenging, projects have been withdrawn and time is running out for the technology, since Germany may find other storage solutions. Therefore, the thesis aims to examine the feasibility for pumped-storage to be implemented in Norway.

## 1.2 Problem statement, objectives and aim

The aim and motivation are to explore the opportunity for a Norwegian pumped-storage to support intermittent solar and wind energy. Norway has reservoirs and hydropower plants that gives opportunities to deploy pumped-storage (SRU, 2011). There is technical feasibility, but challenges have been to install the technology. Therefore, the main objective is to identify the likelihood of pumped-storage hydropower to be integrated into Norwegian hydropower plants. The likelihood is investigated by exploring the Norwegian utilities understanding of the feasibility since they are the decision-makers in Norway that is most likely to implement pumped-storage (Gullberg, 2013)

The likelihood is explored by analysing a pathway were pumped-storage is the solution for an integrated energy system. The pathway aims to start from an "ideal" and integrated European energy system in 2050 and explore the feasibility for the scenario to occur. This might also provide insight into the need and challenges for pumped-storage to be implemented. The pathway investigates “developments, opportunities, struggles, challenges and mobilizations” occurring in different levels international, national and regional (Geels et al., 2016, p. 901).

### 1.2.1 Research questions

In order to achieve the main objective and investigate the likelihood for pumped-storage, the thesis is constructed around the following problem statement, *what is the feasibility for implementing a Norwegian pumped-storage, which can support intermittent power dispatch from increasing deployment of solar and wind technologies?* The overall thesis statement is further operationalised and answers to the following research questions:

1) How is pumped-storage perceived by Norwegian utilities?
2) Which conditions are needed for utilities to implement pumped-storage?
3) How does Norwegian energy companies affect the German energy transition?
4) Will increased intermittency in Norway give needs for a domestic used pumped-storage?

The four research questions have different aims to determine the feasibility for Norwegian pumped-storage hydropower.

The objective of the first question is to examine the perception from different Norwegian utilities, which are operating in the south of Norway and have a high share in the Norwegian energy marked. These energy companies are working close to the future transmission cables and are expected to have a role in the future power exchange with Europe. The aim is to compare similarities and difference in perception between the utilities about the feasibility for pumped-storage. To compare their perception the thesis examines the factor of their, mission and values and technological capabilities and competence. These factors can create lock-in and path-dependent perception about pumped-storage, but also make utilities deviate by having a different mix (Geels, 2014).

The aim of the second research question is to explore the conditions needed for the decision-makers in the variety of energy companies to invest in the technology. The objective is to identify their interpretation and beliefs about future triggers that lead them on the path to implementing pumped-storage. The triggers are further analysed to understand the feasibility for them to occur and the policy implications for a Norwegian pumped-storage. This to get an understanding of the barriers and underlying drivers that might influence the likelihood for Norwegian pumped-storage.

The third question aims to explore the power companies influence on German energy transition with their beliefs on the opportunity for pumped-storage to support the German energy transition. It will picture out a potential scenario for Germany benefiting from the with integration with Norway in the year 2050. The aim is to explore the feasibility for the scenario to occur and the implications the decisions from Norwegian utilities can have on the European energy transition in the long-term.

Finally, the last question investigates the potential of growth in wind and solar power in Norway (NVE, 2018), which may increase the intermittency in the country and give needs for a domestic used pumped-storage. The aim is to explore the need and attractiveness for the energy companies to implement pumped-storage to cope with Norwegian needs. Gullberg (2013) identified that there was low feasibility for a domestic used pumped-storage since it might not be profitable.

## 1.3 Outline

To addresses the research questions the thesis is structured in the following order. Section two introduces the background and context. It presents relevant research in terms of the research questions, the Norwegian energy sector, a simplified description of pumped-storage and the EU and German targets to transform the energy system. Lastly, it provides a scenario with a focus on pumped-storage in 2050.

The third chapter presents the theoretical framework. The theories used are the multi-level perspective, the triple embeddedness framework, and the reconfiguration pathways. It outlines the concepts that will provide insights into the likelihood for a Norwegian pumped-storage, and is the basis to guide the empirical evidence into categories.

The fourth section, present and discuss the design and method. It provides information about the abductive research strategy, the comparative case study, data, the cross-case analysis and limitations of the study.

Section five separately presents each case study. The cases were adjusted due to the length of the thesis and will provide the most important evidence from the different utilities. It has sperate cases on the different utilities to establish a chain of evidence.

The main part is section six, which applies the cross-case analysis on the individual cases. This section discusses the findings and implications for future pumped-storage. The empirical evidence is presented in detail within the theoretical framework. The section starts with a potential scenario in 2050 with Germany and Europe benefiting from integration with a Norwegian pumped-storage. The section further looks on the conditions addressed by the utilities, intermittency in Norway, and utilities different and similar perception. The findings are discussed after the evidence is presented in each part chapter.

Last part concludes on the likelihood for a Norwegian pumped-storage to be installed in the Norwegian energy system.

# 2. Renewable development and a European integrated energy system.

This chapter provides an overview of the context and background, in which a Norwegian pumped-storage can unfold. It provides an overview of relevant findings from earlier research that is related to the research questions. It presents the most important information to understand the case of a potential Norwegian pumped-storage, like the Norwegian energy sector, pumped-storage, Scandinavian power marked, European strategy towards decarbonisation and the potential use of pumped-storage in 2050.

## 2.1 Literature review

Research papers have analysed the drivers and barriers for pumped-storage in specific countries such as the USA (Yang & Jackson, 2011) and Germany (Steffen, 2012). In the USA, Yang and Jackson (2011) give a historical overview of the pumped-storage projects. The results suggest that barriers have been economic, environmental and political, rather than technical. In Germany, Steffen (2012) investigated the opportunities to facilitate pumped-storage in Germany. The paper suggests that a driver for pumped-storage is profitability, which is suggested to come from three factors. Firstly, the opportunity to generate income on differences in prices by pumping on low and produce on high. Secondly, the possibility to earn money on grid service by providing reserve capacity in the short-term when there is a need for pumping or generation due to fluctuation in either supply or demand. Lastly, incentives are given by the government or municipalities. The paper also suggests barriers for implementing pumped-storage like the grid- and water fees, nature conservation and local acceptance (Steffen, 2012)

The SRU (2011) report, which analysed different pathways for Germany towards a 100 percent renewable energy system. The report argues for a prospect of cooperation between Norway and Germany. Norwegian system has a large potential of storage capacity in existing hydropower reservoirs giving opportunities to construct a pumped-storage. The imaginary, Norwegian pumped-storage can be integrated with the German energy system to support the intermittency. This is calculated to be more economically feasible than a self-sufficient German energy transition since the Norwegian pumped-storage is expected to have lower cost and less environmental impact with the use of existing reservoirs and might give more public acceptance to build pumped-storage (SRU, 2011).

CEDREN (2011) evaluates the technical feasibility for pumped storage in Norway. The technical feasibility is determined the highest and lowest water level in different hydropower plant, which is in the south of Norway. The report concludes that the building of Norwegian pumped-storage is technically feasible. NVE (2011) also focused on technical opportunities to build pumped-storage in Norway. The analysis found 17 places suited to deploy the technology, which has high volume in reservoirs and altitude differences that gives a large storage capacity. In addition, Killingtveit, Solvang, Alfredsen, and Leia (2017) gives an overview of the research that investigated technically feasible locations. The results suggest that Norway have potential to build around 20 GW of pumped-storage capacity (Killingtveit et al., 2017).

Gullberg (2013) analysed the political feasibility for Norway to become the "green battery" of Europe. The feasibility is analysed by exploring the constraints between different interest groups and decision-makers on their view of technologies included in the green battery. The different decision-makers did not reject pumped-storage, but the technology was not their main interest. However, the electricity sector represented with Statnett and Statkraft was well informed about the opportunities with pumped-storage. The results suggest policies are driven incremental towards profitability and socio-economic cost. Then, the likelihood for pumped-storage is low in the short-term but might be opportunities in the long-term (Gullberg, 2013). If there is a likelihood for pumped-storage in the long-term. Then Norwegian utilities need to evaluate the conditions to implement for the technology. Therefore, the thesis builds on Gullberg (2013) the political feasibility and fills the gap by analysing the feasibility of pumped-storage seen from many Norwegian Utilities. For a domestic used pumped-storage, the feasibility was low since the technology would likely not be profitable due to exclusion from the European market (Gullberg, 2013).

Gullberg et al. (2014) further compared the interpretation of the "green battery" from German and Norwegian actors. Germany interpreted cooperation as an opportunity to solve the intermittency problem through power exchange with Norway. On the Norwegian side, actors argue for two main reasons to build pumped-storage and expand it with a cross-national transmission system. Firstly, there is an economic opportunity to "buy cheap wind power, store the energy by pumping up to higher reservoirs, and sell the electricity at a higher price" (Gullberg et al., 2014, p. 220). Secondly, contributing to a clean energy system. However, there are barriers on the Norwegian side, some actors are worried about pumped-storage and the new infrastructure to Europe since it has an environmental consequence and there is fear for increased electricity prices (Gullberg et al., 2014).

Moser, Maaz, Baumann, and Schäfer (2015) made a detailed analysis of the benefit for Germany to have access to Norwegian hydropower plants. The analysis described that the German energy transition could reduce cost and reduce problems with intermittency by integrating to the Norwegian hydropower plant, especially the pumped-storage provided the benefits. But, before Germany could benefit there was a need for a substantial increase in the cross-national transmission capacity up to around 30 to 20 GW. The thesis uses the scenario outlined to 2050 as a base to investigate the likelihood of a pumped-storage in a “super battery”.

Henden, Doorman, and Helseth (2016) identify the opportunity for large pumped-storage in Norway. The analysis suggests that pumped-storage is feasible, but not the best solution for the Scandinavian market since there are problems with profitability. Pumped-storage need prices differences to be profitable, but the differences were not large enough to take utilize a pumped-storage. Henden et al. (2016) suggest that in order for pumped-storage to be profitable there need to be increased transmission cable capacity.

The potential development of prices volatility has been analysed by van Hou et al. (2017). The paper used two scenarios towards 2030 with different mikes of transmission cables, pumped-storage and hydropower power capacity, market integration and different need for storage technology in Europe. The results suggested that price volatility is expected to raise in Norway with the transmission cables connecting to European energy systems. For the likelihood of pumped-storage, the findings show that increased transmission cable reduced the volatility. There is suggested a threshold between 10 to 15 MW, but this trend depends on the increased transmission capacity around the whole of Europe. The improved European integration lowered the prices differences in European countries giving decreased prices volatility in Norway. The results also suggest that increased cable capacity with high pumped-capacity and strong expansion in Europe led to higher electricity price than a scenario with lower transmission cables.

A large project was established to investigate the feasibility for Norway to become the "green battery". This report summarises the most important findings (CEDREN, 2018). The feasibility was examined by looking into the balancing of wind and power, future operation and profitability, environmental impact and social acceptance. A case analysed the benefits of building a pumped-storage and cables to Europe. Energy companies have the potential to increase revenues by 22 percent. However, the researchers suggest that utilities are dependent on participating in the European market to make it profitable (CEDREN, 2018).

A paper discusses the need for a shift from providing benefits to "energy only markets" to provide incentives to technologies that provide "flexibility and controllability" (Egging & Tomasgard, 2018, p. 99). The purpose of the need for incentives is to give flexible technologies like pumped-storage higher value. This will provide benefits and create a new market design and instruments. They will give opportunities for further expansion of cross-national transmission cables, further deployment of storage technologies and enhanced infrastructure in the EU. In addition, the paper suggests that the EU and Norway should work together to coordinate projects to design the future energy system.

## 2.2 The Norwegian energy sector

The Norwegian energy sector has large capacity both foreign and domestically. The country exports a large amount of oil and gas, which have a significant role in the economy and welfare creation. (Gullberg et al., 2014). The domestically energy needs are covered through hydropower, which accounts for 95 percent of the yearly produced electricity (Thaulow, Nesheim, & Barkved, 2016). The production from hydropower has variations depending on wet and dry years. Table 2.1 shows the variation, since the start of 2000 with differences between 106 to 143 TWh. Fluctuations occur due to the dependency on the hydrological cycle to fill up reservoirs (Killingtveit, 2012). This makes the Norwegian production clean and renewable energy source. However, the reliability of the cycle may give problems in the security of supply, since there can be variations in water flows occurring in short-term, seasonal and year to year  (Killingtveit, 2013). Solutions have been to use the reservoirs to store water until surplus periods or use pumped storage hydropower to respond to seasonal variations (Killingtveit, 2013).

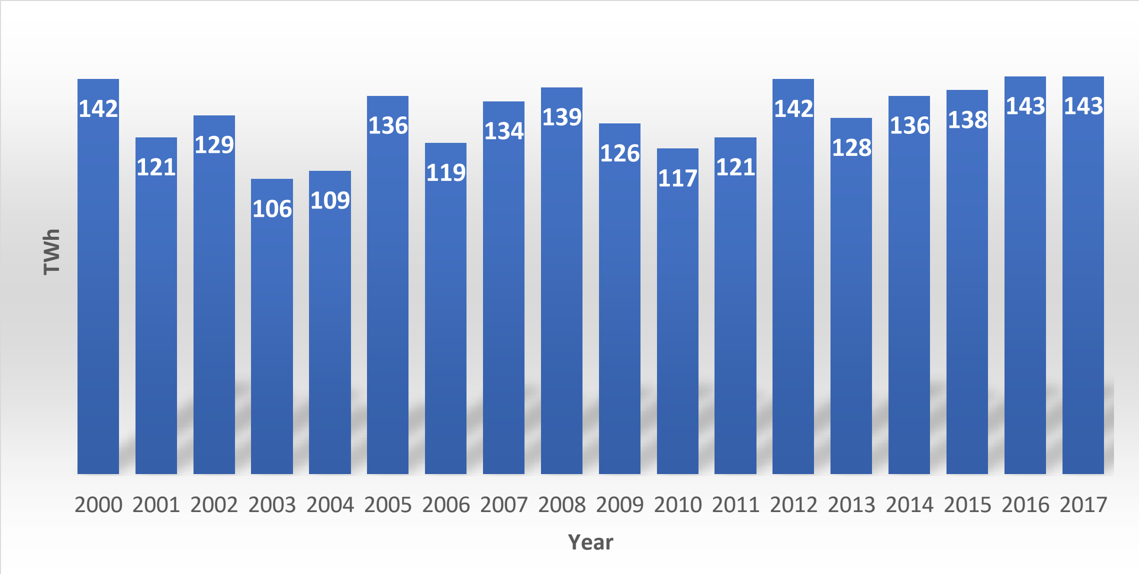


Table 2.1: The total production of Hydropower in Norway *(SSB, 2018a).*

The building of the seasonal storage was feasible due to the suitable natural conditions and no backup from thermal power (Gullberg et al., 2014). The seasonal storage plants were designed after the inflow patterns and energy demand in Norway since the largest inflow occurs in spring and summer from the ice-melting where demand is on the lowest, while peak demand is during the winter when the inflow of water is on the lowest (table 2.2) (Killingtveit, 2012).

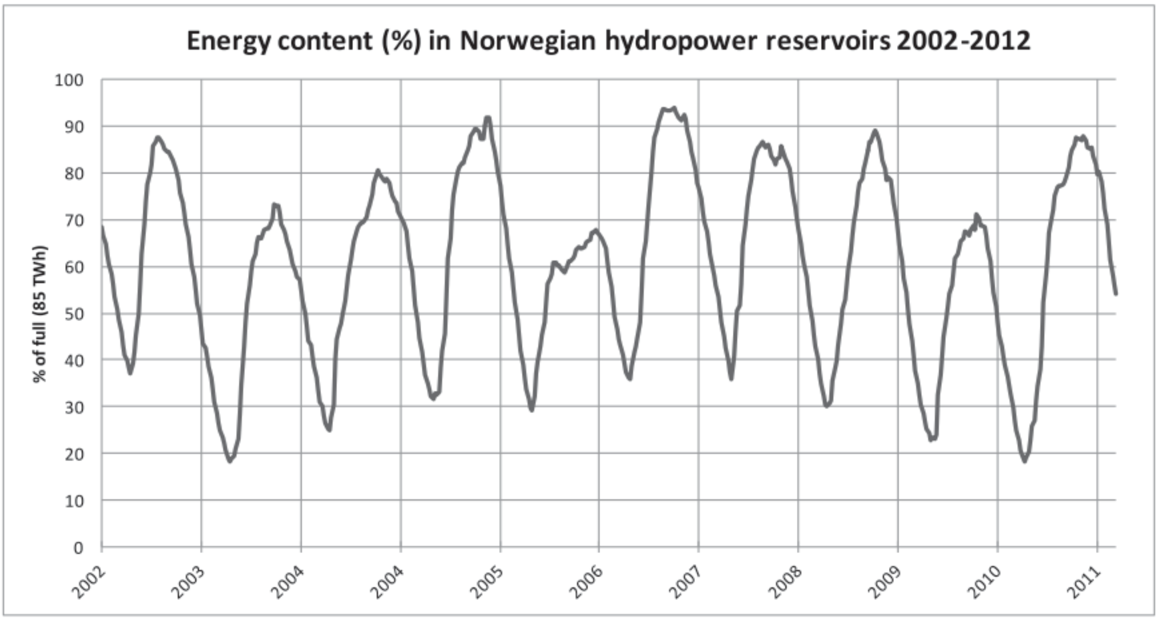


Table 2.2:“Energy stored in Norwegian hydropower reservoirs” *(Killingtveit, 2012, p. 72)*

The Norwegian Utilities are responsible for producing and delivering electricity to the national grid. The Norwegian utilities were liberalised in 1990 through the energy law, which marked the shift from management and politics to companies making decisions in terms of strategy, economic and value creation and a "free market for buying and selling" electricity (Thaulow et al., 2016, p 21). But it made consumers more flexible to choose the power company which produced the cheapest electricity, "even if the energy company is located far away". The new regulation increased the competition between utilities, but it made the companies more "efficient and effective in the production and distribution" since they did not rely on "forecasts, planning and political decisions" (Thaulow et al., 2016, p. 21). Still, energy companies are owned by municipality and government and the value creation goes back to the owners in terms of increased welfare production.

Other important actors in the electricity sector are Statnett and NVE. Statnett has a monopoly over transmission and distribution in Norway (Thaulow et al., 2016). NVE is the national regulatory agency for the electricity sector and works for the Norwegian ministry of petroleum. They have the responsibility of governing the "domestic energy resources" and give concessions to projects related on the deployment of renewable energy, expansion of interconnectors and building new of hydropower and pumped-storage capacity (Gullberg et al., 2014; Thaulow et al., 2016, p. 25).

For utilities to get a concession, they start by enrolling a simple orientation to the authorities about a planned project. The energy company must go through all implications and consequences on the environment and society. Then the application can be sent. Then NVE starts to evaluate the implications and make a setting to oil and energy department. The oil and energy department give permission through a royal resolution. When the projects are large and have major implications on the society, the concession comes from the Norwegian parliament, which debates and votes if the project should be deployed (Thaulow et al., 2016). If the concession is given, the energy companies take the final decision (Gullberg et al., 2014).

## 2.3 Norway an integrated energy system

The Norwegian electricity market is integrated into Nordic energy marked with direct cables to Sweden, Denmark, Finland, Russia, and the Netherlands, and indirect contact with Germany, Poland and Estonia (Dalfest, 2015). The aim of the cooperation is to improve the security of energy supply and sufficiently utilize the power. Norway sends power to the cooperating countries in periods with much rain and buys electricity in dry periods or other security of supply problems (Dalfest, 2015). Table 2.3 shows the balance between import and export for Norway and the country have a strong tendency of being a nett-exporter of electricity.

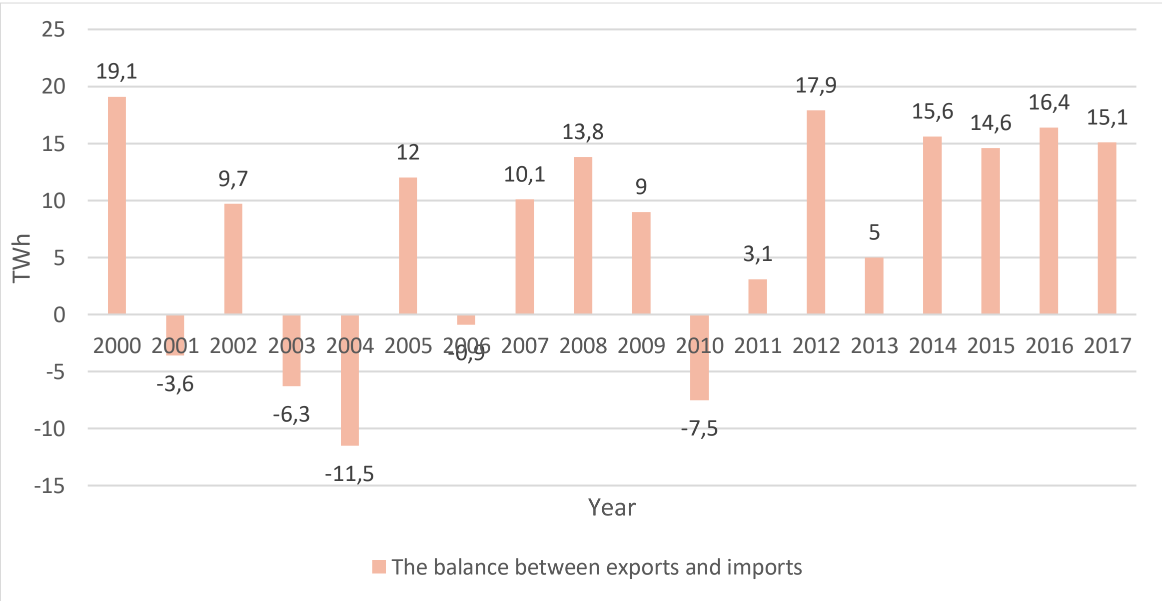


Table 2.3: Norway nett-exporter of electricity *(SSB, 2018b).*

Statnett is working on transmission cable projects to connect to Germany and the UK. The German cable is planned in cooperation with TenneT and public owned bank KFW. The cable to the UK is in cooperation with the British grid operator.  The objective is to improve the utilization of power and gain profits. In addition, the infrastructure is important to succeed with renewable energy production. Both cables have a capacity of 1400 MW. UK cable is planned to go from Kvilldal to Blyth and Transmission cable in Germany is expected to go from Tonstad in Norway to Wilster in Germany (NOU, 2014).

The new cables will increase the Norwegian potential for trading. Electricity trading occurs in different periods in day-ahead markets (DA), Intraday market (ID) and balancing the market. The DA and ID “are organised by power exchange”, where the electricity price is determined by the equilibrium of supply and demand (van Hou et al., 2017, p 11). The DA is a long-term marked where the price is set the day before the delivery, which provides a spotted price for the next day at each hour. The ID marked is the medium-term and is closed 5 minutes before delivery. The balancing marked is short-term and is activated when the ID marked is closed with the purpose of providing stability to the system. (van Hou et al., 2017). In Norway, Statnett regulates the balancing market. The balancing market includes different balancing regulations in primary reserve (PR), secondary reserve (SR) and tertiary reserve (TR). Statnett is responsible to guarantee enough primary reserve. The activation of the SR and TR is done when there is a need for more balancing in the system (Energi Fakta Norge, 2019).

## 2.4 The European strategy towards decarbonisation

The EU has stated an ambitious target to increase energy efficiency and develop more renewable energy. The target involved a long-term strategy to decarbonise the energy system by 2050 to reduce GHG emissions with 80-95% compared with 1990 levels (European Commission, 2011).

Germany has particularly adapted a long-term strategy to transform the energy system. The strategy involved targets reaching until 2050 which are driven by four political objectives to fight climate change, avoid the risk associated with nuclear power, improve energy security, and guarantee competition and growth. (Agora Energiwende, 2015). The first policy was introduced at the start of 1990 with the feed-in law and feed-in tariff (FiT). The aim of the policies was to support the deployment of renewable energy. Later in 2000, it was replaced by the German renewable energy act (EEG), leading to large-scale deployment of renewable energy technologies with the generation rising from 29 TWh to 161 TWh in 2014 (Lauber & Jacobsson, 2016) and 191 Twh in 2016 (Morris & Pehnt, 2016).

The result of the policies is a diversification of the energy mix. Traditional the energy system has been based on coal and nuclear energy, but the subsidies stimulated growth and learning effects, which made solar and wind energy cost competitive. However, the increased penetration of renewable energy has created problems for the Germany energy system. The power generation from solar and wind have variable dispatch, in some periods there is to low supply to meet the required demand and in surplus periods there is overproduction (Agora Energiwende, 2015).

## 2.5 Pumped-storage Hydropower

To handle the intermittency there is a need for storage technology. Pumped-storage hydropower is a storage technology, which is a deployment of hydropower plant that can "store electricity in the form of hydraulic potential energy"(Deane, Gallachóir, & McKeogh, 2010, p. 1294; United States Army Corps of Engineers, 1985). The technology contains a reversible powerhouse and two or more reservoirs that are linked by pipes or tunnels (Killingtveit, 2013). The plant can be designed in different ways, the most common is either pure-pump or pump-back. In pure-pump water is pumped from a lower reservoir located close to a sea or a river with a connection to an upper reservoir. Pump-back have both capabilities of pumping and share similar characteristics as conventional hydropower plant by producing power (Deane et al., 2010, p. 1294). The powerhouse can be constructed through separating the turbine or use of integrated reversible turbine (Figure 2.1). By separating the turbine, the plant needs additional tunnel systems to separate operation modes of pumping and generation (1). The integrated turbine has a combined pump and turbine in the same pipe system (2) (Harby et al., 2013).

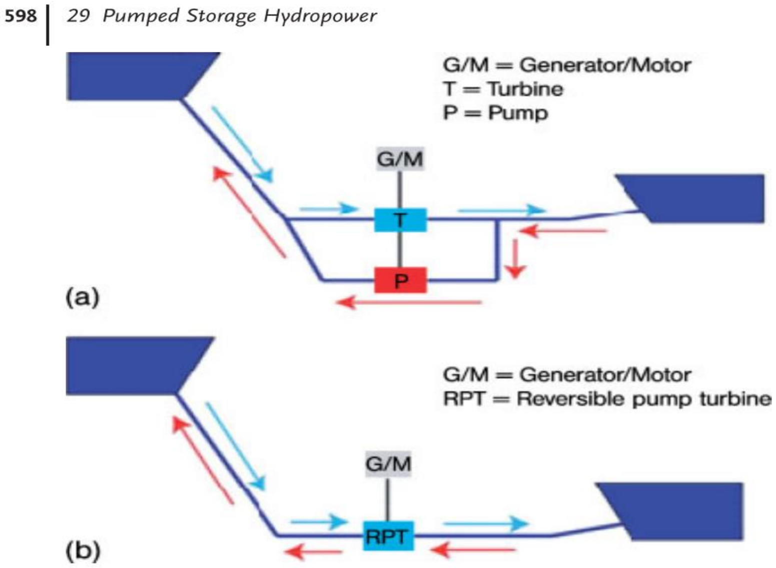


Figure 2.1: Basic principles of pumped hydro with separate turbine and pump (a) and with reversible pump turbine (b)" *(Harby et al., 2013, p. 598).*

Deane et al. (2010, p 1294.) suggest that opportunities to deploy pumped-storage dependents on essential factors such as having a “high head, topological conditions with an upper and lower reservoir, suitable geotechnical conditions, sufficient amount of water, access to transmission and low-cost on the production of energy”. The technology was for the first time deployed in the 1890s in Switzerland, Austria, the Italian Alps, and Germany. The technology was used to improve the management of water resources to respond to changes in energy demand. (Harby et al., 2013). In 1960-1980, changes in energy policy towards build out nuclear energy plants made the technology widely adopted by many states, since it gave opportunities to allow more nuclear and coal in the energy mix. Pumped-storage made it possible to respond to changes in demand, in surplus periods the technology filled the storage reservoirs. (Harby et al., 2013). In recent time, political targets with a focus on the development of solar and wind energy have renewed the interest to facilitate pumped-storage. The main drivers are growing intermittency, “increasing demand for electricity, growing interconnected markets across Europe, the security of supply, and upgrading of existing plants” (Harby et al., 2013, p. 598).

Pumped-storage hydropower has the ability to support the intermittency with the capability to operate in two phases production and pumping, which can increase the flexibility and controllability to intermittent wind and solar (Egging & Tomasgard, 2018). In pumping, pumped-storage hydropower can create demand in periods of oversupply of wind and solar by using the additional energy to pump water to a higher elevation. In production, pumped-storage hydropower operates as a hydropower plant were potential- and kinetic energy in water is used to produce electricity to meet the needed demand. (Harby et al., 2013).

## 2.6 A Norwegian pumped-storage in 2050 integrate with Europe

The thesis uses Moser et al. (2015) scenario to 2050. The scenario aims to show the benefits for Germany to integrate with the Norwegian energy system. It also provides modeling on benefits for a Norwegian pumped-storage and the use of the technology in 2050. In the scenario, there is strong will to build a “big green battery” in Norway with a hydropower capacity on 60 GW, pumped-storage on 15 GW and Transmission capacity 30 GW (Moser et al., 2015).

The scenario estimates Europe in 2050, the energy transition is projected to have changed the power generation. Table 2.4 shows the power generation and demand in 2050. In Germany, there is a high amount of power generation from wind and solar. In Norway, the energy mix consists of hydropower and wind power and supply is estimated to be higher than the demand giving needs to export the surplus or decrease power generation of intermittent wind (Moser et al., 2015).

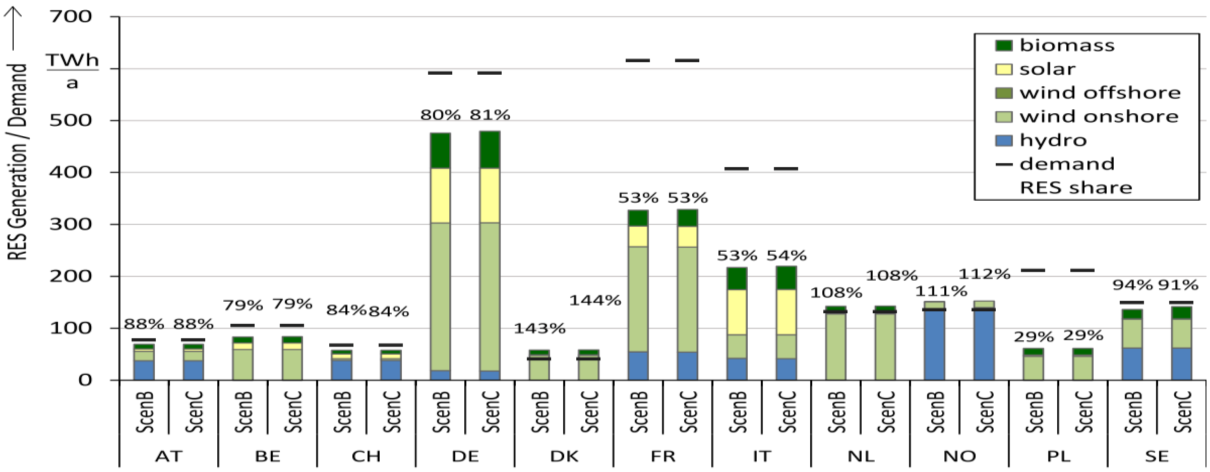


Table 2.4: Energy supply and demand in Europe 2050 *(Moser et al., 2015, p. 37).*

The energy transition has increased the intermittency in the power generation and in surplus, there is a need to transfer the energy to other states. In this scenario, there is a high amount of cable capacity giving opportunities to transfer to other states This provides benefits of the European system and opportunities for more trade (Moser et al., 2015).

The Norwegian trade is a net-exporter by providing support from there hydropower to the European states. In imports comes in surplus periods of solar and wind. Table 2.5 show Norwegian import from German wind (Moser et al., 2015).

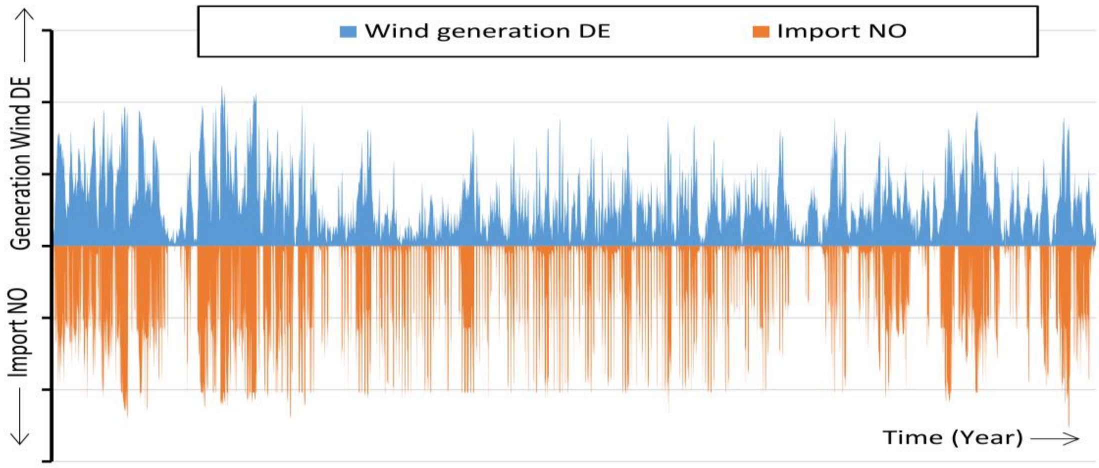


Table 2.5: Norwegian import of intermittent wind from Germany *(Moser et al., 2015, p. 40)*

The German import is pumped to higher reservoirs and stored. With higher transmission capacity there is higher utilization of the pumped-storage and the plant is used for more hours a year. This makes it the system able to produce more renewable energy. Table 2.6 shows the operating hours of Norwegian pumped-storage and duration curve for production and pumping compared with another scenario C with cable capacity of 20 GW, hydropower of 50 GW and pumped-storage of 10 GW  (Moser et al., 2015).

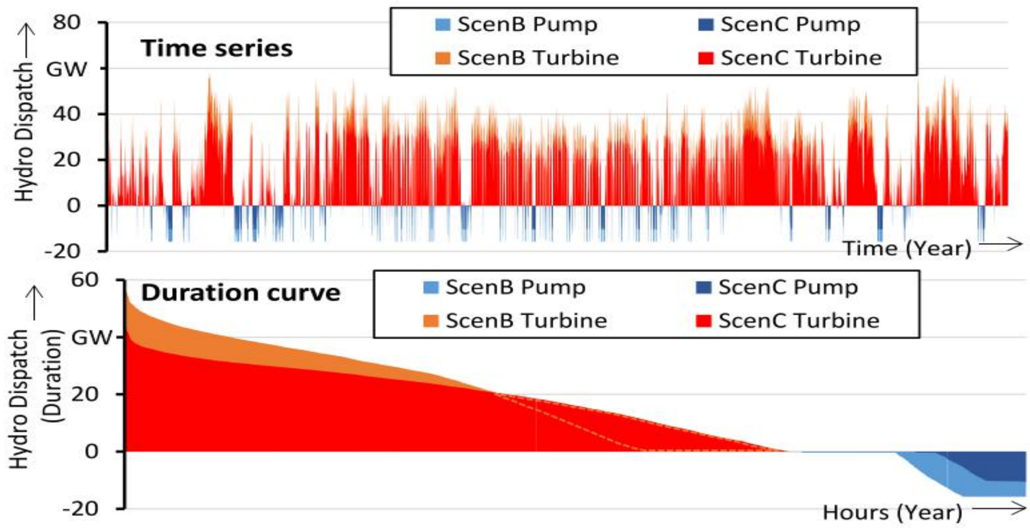


Table 2.6: Scenarios with high capacity of transmission. the hourly use and duration of a Norwegian pumped-storage  *(Moser et al., 2015, p. 41).*

The transmission cables are important for the operation of pumped-storage. With more capacity, there are opportunities to increase trade and transfer more electricity. The hydropower capacity of 60 MW is in periods at full utilization when there is low production from wind and solar in Europe (Moser et al., 2015). In the dynamic European system, the "combination of large hydro storages, large generation capacity and high natural inflows", which make pumped-storage operate for a "few 1,200 hours per year". The total storage level for pumped-storage varies in a year where it is nearly on the total capacity in some periods (table 7)  (Moser et al., 2015, p. 41).

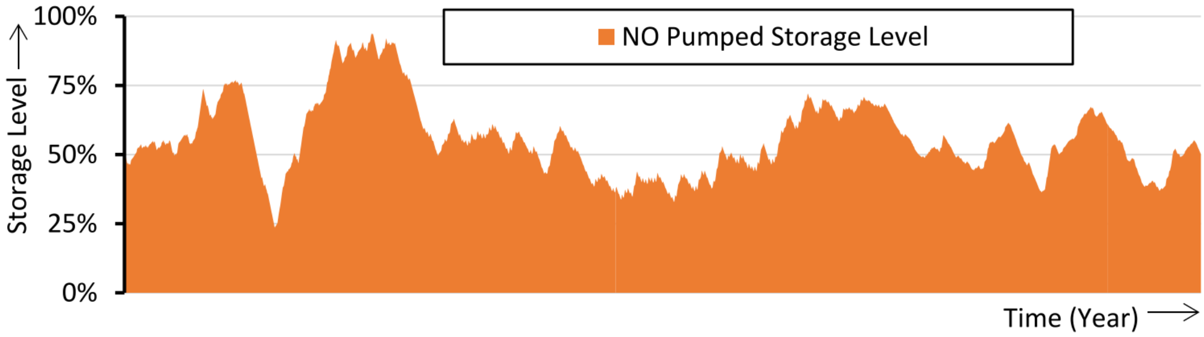


Table 2.7: The use of pumping function in pumped-storage in 2050 *(Moser et al., 2015, p. 42).*

# 3. The framework to understand the feasibility for a Norwegian pumped-storage.

This chapter presents the theoretical framework that is used to analyse to the likelihood for a pumped-storage. The framework consists of an integrated multi-level perspective with triple embeddedness and a re-configuration pathway. These theories can give insight into long-term transitions and the power companies interaction with different actors.

## 3.1 The multi-level perspective and triple embeddedness framework.

The Multi-level perspective (MLP) provides insights into complex and long-term transitions of socio-technical systems. The transition of socio-technical systems occurs in an evolutionary process with interaction in different levels and different phases in the niche, regime, and landscape (Grin, Rotmans, Schot, Geels, & Loorbach, 2011). Traditionally the MLP has been used to analyse a niche entering into the regime (Geels, 2002). However, to investigate the likelihood for pumped-storage to be part of the Norwegian energy system, the focus is on the dynamics in the regime, since pumped-storage is a mature and efficient technology that can be a used in the existing system (Harby et al., 2013). Therefore, more an incremental component rather than a niche.

### 3.1.1 Niche

In the socio-technical system, niches are emergent innovations operating in protected spaces. These emergent innovations have a different characteristic and deviate from the existing regime. Within the niche, there are actors working on radical innovations with the belief of entering into the regime (Grin et al., 2011). In the niche level, there are developments, which can create needs for a domestic pumped-storage. The green certificates have provided an increase of power generation capacity in wind power in Norway. But the subsidies will end in 2021. Then future attractiveness of wind development depends on cost reduction through technological improvement to make wind economical feasible and needs social acceptance to deploy in the potential areas given by NVE framework (NVE, 2019). NVE (2018) also expects an increase in solar energy, the technology has currently low capacity in the energy system, but the reduced cost had the potential to increase the attractiveness. These developments can create more intermittency and make the need for domestic used pumped-storage to support the technologies.

### 3.1.2 Landscape

The developments in the landscape occur in a wider context. The landscape consists of a technological trajectory, political ideologies, societal values, and macro-economic patterns. All these factors are combined into a landscape since they form an external context that actors in the regime are not able to influence in the short-run (Grin et al., 2011).

The landscape is operationalised into the developments occurring in Europe with ambitious targets to reach a low carbon society. The focus is on the UK and particularly Germany since they have a rapid growth in solar and wind energy. The developments occurring in the European states will influence the likelihood of pumped-storage since the European states need storage technology to handle intermittency. Norway is a promising solution for Europe and the speed and scope of Norwegian utilities decisions can influence the feasibility to build pumped-storage. With low speed, the likelihood for a large scale pumped-storage is lower since Germany might try to find other storage solutions to handle their problems.

### 3.1.3 Industry regime

The focus of the analysis is on the dynamics in the socio-technical regime, which is conceptualised into an industry regime. In Geels (2002) socio-technical regime consists of many elements that are similar to the industry regime like the industry, technology, and customers. By moving the focus on the industry regime, it gives opportunities to focus particularly the industry and their role in the socio-technical transition. It gives specific attention to the developments occurring between the industry, landscape, and niche

#### 3.1.3.1 Elements in the industry regime

In an industry, firms produce similar products and services. The industry regime is the “specific institutions”, which forms the industries “perceptions and actions”. The perceptions are formed by three elements, technical knowledge and capabilities, interpretation and beliefs and mission and values (Geels, 2004, p. 267).

The firm operational process is shaped by the technological knowledge and capabilities (Geels, 2014), which determines the technological trajectory of an organisation (Dosi, 1982). The technological knowledge is the skills the organisation wants to improve and build on (Tushman & Anderson, 1986). These vital skills can make organisations path-dependent and locked-in by focusing on incremental improvements (Leonard-Barton, 1992). This lock-in and path-dependency gives organisations stability but makes it hard to change, since they are not orienting towards technologies that are out of there focus. However, organisations can share core competence but have different specific knowledge in the organisation, which make them look different on technological opportunities (Grant, 1996).

The firms perceive reality through shared cognitive maps through "industry recipes" (Spender, 1989) and "industry mindset" (Phillips, 1994). These concepts form a similar culture and cognitive maps, which influence on firms interpretation and beliefs of technologies and guides the selection of decisions (Geels, 2014; Hoffman & Ocasio, 2001). Organisations interpretation and beliefs have the potential to blind the organisations and making them orient towards similar developments (Tripsas & Gavetti, 2000). On the other hand, organisations can differ on opportunities with pumped-storage, "the consensus is a set core belief that is shared by many individuals within a group but around which there exists intracultural variation" (Porac, Thomas, & Baden-Fuller, 1989, p. 405)

The identity and mission is the driver for the targets the organisation tries to achieve in the future (Dutton & Dukerich, 1991; Geels, 2014). A target determines the purpose of the organisation and directs the firms towards a path (Hoffman & Ocasio, 2001). The objective might make it hard to change since they are the settled targets the organisation's struggle and dream to reach (Dutton & Dukerich, 1991). On the other hand, Norwegian utilities can deviate on a mission since they compete on reputation. The good reputation enables firms to get legitimacy from the actor in different environments (Fombrun & Shanley, 1990).

The industry-regime is operationalised into the Norwegian utilities, which focus on pumped-storage. The utilities can share a similar perception of the technology by having similar skills in the organisation, which make organisations see opportunities with pumped-storage. Moreover, the organisational value and mission can be similar between the organisation and targets the organisation wants to reach and pumped-storage might give opportunities to reach the settled targets.

The industry regime also can make organisations deviate on the look on pumped-storage. The utilities can have specific knowledge that makes the organisation orient towards the technology in a specific way. In addition, the aim of the organisation might be to build a good reputation and pumped-storage might not have the same advantages for the actors in different environments.

In Gullberg (2013) the analysis shows that the Norwegian utilities were most likely to introduce pumped-storage in Norway. The policy of Statkraft was characterised for being oriented towards profitability and cost-efficiency. Then the likelihood for pumped-storage depends on the economic feasibility. The Norweigan might see opportunities with pumped-storage due to economic attractiveness from price arbitrage, grid service and incentives (Gullberg et al., 2014). In addition, the utilities have technological capabilities and competence with the operation of hydropower plants and are familiar with cross-transmission cables. Pumped storage hydropower can be an incremental adjustment on the existing hydropower plant, which may orient utilities to the technology.

#### 3.1.3.2 Economic- and Socio-Political Environment

In the triple embeddedness framework, the industry regime is embedded in an economic- and socio-political environment, where the industry needs to adapt to different actors on different criteria (Geels, 2014). In the economic environment, the interaction is with customers, new entrants and technological opportunities (Porter, 1980) by meeting the criteria on “prices, cost, technological performance, and efficiency” (Turnheim & Geels, 2012, p. 37). In the socio-political environment, the industry regime operates with policymakers, civil society and social movements (Turnheim & Geels, 2012) and need to meet criteria of social fitness and legitimacy (Fligstein, 1996; Suchman, 1995).

When utilities make decisions that are against the criteria in the environments. The environments can oppose the industry. The resistance from pumped-storage might come from customers such as electricity-intensive industry and household, which fears higher electricity prices (Gullberg, 2013) However, actors need electricity to function, therefore customers have small barging power towards the power companies. But, can mobiles in social movements to de-legitimacy the plans Norwegian Utilities have with pumped-storage.

The majority of a politician is positive for pumped-storage, but implementation requires consideration of the nature conservation before pumped-storage can be justified. Other argue for limited storage potential compared to the expected European growth in renewables. They argue Norway should orient towards exporting natural gas to support the intermittency in Europe (Gullberg, 2013).

The industry regime is not only are formed by meeting the expectations from the environments, but the can strategically attempt to shape the environment in their favour (Geels, 2014). In the field of business strategy, the external-oriented strategies explore opportunities for a firm to get a competitive advantage (De Wit & Meyer, 2010; Furrer, Thomas, & Goussevskaia, 2008). In the external-oriented strategy, the industry regime explores opportunities to find profitable positions to outcompete others (Porter, 1980). Which studies the relationship between “external conditions and internal strategies” to find the “ideal strategy” under certain conditions (Mintzberg, Ahlstrand, & Lampel, 1998, p. 99).

If the industry regime uses positioning strategies the main objective is to find positions that give long-term profitability to increase the attractiveness of the industry to discover the desirable innovation strategy (Porter, 1985). The industry aim is to develop and protect firm-specific technology by positioning themselves against competitors (Tidd, Bessant, & Pavitt, 2005). The competition arises from five competitive forces entry of new competitors, the threat of substitution, barging power of buyers, barging of suppliers, and rivalry between existing competitors (Porter, 1980). The threat from these forces determines the strategy firm use and the prices utilities can take on electricity. Porter (1980) argues that industries are shaped differently by the five force and structural changes can develop in favour of the industry.

The structural changes in the industry towards decarbonisation gives Norwegian utilities a favourable situation since production is based on clean and flexible energy, and threats from of substitution, suppliers and new entrants have limited effect on the development in the Norwegian energy system. For Norwegian power companies, the technology from suppliers last over long periods and get resources from mother nature, and new entrants have high entering barriers through regulations and limited suitable locations for hydropower plants. On the other hand, the force of customers and competitive firms might central threat and pumped-storage hydropower gives more control over electricity prices. The utilities try to get better position towards these forces by either increasing or decreasing electricity prices.

Norwegian utilities can benefit by being a first mover where firms get increased revenues to first deploying a technology (Lieberman & Montgomery, 1988). However, the first mover involves "strong commitment to risk-taking, with close linkage both to major sources of relevant knowledge and the needs and response of customers" (Tidd et al., 2005, p. 121). Another alternative is imitation involving the late deployment of the technology where firms learn from the experience of other firms experience (Tidd et al., 2005). With pumped-storage, there is a need for capital investment, high uncertainty with the development of the market and risk of customers response if electricity prices rise. Hence, limited benefits for being to get first mover advantages might reduce the likelihood of deploying pumped-storage.

## 3.2 Pathways towards implementing pumped-storage

Within the MLP framework, transitions can take various pathways depending on the struggle between the industry regime, niche and the environments over "technology deployment and institutions" (Geels et al., 2016, p. 900). The relevant paths for pumped-storage are transformation and reconfiguration. In transformation, industry regime can reorient incremental or radical to new technologies to respond to landscape changes. When the industry regime orient incrementally, the technology can be "competence additions or creative accumulation, which refers to new knowledge within existing regimes", but there is a limited change in the regime elements (Geels et al., 2016, p. 898). The path for pumped-storage is likely to have started with transformation where utilities oriented incrementally to take advantage of landscape developments in Germany. However, pumped-storage might need substantial changes in the regime elements to have the opportunity to be part of the existing regime. Gullberg (2013) argues that the belief in pumped-storage turned from optimistic to pessimistic when projects got canceled. Therefore, struggles might have changed the route towards reconfiguration for the industry regime to get extra components before implementing pumped-storage.

When the industry regime remains the same the path is a transformation, but if there is a need for substantial changes in the regime elements the route turns to reconfiguration. In the pathway, technologies are an add-on to the existing system, but the implementation of technologies lead to “unintended problems and opportunities” with the result of a “cascade” of change in regime elements with other components added on to the system. This “knock-on” effect of new technologies leads to changes in interpretation, beliefs, and missions, in the start changes are limited but ends up to be substantial with a new industry regime growing out of the old one (Geels et al., 2016, p. 899).

The pathway of reconfiguration provides insights into the complexity of components that may need to be changed before pumped-storage can be part of the Norwegian energy system. To get insights into the feasibility for pumped storage hydropower, the components are divided into different scenarios to analyse the feasibility for pumped-storage.

The scenarios are storylines “that describes a possible future and identifies significant events” (Shell, 2008, p. 8). It can provide insights into trend-breaking developments that are important for future pumped-storage (McDowall & Eames, 2006). All the scenarios are based on development towards a decarbonised energy system. The long-term scenario to 2050, which was presented in chapter 2.6 is used as beneficial for Germany. It shows the benefits landscape to have access to the Norwegian pumped-storage.

The scenarios until 2030 are based on van Hou et al. (2017) analysis on future impacts of Norwegian hydropower until 2030. The main use is to analyse the development of electricity prices. The two scenarios are developed and translated into Niche storage and big storage. The scenarios share the same characteristic by having a strong expansion and improvements of the European transmission grid. But differences are in the transmission capacity between Norway and Europe, Norwegian hydropower- and pumped-storage capacity, and Norwegian integration to the European power markets (van Hou et al., 2017).

In business case for pumped-storage, the ambitions for Norway to build interconnects are moderate with 10 GW capacity. The Norwegian hydropower capacity is 40 GW. For pumped-storage capacity is 10 GW. Market integration is only in the DA market due to low transmission capacity. Low transmission capacity also gives high competition from other flexibility solutions in Europe. In Europe are developed own storage technologies (van Hou et al., 2017).

The beneficial for hydropower plant there are high motivations for building interconnectors with a capacity of 15 GW. Here the Norwegian hydropower capacity is 45 GW. For pumped-storage, the capacity is 15GW. The market integration is in both DA and ID with higher transmission capacity. Europe there is a strong need for Norwegian storage capacity due to limited storage

Gullberg (2013) develops a scenario for a pumped-storage used as domestic support of intermittency. In this scenario, there is niche development that increases the intermittency in Norway giving the need for Norway to use a pumped-storage for domestical purposes. NVE predicts the development of total onshore wind power capacity to grow from 4 TWh in 2018 to 10 TWh in 2022 and further increase towards 2030 with 25 TWh (NVE, 2018). For solar power current production capacity is low. But, the reduction in price have can increase the attractiveness for solar power production. NVE predicts an increase from 0,2 to 1,9 TWh in 2030 (NVE, 2018).

## 3.3 The operationalisation of research questions

With the theoretical framework the research questions are operationalised into:

1) How is pumped-storage perceived by Norwegian utilities?

To analysis the perceived interest from Norwegian utilities. The concept of mission and values and technological capabilities and competence will be used. They give opportunities to identify similar and different perception. With technological capabilities, there will be opportunities to compare similarities in technologic competence. This can give insight into a lock-in and path-dependency. The differences are in specific competence. For the mission, utilities can share a similar objective with the technology, but also have different by competing on reputation. This question also uses the concept of strategies, which might be formed of their objective with the technology.

2) Which conditions are needed for utilities to implement pumped-storage?

The conditions use the concepts of the mindset. The mindset and cognitive memory form their interpretation and beliefs on the conditions needed for pumped-storage to be implemented.

The conditions might also be dependent on developments occurring in the landscape and niche. The conditions might lead pumped-storage on a path, where new elements need to be implemented before pumped-storage is feasible.

3) How are Norwegian Utilities decisions influencing the development occurring Germany?

This question looks closer to the relationship between the developments occurring in the triple embeddedness with the socio-political environment, economic environment and industry regime, which makes decisions that influence the landscape. It aims to investigate the influence the Norwegian energy system might have on Germany.

4) How will increased intermittency in Norway give needs for a domestic used Pumped-storage?

While the question three particularly focus on the interaction between landscape and industry regime. The fourth question uses the niche and industry regime to analysis the need for a pumped-storage that support intermittency in Norway

# 4. Design and method

This chapter presents the design and method used to answer the research questions. The section discusses in which way the research design and methods where feasible to answer the research questions. The section describes and discusses the research strategy, chosen design, the data used, data reduction and strength and weaknesses with the study.

## 4.1 Abductive Research Strategy

To identify the feasibility for a pumped-storage to enter into the Norwegian energy system the thesis uses an abductive research strategy, this strategy can interpret and re-contextualize the likelihood for pumped-storage within a theoretical framework (Danermark, Ekstrom, & Jakobsen, 2002). In abductive research strategy, the framework has a significant role to determine the understanding of the feasibility for a pumped-storage. However, this does not mean the conclusion will represent the truth, but show what might be true in terms of the framework (Danermark et al., 2002).

The framework is represented with the theories from MLP, triple embeddedness, and the re-configuration pathway. The aim is not to justify the truth of the theories. But relate empirical evidence to the theories to "give meaningful interpretation"(Dey, 2004, p. 91). If one compares abduction to induction, induction tries to make generalisations to the real world, while abduction uses the theories to get something specific from the empirical evidence (Dey, 2004). The specific gives opportunities to examine the likelihood of pumped-storage in-depth. Moreover, abduction differs from the deduction, while deduction produces a "logical conclusion" followed from the premises. Results from "abduction give a plausible interpretation", which is represented by the framework (Dey, 2004, p. 91). The main reason to use an abductive strategy is that when phenomena are contemporary it is difficult to not consider the context around. The interpretation from actors and utilities can change and be different depending on time and circumstances. Therefore, abduction has potential to give a sensible analysis of a contemporary phenomenon by recontextualizing and bringing it up to a higher level with a theory, where inference depends on a theory, which can give serval understandings depending on the used theory (Dey, 2004).

Abduction will force my interpretation towards the theories in MLP, triple embeddedness and re-configuration pathway. Then my understanding of phenomena will depend on the ideas form these theories (Danermark et al., 2002). The concepts will move the attention to the most relevant evidence to answer the research questions. However, an issue with abductive inference is uncertainty in the conclusion, since there are no fixed criteria to make them valid (Danermark et al., 2002). However, in social science often events are not directly observable, and with a different framework, I can observe other things than Gullberg (2013) did in her research about political feasibility. Moreover, Danermark et al. (2002) argue that abduction guides interpretation by putting them into a larger context. By putting the finds into a larger context, the thesis can have a  holistic perspective. Where the evidence represents the likelihood for a Norwegian pumped-storage. This recontextualizing comes from the theory and provides meaningful reasoning.

## 4.2 Design and case selection

The thesis uses a comparative case study to explore the feasibility of Norwegian pumped-storage seen from different Norwegian Utilities, Agder Energi, Lyse, Skagerak Energi, and Statkraft. The potential energy transition will be investigated as a longitudinal case study, reaching from the current time to 2050. A transition is long-reaching process and involving “developments, resistances, mobilizations and opportunities” (Geels et al., 2016, p. 901). The energy companies were selected because of similar characteristics with a high market share in the electricity sector and having hydropower plants located in the south were the transmission cables from Norway to Germany and UK are planned to be deployed. Moreover, all the companies are also the owners in Sira-Kvina, which cancelled an application to build pumped-storage. Therefore, they have both shown interest and withdrew a project.

The strength of a comparative case study is the ability to go into depth with a contemporary problem (Yin, 2014). This gives opportunities to compare similarities and differences in perception between utilities. The comparative case also gives the opportunity to identify differences and similarities between cases on the conditions needed to implement pumped-storage, decisions made to build a pumped-storage for domestic and international usage. This gives opportunities to reach a conclusion that identifies the likelihood for pumped-storage to be part of the Norwegian energy system. The data comes in both a quantitative and a qualitative form. Blaikie (2010) argue that mixed method can help answer research questions that need more than one method. The difficulty with one approach is to exclude secondary data in the scenario developments, which includes data on the infrastructure in different scenarios.

It could have been possible to use a single case to identify the opportunities for a Norwegian pumped-storage. However, the weakness with a single case study gives a more uncertain conclusion, since it is not sure that one company represent the industry view. A comparative case study is more time consuming by needing to replicate the cases before concluding, but the opportunity is to replication increases the reliability in the research.

## 4.3 Overview of the data and analysis

To explore the feasibility for a Norwegian pumped-storage the thesis used a cross-case synthesis. The cases were analysed by first replicating into individual cases[1], later shorten down to must vital elements before it was synthesised together. The evidence was obtained through different qualitative and quantitative data through documents, scientific journals, newspaper, webpages and four semi-structured interviews from different Utilities. The semi-structured interview was conducted by the author and took places at different places and different time with different utilities. This can have influenced the research since pumped-storage is contemporary phenomena and changes in the context can have influenced the interviews. One contextual development that might have influenced the research, particularly the fourth research question, was the release of the wind framework in Norway. The question of developing new onshore wind was put high on the agenda with high resistance towards building more windmills.

The interview asked about the informant's perception and conditions needed for a pumped-storage used in power exchange with Europe and used to support intermittency in Norway. As an aid interview used a semi-structural interview guide, which is put in appendix A2. Newspapers, webpages gave additional information of the utilities, pumped-storage, and actors located in the environments. The documents provided information to identify different scenarios, which focus particularly on pumped-storage, where the technology provides significant benefits for Europe and Norway.

[1] The individual cases were composed by excluding the similar details in landscape, niche, socio-political and economic environment in the thesis. The focus was more on the dynamics in the industry regime.

## 4.4 Data

To explore the feasibility for a Norwegian pumped-storage the data was collected to apply the theoretical framework. To use the framework there was a need for information from energy companies, politicians, customers, developments in Germany and the UK, and potential solar and wind development in Norway. To get information the data was collected through interview, scientific articles, documents, newspapers, and webpages.

### 4.4.1 Access to data

The documents, newspapers, scientific journals and webpages were accessible through the web. For the interviews, there was sent a mail to the different organisations. I asked to talk with personnel, which is part of the decision-process and has knowledge about pumped-storage. In the appendix is the cover letter that was sent to the informants.

### 4.4.2 The data collection

The qualitative primary source comes from interviews with different utilities. The aim of the interviews was to get evidence, which can be used to understand the case (Rapley, 2004). The interview was with key informants in the organisation. The key informants have a position in giving them specialised knowledge, which can provide specific and valuable information about the case  (Payne & Payne, 2004).

The interview was in semi-structural format with a key question that answered the research question. It was designed after the research questions and theory to be sure to get relevant data. The objective was that the informants could take freely around their view of a Norwegian pumped-storage. this gives opportunities to have variation depending on the informant's specialisation. This gives opportunities to go in-depth and find unexpected data. However, to make the interviews comparable some question will be the same (Ringdal, 2013). This to make it possible to discuss similarities and differences in perceived interest in the technology. Moreover, with a semi-structural approach, it is possible to confront and be sceptical about the informant's answers (Rapley, 2004). The approach increased my flexibility in the interview situation. In the situation, I had followed up a question and asked further on topics, which was most important for the informant. It provided valuable information about the differences and similarities between the utilities. The flexibility was increased by using a recorder with permission from the informants. However, the phone interview I needed to take notes during the interview since there was uncertainty around the function of the recorder, this reduced the flexibility in that interview.

The plan was to start the data collection in March and end in April. However, the interviews were started at the start of May and ended in the middle of May. There was a need for additional understanding of pumped-storage before doing the interviews. This made me really prepared before the interviews. The interviews were done at informant's offices, besides the one interview over the phone and lasted for 30-50 minutes.

The interview involved traveling to different places and at different times. Then contextual factors can influence the interviews (Halvorsen, 2008). Two of the interviews had a travelling time of over 3 hours. For the next time, I would not travel and have an interview on the same day. One of the informants I travelled by train at 23.00 and got to the place at 8.00 with the interview starting at 12.00. The time factor influenced the interview particular the NVE wind framework which was high on the agenda. This can have influenced the informants understanding of increased intermittency in Norway since there was strong resistance to implement new onshore windmills.

The qualitative secondary sources were also collected in newspapers, webpages, reports and scientific articles. These provide information about politicians, pumped-storage, German actors, environmental movements, electricity-intensive organisations. It was used 21 newspaper articles, webpages from the different organisation, and scientific articles primary the paper listed in the literature review (2.1). In addition, the newspapers gave preliminary understanding. It showed that pumped-storage was high on the agenda around 2009-2011 in Norway. This was in the period were the report SRU (2011) was realised, which was frequently mentioned in newspapers. In the same period, the Sira-Kvinas pumped-storage project was cancelled.

The quantitative data comes in a secondary form. The second handed data is collected by other research and made for a different purpose. However, collecting data is an expense and using others work can save time and resources but one should be aware that the data might have biases and errors from other researchers (Blaikie, 2010). Therefore, carefully deciding the material. The material comes with the number on the scenario (Gullberg, 2013; Moser et al., 2015; van Hou et al., 2017). The scenario tries to identify the needs pumped-storage provides in the future. In addition, it also is used for modeling of future volatility in energy prices (van Hou et al., 2017).

The thesis converged the evidence through a triangulation. The triangulation link and produces facts by linking the different data. This pulls the evidence in a direction and gives a meaningful conclusion (Yin, 2014). This was done especially to the informants that were not a leader in the organization. They were cross-checked with data from newspapers, websites, and scientific reports.

The first challenge was the amount of preparation need before the interviews started. In addition, it was challenging to find an informant that has time to be part of the interview. In some of the organisations, I used a lot of time. In the period of May, there was a lot of vacation that gave challenges since many of the relevant informants was on holiday.

### 4.4.3 Ethical consideration

The project was reported to NSD because the data collection identifies individual persons through the organisation they are connected with. Projects need to be reported if the project contains information about personal data downloaded on equipment such as a transcription from interviews (Wadel, 2014). This to make sure that the project is in line with ethical principles.

## 4.5 The method used for analysis

The analysis used for the thesis was first to replicate into individual cases. After the replication, the cases were analysed through a cross-case synthesis. The technique has the potential to synthesise the result across the individual cases and gives opportunities to look at differences and similarities between them (Yin, 2014). It was used to compare differences and similarities in perception, conditions needed for pumped-storage, the decisions influencing Germany and need for a pumped-storage to support intermittency in Norway.

The data was gathered and analysed into the software, NVivo. The software was used to code the empirical evidence into different categories. The categories were represented with the theoretical framework. The empirical evidence was re-contextualised and put into a larger context with the framework, which gives opportunities to get a holistic understanding of the likelihood for Norwegian pumped-storage (Danermark et al., 2002). This is done by applying the theoretical framework to the evidence.

## 4.6 Limitations in the study

To increase the reliability of data collection the evidence was put into the software, NVivio. This gives opportunities for another researcher to replicate the findings. However, by going in depth with a contemporary phenomenon and the use of an abductive research strategy. It makes it hard for others to get the same conclusion, informants can change their opinion and technological changes will give a completely new understanding of pumped-storage in Norway. In the future, the contextual factor can influence the development, renewable development and building and resistance of transmission cable in Norway, which was not discussed in detail. Therefore, it might be challenging for researchers to find the same evidence. However, the aim was not to produce generalisable results but to understand a contemporary phenomenon by applying a framework

There are many companies in Norway that could have interesting to investigate like E-CO Energi and Norsk Hydro with more. These organisations might have a different understanding of the feasibility for pumped-storage. However, a master thesis does not have the time and resources to investigate all the organisation. Therefore, the focus was on the organisation, which is a member of Sira-Kvina since these organisations have earlier been interested in the technology.

In the organisation, there was only one informant in each organisation. This affects the reliability of the evidence. In addition, it was challenging to get informant from the same position in the organisation. Therefore, the informants have different roles in the decision-making process. But the informants were cross-checked with the other documents to give additional information.

For the interview, it should be marked that I am an experienced interviewer. This can have influenced the answer form the informants. However, a semi-structural interview form makes it possible to give make the informants talk more freely.

# 5. The utilities view on the feasibility for pumped-storage

This part presents the individual case from each power company and their view on the feasibility for a pumped-storage. The energy companies presented is all owners in Sira-Kvina. Sira-Kvina sent an application to build pumped-storage in 2007. The purpose of the project was to have power exchange with Germany. The projects were withdrawn in 2011, due rapid changes in the power market.

## 5.1 Lyse

Lyse is a regional power company with a base in Stavanger. The company has a long tradition in the operation of hydropower in Floerli and Lysebotn, which represent the core of the business (Lyse, 2019). A future pumped-storage fit well with their business profile, since their values orient towards being innovative and implement promising technological solutions, However, currently Lyse has no existing plan to deploy the technology. Still, the company has mapped out the opportunities in existing hydropower plants and their seasonal pumped-storage. Lyse argues that with the right circumstances there might be opportunities to implement the technology.

### 5.1.1 The need for volatility in electricity prices

For Lyse, the attractiveness of pumped-storage depends on the opportunity to utilize differences in power prices. This to make the operation of the plant profitable. The differences must be systematic and substantial with price fluctuations on daily, weekly and monthly basis before there are taken any decisions on making installation of pumped-storage.

Lyse believe that pumped-storage is a future opportunity in a changing power marked. There is a strong tendency for more wind and solar power generation in Europe. In the short-term, the cables connecting to Germany and the UK might give opportunities for pumped-storage. Norway currently has stable electricity with the operation of the controllable and flexible hydropower plant. With integration to renewable, there is expected for more fluctuations in the power price. However, Lyse argues that there is uncertainty on how much differences the cables will create. Pumped-storage should give positive value and for the technology the bottom price is important. Moreover, when price differences occur Lyse will first look on opportunities to upgrade the effect in existing hydropower plant.

Pumped-storage is not excluded, but first, there might be a doubling of effect in existing hydropower plants. This is cheaper and has been a tradition for the company. The Floerli power station have 80 MW of installed capacity and usage 3600 Hours, produces around 250 GWh. Upgrading the effect to 160 MW is profitable. Moreover, there are many short of pumps that can increase the effect by lifting water to a higher reservoir. Lyse has a planned project in Lysebotn 2 to utilize large height differences. Lysebotn 2 have two reservoirs by putting a pump between the reservoirs and increase the flexibility and effect by lifting water to higher reservoirs (Figure 5.1).

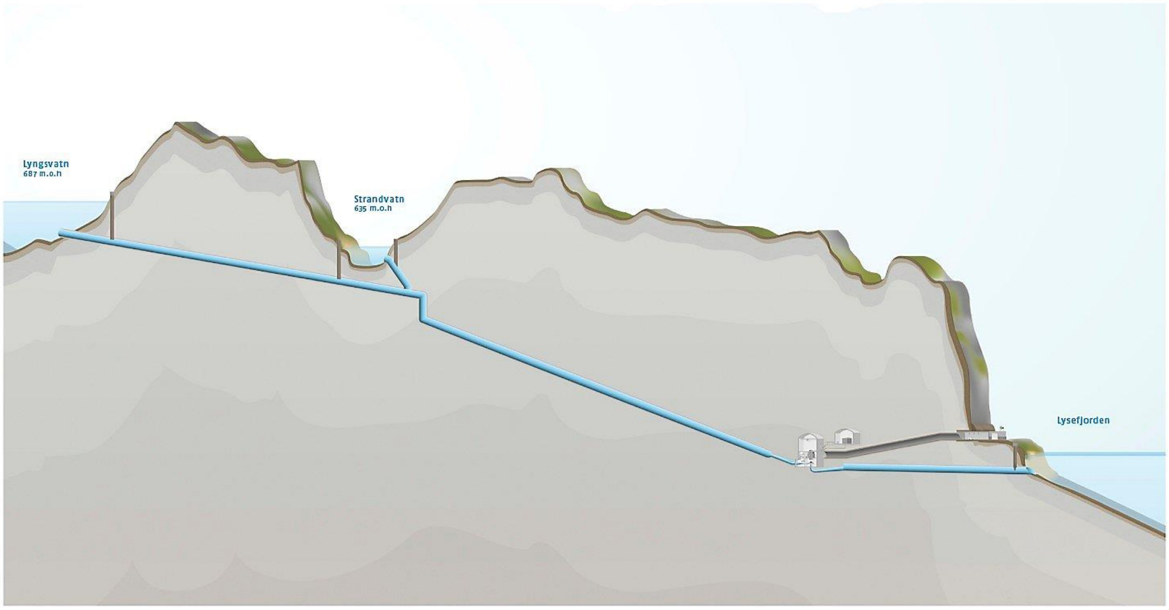


Figure 5.1: Lysebotn 2, the potential for a pump between the reservoirs to utilize higher height differences *(Andersen, 2015)*.

Lyse believes that the power exchange with Europe only should be considered as a part solution for Europe. The solution for Europe to solve intermittency in the short-term is believed to gas and other local storage technologies such as batteries and hydrogen.

### 5.1.2 Domestically use of pumped-storage

The development of wind and solar have the potential to create intermittency in Norway, which might give the need for a domestically used pumped-storage. Lyse argues that it will be hard to realise price differences for a pumped-storage used to support intermittency. The Norwegian energy system has currently a high amount of effect, which has the potential to reduce fluctuations in prices and support intermittency. The fluctuations for Norwegian windmills might not give fluctuation, which makes pumped-storage profitable. However, there might be many hours at very low prices. Nevertheless, might not large enough to defend the installation of pumped-storage.

The energy company further addresses that the idea should not be excluded it depends on the speed and scope of the electrification. This can give periods with fluctuations in power prices. However, there are opportunities with smart grid and business models, which will give fewer effect jumps thereby reduce the volatility. This will be an objective since it will reduce the required investment in grids.

## 5.2 Statkraft

Statkraft is an international power company, currently is operating in 20 countries. The Power company is Europe largest producer of renewable energy. The company is interested in doing an installation if the right conditions are in place.

### 5.2.1 The need for volatility in electricity prices

Statkraft has installed pumped-storage in Duge, Saurdal and is part owner in Aurland. The plants are used for seasonal pumping to increase the security of supply. Statkraft argues that seasonal pumping is different when it comes to the economy, compared to a weekly and day and night operating pumped-storage. For weekly and daylily there need to be substantial and systematic price differences to make the technology profitable. The Duge plant, which is owned together with Lyse, Skagerak Energi, and Agder Energi, have capabilities to operate in the mode to support intermittent wind and solar. The plant has an installed Francis turbine with a reversible pump (Figure 5.3). It gives opportunities for water to be pumped up to a higher reservoir in an integrated process with solar and wind technologies. However, it needs to be profitable with large fluctuating in power prices before operating in the mode.

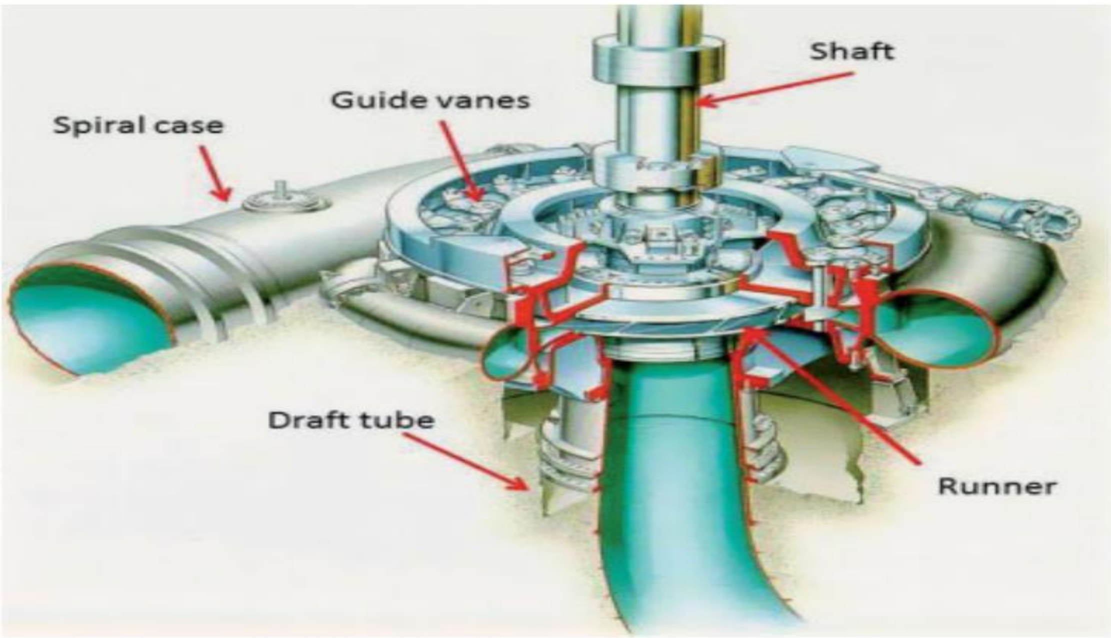


Figure 5.2: A reversible pump turbine *(Harby et al., 2013, p. 600)*

Statkraft believes that transmission cable can be a driver to create differences. However, the company is uncertain if there will be enough to make pumped-storage profitable. The company does not expect any radical changes in the future with power prices. Therefore, the informant does not believe the development currently is going in favour of a future pumped-storage.

In relation to Germany, Statkraft argues that Norway has a large potential to support Germany. But Norway alone cannot solve the problems with intermittency in Germany. For Germany, there is a need for many storage technologies such as batteries and own pumped-storage, hydrogen and increased consumption flexibility.

### 5.2.2 Domestically use of pumped-storage

Statkraft argues that there might not be enough fluctuations in Norway to make a domestic pumped-storage profitable. The intermittency can be handled with the effect in the Norwegian hydropower plants. The plants have enough effect to handle large variations by adjusting the consumption and will cover the variations we are going to see in the future. The effect is also possible to upgrade further by lifting water to a higher reservoir with pumps between reservoirs and by upgrading the turbines.

## 5.3 Skagerak Energi

Skagerak is a Norwegian power company owned by Statkraft and three municipalities. The vision of Skagerak Energi is to be a future-oriented supplier of pure energy for welfare, growth, and development. The values and objective with well fit with a future installation of pumped-storage. However, there are currently no plans to build a pumped-storage, either for use as a seasonal, weekly and day and night operation.

### 5.3.1 The need for volatility in electricity prices in Norway

The attractiveness for implementing pumped-storage depends on fluctuations in power prices. The difference needs to be systematic and large with the potential to earn money on the technology by pumping on low prices and generating high prices. Currently, Norway has stable electricity price due to the high capacity of flexible and controllable "hydropower and a small amount of intermittent renewable energy and relatively small capacity on the transmission cables" (van Hou et al., 2017, p. 31).

The integration to Germany and the UK is likely to increase prices in Norway. However, Skagerak believes that the planned capacity may not be enough to create volatility and make pumped-storage feasible. Even if the integration would create differences the technology is long in the future since there need to be an application for concession. The concession takes time at least five years to get approval from NVE. Moreover, there is a construction that takes around 2-3 years. Therefore, in the best case for pumped-storage is implemented in 8 years.

On the other hand, Skagerak Energi argues that the key for a need of a pumped-storage is in the dynamics between consumption and installed effect. In the Norwegian energy system, the high consumption and installed effect work like a virtual pump, since increased effect has capabilities to adjust the production after consumption. Pumped-storage will give increased consumption in periods with a surplus of wind and solar. Therefore, pumped-storage will take care of the oversupply. If there is not enough effect in hydropower to cover the consumption in future power marked with much wind and solar, then there is a need for pumped-storage.

### 5.3.2 Norwegian pumped-storage in interaction with Germany

There is theoretical feasibility to build pumps and effect in Norway to become a green battery of Europe. Skagerak Energi argues that the limitation is in the required facilities needed, if one look at the required facilities and the area it takes, for a relatively small amount of effect 1 400 MW. The large transmission facilities needed are both expensive and takes space to transfer electricity over long distances. There might also be resistance to build the facilities. This is believed to be the main barrier, not a Norwegian pumped-storage.

There are other opportunities for Germany to handle the problems with intermittent energy. Firstly, if Germany builds a good transmission network which will allow them to send surplus from one region to another. Secondly, taking better advantage of the flexibility on the consumption side. Thirdly, local storage technologies can be used to handle the overproduction, maybe not batteries but hydrogen and gas. This might come before Norway becomes a green battery

### 5.3.3 Increased intermittency in Norway

The profitability to invest in a domestically pumped-storage is doubtful. There is a need to be a substantial amount of wind power before it is suitable to build a pump to utilize price differences. The company expects the electricity consumption to rise with the electrification, which will give less need for a domestically used pumped-storage. If the consumption is lower than it is cheaper to invest in effect in existing hydropower plants, rather than build pumps.

However, the feasibility of a domestic pumped-storage is dependents on the development of consumption in Norway. Skagerak Energi believes that there might be problems during the summer since there might come more solar power than NVE and Statnett expects in their forecasts. The development might come fast.

The future development of solar power and consumption will show if there is a need for pumped-storage in Norway. The informant argues that in Norway there is a strong belief that hydropower plants can stop whenever they want. However, there a regulation on the minimum of water level in plants and many are unregulated. The regulation of water level is given by NVE, which provides guidelines on the lowest and highest water level in the Norwegian reservoirs. Where power companies are responsible to keep the water level within the lowest and highest (Skagerak Kraft, 2019). With the consumption level during some summers, the hydropower plants already operate close to the minimum production level. Therefore, every single new installation of MW from solar and wind power can give problems for the energy system, especially in the mouth of July. This will give need to export the surplus, then the energy is entering a marked that have subsidies on solar and wind from Germany, Denmark, and the UK. Then there might be challenges to send the electricity out of Norway and give problems with overproduction.

## 5.4 Agder Energi

Agder Energi is regional power company with a base in Kristiansand. The company has a long tradition for operating hydropower plants. A future pumped-storage installation will fit well into the company's skill profile since the operation of such technology is not very different from operating traditional hydropower plants. However, the company has, at the moment no concrete plans for the realisation of pumped-storage. Nevertheless, they are continuously updating their knowledge around pumped-storage and looking at the business opportunities for new technologies

### 5.4.1 The need for volatility in electricity prices

The attractiveness of pumped-storage depends on profitability. For the technology to be profitable there need to be differences in power prices. The differences will make it possible to earn money on the technology by pumping on low prices and produce on high.

Agder Energi believes that pumped-storage technology is an opportunity in a future power system dominated by intermittent power production technologies like wind and solar. However, the power price prognosis must indicate systematic and substantial price fluctuations on a daily, weekly or monthly basis before investments in such technology will be subjected to a concrete assessment. Currently, prices difference are too low to take advantage of the technology, due to stable electricity prices from flexible and controllable hydropower (van Hou et al., 2017).

To create differences the technology is largely dependent on the integration with the European continent and UK. The transmission cables planned to UK and Germany give opportunities to increase the volatility. Germany and the UK have large price differences due to the power that varies in a generation. Integration between the countries may influence this trend by increasing the volatility in Norway and decreasing the price difference in the UK and Germany (van Hou et al., 2017).

Agder energy argues that the Norwegian pumped-storage and power exchange only should be considered as a part solution for Europe. Germany can use other technologies like gas and coal. Moreover, they have opportunities to implement storage technologies like batteries, vacuum storage, and air pressure storage.

### 5.4.2 Regional environmental problems

Agder Energi considers potential opportunities with pumped-storage in the Otra watercourse. The Otra watercourse is the seventh largest in Norway and starts in Sævatn in Vinje, Telemark, goes down through Setesdal and ends up in the ocean in Kristiansand. In the upper part of the watercourse, there is large reservoir capacity in Vatndalsvatnet, Urevatn and Botsvatn are thus technically well-suited for pumped-storage installations (Heggestad & Thorsnæs, 2017).

When building pumped-storage installations utilizing existing reservoirs, dramatical landscape changes are limited (Harby et al., 2013). Besides the pump, there is a limited need for new infrastructure. However, there are environmental consequences. When alternately pumping and producing, the water tables in the up- and downstream reservoirs will frequently move up and down. This will give environmental and visually effect, which is one of the main problems with the operation of pumped-storage.

The Municipality in Bykle is worried about environmental consequences with the implementation of the pumped-storage. The municipality fears consequences with the same water being used many times. This can give larger variations in water flow in the reservoirs between day and night giving environmental problems like washout, problems for fish and aquatic macrophytes problems (Raustøl & Sundsdal, 2017).

The municipality is particularly focusing on the problem of aquatic macrophytes since it has been a problem in the watercourse for a long-time (Raustøl & Sundsdal, 2017). Aquatic macrophyte is a plant growing near the water and are often found floating in the river. The plant has taken a larger place in the watercourse (Figure 5.4)(NIVA, 2018). The problem has been to identify the cause of the growing plants. Many solutions have been tried to limit the expansion of the plant. But attempts have given limited success (NIVA, 2018).

Figure 5.4: Aquatic macrophytes floating in Otra watercourse *(NIVA, 2018)*

On the national level, politicians argue that nature conservation is important when considering building pumped-storage in Norway. They might get support from the environmental organisations, which fears the consequences of building pumped-storage in vulnerable areas (Gullberg, 2013).

### 5.4.3 Increased intermittency in Norway

The use of a domestic pumped-storage and take advantage of prices differences might be interesting in the future. There is a tendency for more intermittent power generation in Norway. The national framework for wind displays the potential areas to build wind in

Norway (figure 5.5). There one large area is in the region where the company is operating. In addition, NVE predicts an increase of around 5-6 TWh in the region. Therefore, to utilize the increased in wind power generation there might be a need for storage technology.


Figure 5.5:A Potential wind area in Aust-Agder *(NVE, 2019).*

NVE (2019) evaluates the area is promising and give opportunities to produce cheap electricity. In the region, there are many potential sites to build windmills. The challenge is to build a regional transmission capacity connected to the windmills, especially if there is built windmills in the north. If windmills are deployed in the region it is likely to be a large expansion to cover the cost of building transmission capacity. Moreover, problems are with rich wildlife for birds and the area is a popular outdoor activity.

The Norwegian wind power development can be a driver for a domestically marked that can give an opportunity for pumped-storage, which can be supplemented with the integration to the European market. However, the key is if there is going to be enough volatility to take advantage of a Norwegian pumped-storage.

# 6. The likelihood for a Norwegian pumped-storage, which is system integrated with solar and wind energy.

This section is the core of the thesis. It provides a cross-case analysis of individual cases. The aim is to explore and discuss the likelihood for a Norwegian pumped-storage. The section starts with a scenario potential scenario in 2050, which was presented in chapter 2,6. In the scenario, pumped-storage have a major role in a European energy system. The chapter further addresses the conditions needed for Norwegian utilities to implement the technology in the future and identifies the potential for a domestic used pumped-storage. It further identifies the similarities and differences from the Norwegian utilities on the feasibility to make an installation of a pumped-storage technology.

## 6.1 Norwegian pumped-storage a part solution for Europe.

Germany has set long-reaching ambitious targets to transform its energy system by increasing the share of solar and wind in the energy mix. In Germany, the targets have significant support from the public in the period from 2013 to 2019, with 90 percent in 2015 (Agora Energiwende, 2015; Amelang, Wehrmann, & Wettengel, 2019). Therefore, the developments towards more renewable energy in Germany is likely to continue in the future (Geels et al., 2016). Renewable energy has problems with intermittency. This comes from the variations in power dispatch from solar and wind power. The intermittency has made the transition gradual with growing coal consumption since fossil fuel is needed as a reserve to support the growing renewable energy (Smil, 2016). In addition, the transition has been criticised for being expensive and the German environment mister in 2013 addressed that reaching the targets may imply a cost of "€ 1 trillion by 2040" (Moe, 2015, p. 140; Smil, 2016).

For Germany to reduce the cost and dependency on coal, integration with the Norwegian energy system gives opportunities to solve the problem. The integration with Norwegian hydropower plants can balance the system and Norway is attractive for two main reasons (Gullberg et al., 2014, p. 220). Firstly, compared to another feasible storage solution in the Alps, which have a capacity of 12 TWh (Ess, et al. 2012). The Norwegian reservoirs have opportunities to store 85 TWh, which is 50 percent of the European storage capacity (CEDREN, 2018). Lastly, Norwegian hydropower plants are flexible, reliable and have suitable design for an upgrade with a pumped-storage (SRU, 2011).

Norwegian hydropower and pumped-storage have the significant theoretical potential to solve and provide benefits to Germany. In a scenario towards 2050, Moser et al. (2015) show the benefits for Germany to have access to an upgraded Norwegian energy system with hydropower capacity up to 60 GW, pump capacity on 15 GW and transmission capacity on 30 GW, which is economically feasible form a system point of view. The upgraded hydropower capacity and integrated pumped-storage increase the trading of electricity in North Europe (figure 6.1). The flexible hydropower provides benefits in most hours, but pumped-storage support in the surplus periods and thus operating a few hours a year (Table 2.6)(Moser et al., 2015). The increased transfer of electricity comes mainly from the capabilities pumped-storage give in surplus periods of intermittent power generation. Pumped-storage create consumption, then there is less need to stop the generation of wind and utilize more of the dispatch of solar power, which can flow into the Norwegian energy system (Moser et al., 2015).

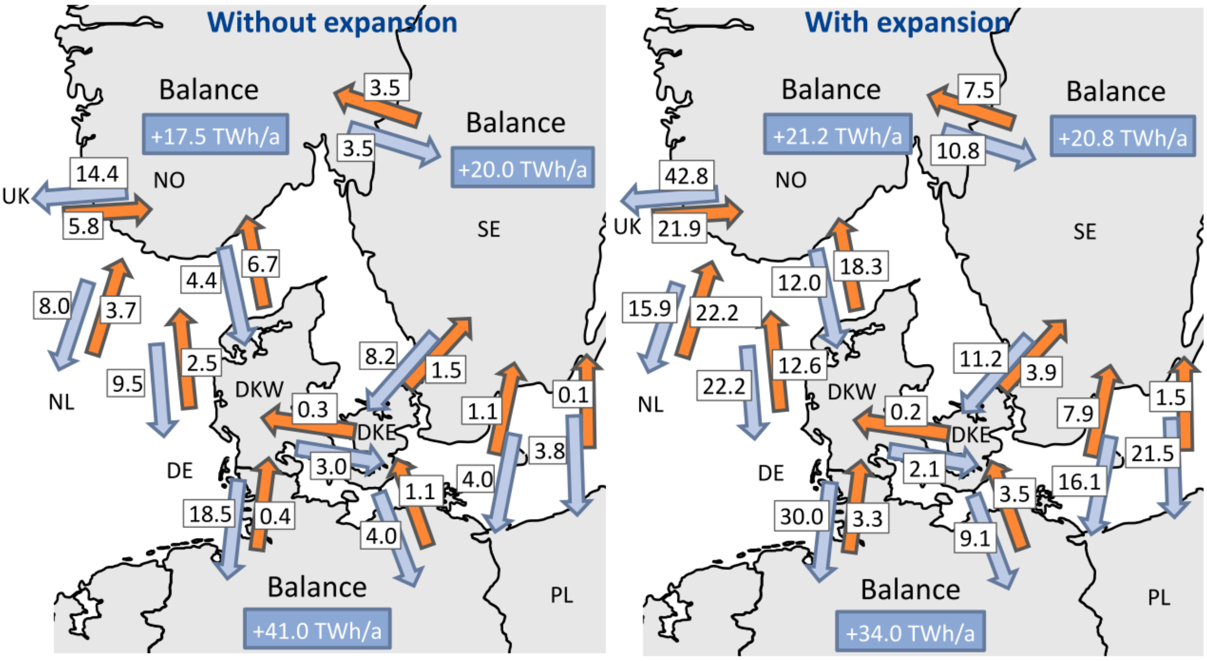


Figure 3.1: Scandinavian trade, without and with an expansion of hydropower in a system with increased transmission cables *(Moser et al., 2015, p. 33).*

The owners in Sira-Kvina, Lyse (41%), Statkraft (32%), Skagerak Energi (14%) and Agder Energi (12%) (Sira-Kvina, 2019) perceive pumped-storage as a future opportunity within a changing power marked based on the increased generation of intermittent power generation. The technology fits with the organisation's skill profile and they believe that there is a theoretical potential to build pumps, effect, and infrastructure to become a “green battery” of

Europe. However, the utilities only see Norway as a partial solution. They argue that Germany should consider natural gas and local storage solutions to solve the problems the energy transition is facing.

Germany has other feasible technologies that can be installed to solve the intermittency. Figure 6.2 shows a comparison of the most feasible alternatives. Pumped-storage have advantages of being a mature technology, which has been used in Europe for a long time. Moreover, It has “long-life expectancy between 50 and 100 years, high efficiency of 70-85 percent, fast response time, low cost of operation and maintenance, and opportunities to store a large amount of energy over many days” (Harby et al., 2013, p. 599; Winfield et al., 2018).

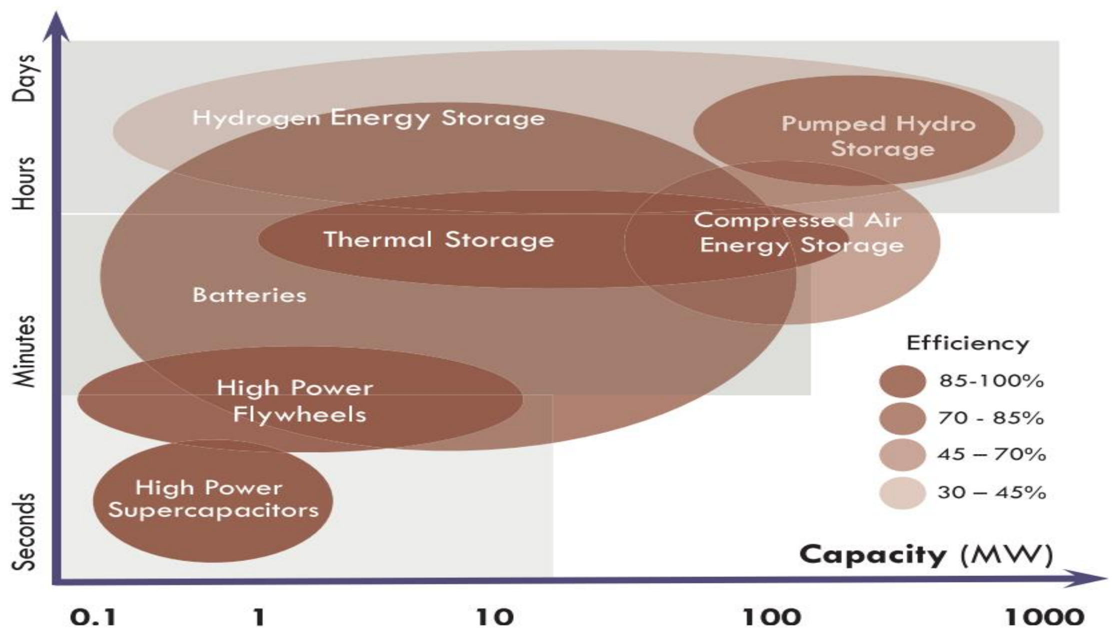


Figure 6.2: Different storage technologies and abilities of capacity, response time and efficiency *(Winfield et al., 2018, p. 573).*

The Norwegian energy system has opportunities to build a large amount of storage capacity with a storage technology with high quality. However, actors in the socio-political environment, the Norwegian politicians argue for the limited storage potential compared to the future development of renewable energy supply in Europe. They express the opportunities with natural gas to solve the intermittency problem in Germany. Norway is a large supplier of gas and the energy source is cleaner than coal and oil have opportunities to respond on fast on changes in peaks (Gullberg et al., 2014). However, with gas, there is a need for long-term contracts and significant upfront investments in infrastructure (Gullberg et al., 2014). It also has emissions and limited capabilities to create consumption. Therefore, Germany needs to include additional investment in carbon capture storage (CCS) to reach its ambitious targets.

The required cost of the German transition will increase with needed investment in gas infrastructures such as OPGT and CCGT and investment in a CCS plant that will limit the emission. Korpås and Wolfgang (2015) compared the cost of implementing the different storage solutions. The results suggested that pumped-storage had advantages over the other storage alternatives even when the cost for transmission cables where included. However, for pumped-storage to be beneficial there was a need for a large investment in cross-national transmission cables to Europe. In Norway, the electricity-intensive industry, customers and politicians fear higher electricity prices with cables connecting to Europe and are strongly opposed to the idea (Ask, 2019; Gullberg, 2013). Moreover, Statnett has no intentions to build more cables to Germany and UK before there is experience with the operation of the new cables and have no ambitions to make suitable conditions for a massive expansion of pumped-storage (Lie, 2012). Therefore, the pumped-storage have the technical potential for large-scale building, but limited interest to make suitable conditions for large-scale pumped-storage development.

For Germany, the implication is more self-sufficient energy system based no high amount of own renewable generation and a high amount of storage capacity from OPGT and CCGT (SRU, 2011). However, If the Energiewende fails due to high cost in the deployment of renewable energy and not able to cope with intermittency. Then nuclear power plants are shifted out with increased power generation of coal generation. Therefore, in the worst scenario for Germany without integration to Norwegian pumped-storage, there plans towards decarbonisation might be a failure. But there might find be another solution that has capabilities to cope with intermittency.

If one compares the operation of pumped-storage with the OPGT and CCGT. The OPGT and CCGT have high flexibly by being able to support the intermittency by turning on and off the supply fast. But, have limited potential to create consumption. With pumped-storage, the creation of consumption gives opportunities to allow more renewable electricity to be produced and trade between the states (Moser et, al 2015). In pumping, consumption is created by lifting the water up to higher reservoirs. However, consumption can also be created by increasing the electrification of the society and transmission cable giving the opportunity to transfer energy out of the countries. Nevertheless, pumped-storage is used in periods of a surplus of supply, which gives stronger abilities to support renewable power dispatch. Therefore, pumped-storage is a feasible solution to create a low-carbon energy system, But, domestically challenging in Norway due to limited ambitions. On the other hand, it is possible to combine pumped-storage with CCGT and OCGT. Figure 6.3 shows the interaction with pumped-storage integrated into the operation of CCGT and OCGT. CCGT have high cost and during low prices, the plant is turned off. The CCGT operates when prices are high due to variation in expenses. Norwegian pumped-storage support the operation of the technology by reducing the sluggishness in a dispatch by supporting with pumping and generation (Moser et al., 2015).

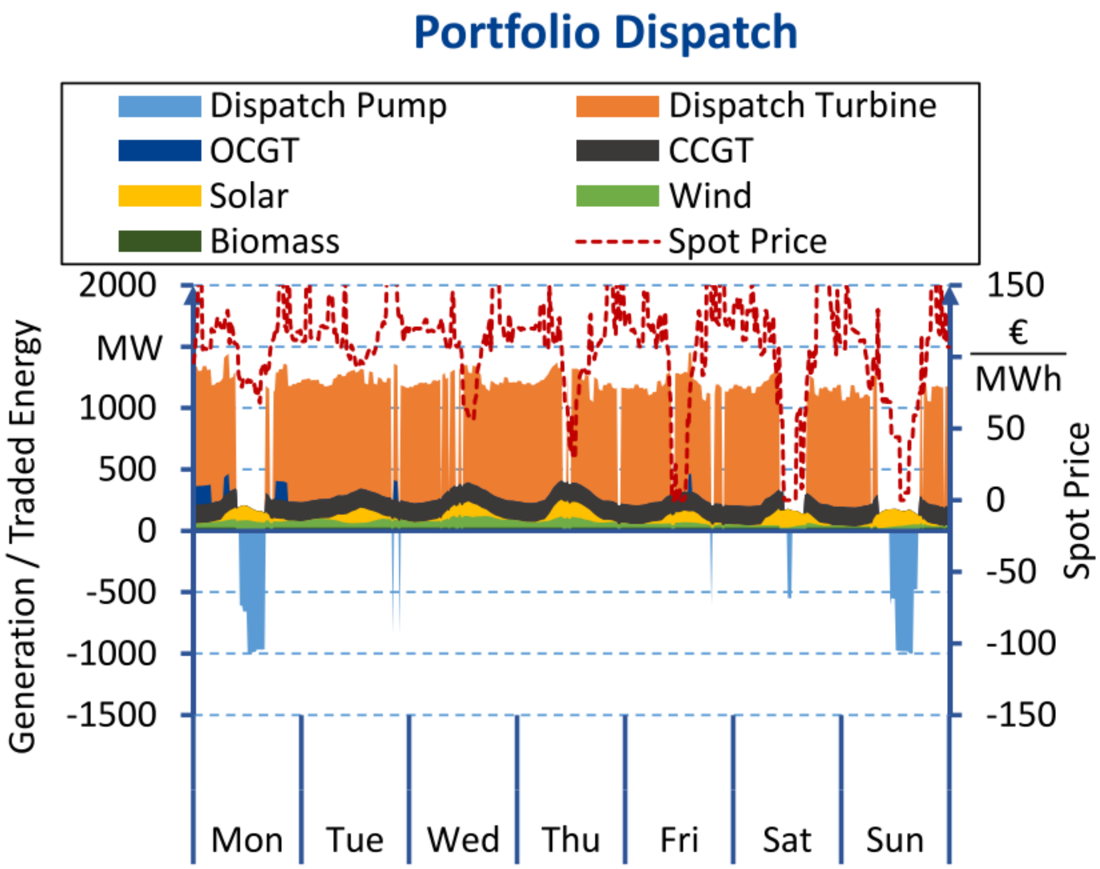


Figure 6.3: Norwegian pumped-storage integrated into German storage technologies*(Moser et al., 2015, p. 58).*

### 6.2 The conditions needed for utilities to implement pumped-storage

The Norwegian utilities believe that an implement of pumped-storage needs to be profitable. They argue that there should be opportunities for earning money on prices differences. However, currently the Norwegian power prices are stable due to ”high capacity of flexible and reliable hydropower, a small amount of intermittency in the power generation and relatively small capacity on the transmission cables” (van Hou et al., 2017, p. 31).

A turning point for pumped-storage might be the transmission cables coming in 2021. In Europe, there are larger differences in prices due to the generation from intermittent power generation. With the integration, it is expected that the integration will increase the volatility in Norway and decrease the price difference in the UK and Germany (van Hou et al., 2017). However, the utilities are not optimistic that the plans for expansion are enough to create differences in to make pumped-storage profitable. The technology needs a large upfront investment and energy is lost in the process of pumping. Therefore, there are no correct plans for the moment to do an installation of pumped-storage. The companies argue that it might be more likely in the future with increased cable and more development of solar and wind power in Europe.

Even if the integration creates enough differences in prices, technology has a long way to go before it gets implemented. Before the utilities can make installation, the power companies need to apply to NVE to get a concession. This process takes at least five years. When the process is and received an application the utilities can start the construction, which takes around 2-3 years. Therefore, in the best case, it takes eight years to have to build a pumped-storage and additional time needed to make the plant operational. Moreover, Lyse will first look at opportunities to build out more effect in existing hydropower plants to take advantage of prices differences, since this is cheaper and have been a tradition for the company.

In Europe, towards 2030 there are plans to expand the transmission network in Europe. This will make it possible to improve the transfer of electricity between the European states. Figure 6.4 shows the existing cable capacity and planned cables in Europe (van Hou et al., 2017). The expansion of the European network is likely to decrease the volatility in power prices, due to the smoother transfer of electricity between the countries (van Hou et al., 2017). Like for Germany, currently, the north has dominated share of supply from renewable energy, while the demand is in the south. The weak transmission gives reduces abilities to transfer and lead to variations in prices since there are weak opportunities for the electricity to move south in the country. With upgraded transmission network there is more potential for the electricity to flow to these areas.

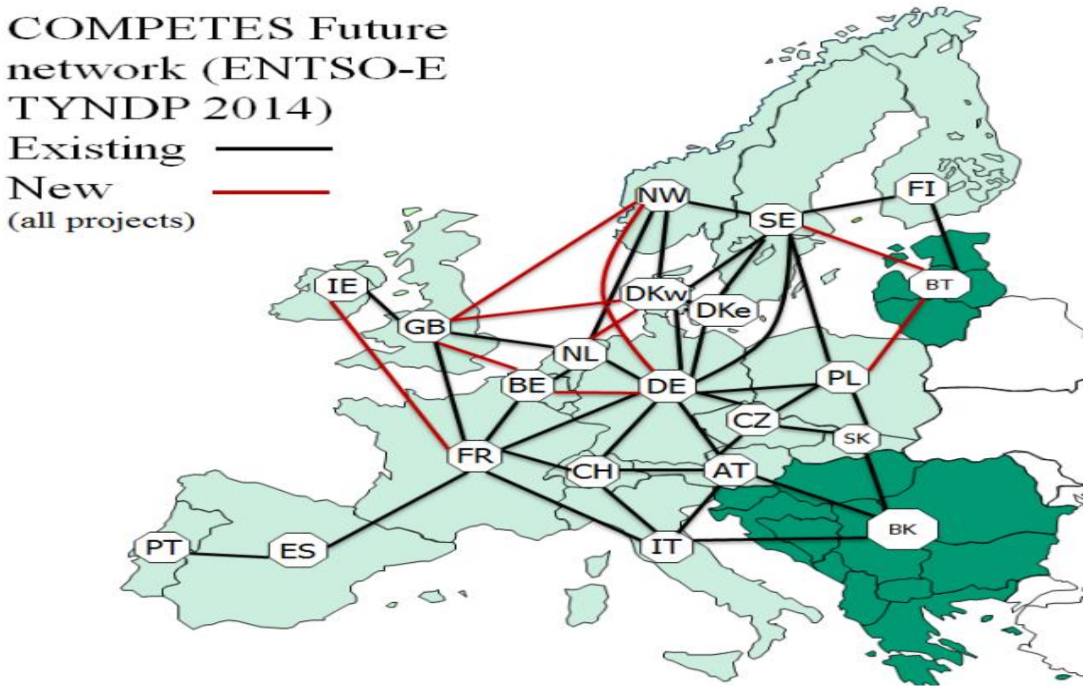


Figure 6.4: Representation of potential cross-border transmission links in 2030 with ENTOSO-E-TYNDP *(van Hou et al., 2017, p. 38).*

This might reduce the feasibility for pumped-storage to be installed. Currently, the utilities have low ambitions to build pumped-storage due to the low-price difference. If power prices decrease due to the improved transmission network. The utilities might be on even status quo or even have a worse situation for pumped-storage.

Then the opportunity for pumped-storage is the creation of differences from the new transmission cables that makes it able for more wind and solar to enter into Norway. However, van Hou et al. (2017) argues for a threshold for transmission capacity when there is improved network in EU. Table 6.1 shows two scenarios with different cable capacity. The scenarios have a higher volatility than the current situation. The niche storage has 10 MW transmission cable capacity and has higher volatility then big storage with 15 MW[2]. (van Hou et al., 2017).

| | Niche storage | Big storage | Current level |
|---|---|---|---|
| High prices | 65 | 65 | 36 |
| Low prices | 44 | 52 | 27 |
| Average prices | 54 | 59 | 32 |
| Delta difference | 21 | 13 | 9 |

Table 6.1: Volailtiy in prices *(van Hou et al., 2017, p. 24).*

There is much uncertainty in the creation of volatility and the potential future for pumped-storage. The opportunities may come with the cable connection in 2021. However, the utilities it is no very feasible that the utilities will take advantage of the potential opportunity, In the period towards 2030, there might be improvements in the transmission network in Europe giving decreased volatility in Norway, which give less attractiveness. However, the development might be more beneficial for utilities than the scenarios, since the capacity may not high enough to reduce the volatility. However, with the strategies with more effect, there might be a reduction in volatility in prices. Therefore, the developments towards 2030 are very uncertain when it comes if the best opportunity is in 2021 or to 2030 to build a pumped-storage. The utilities argue that is easier to follow the development of power prices, than calculating the price volatility.

## 6.3 The development of intermittent power generation in Norway

There is uncertainty about the likelihood for a Norwegian pumped-storage to support the European countries. However, pumped-storage might be needed for domestic support to cope with intermittency in Norway. With the technological improvements in solar and wind technology, it might be more attractive to build technology in the country. This development can give opportunities for future pumped-storage.

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[2] The volatility is also reduced due to factor such as more marked integration in both DA an ID and pumped-storage capacity in big-storage (Van Hou et al., 2017).

The potential development occurring can influence the utilities to need to implement pumped-storage. The utilities believe that there is limited potential for pumped-storage to be profitable in the support of Norwegian intermittency. In the Norwegian energy there already high amount of flexible hydropower capacity that will reduce the differences. The prices curve might have many low hours but might not be high enough to support a pumped-storage.

The utilities are divided when it comes to pumped-storage needed to support intermittency. Lyse and Statkraft believe in the capabilities in Norwegian hydropower plants to support the intermittency in Norway. On the other hand, Agder Energi and Skagerak Energi address that there are strong capabilities in hydropower plants to support intermittency, but the pumped-storage technology might be needed in surplus periods of intermittent power production.

From the perspective of Agder Energi and Skagerak Energi, a future pumped-storage depends on the future consumption level in Norway. This is especially addressed by Skagerak Energi. they base their decision to build pumped-storage on profitability and future consumption level. If there is not enough consumption in Norway to utilize the supply, there might be problems with overproduction.

In some circumstances, there might be a need for a pumped-storage to support domestic intermittency. With wind technology, there are opportunities to stop the production of energy. Then a pumped-storage is used to increase the generation of wind by giving opportunities for more energy to be put into the system. The effect from hydropower plants can play a significant role to adjust the production after need. However, if there is oversupply for wind more then there is consumption the windmills will stop to operate. On the other hand, in a scenario with increased prosumers, which consumes and produces solar power. Then there may be a need for increased consumption in Norway in periods of surplus. Therefore, pumped-storage might be feasible even if the utilities doubt that it will be profitable since it needs to handle overproduction. But, the likelihood for the scenario depends on transmission cable capacity to Europe, solar power development and the electrification.

## 6.4 The Perception of the industry regime

The analysis suggests that the knowledge of operating hydropower plants give shared perception between the utilities. The utilities see the technology as a future opportunity in a power marked with increased penetration of solar and wind and need differences in prices to make investments feasible. However, there is a tendency of differences, which might be explained by specific technological competence. Lyse and Statkraft are the organisations that argue much about the opportunities to increase the effect by upgrading the turbine and pump between the reservoirs. Lyse addresses that when price differences occur, they will start upgrading effect since this has been a tradition for the Lyse. This has also been a long tradition in Statkraft. The competence on effect can from the perception from Norwegian utilities about pumped-storage and may keep the company on the trajectory that makes them path-dependent and locked-in by not addressing the problems and limitations for hydropower in extreme cases. However, they both see pumped-storage as an opportunity. But would likely not be the first to install a pumped-storage, if the problems are the need for additional consumption.

On the other hand, Skagerak Energi and Agder Energi also are interested in upgrading effect, since it is cheaper than building pumped-storage. However, these companies address the limitations of Norwegian effect. Especially, Skagerak Energi that is the only organisation that addresses limitation with effect in hydropower plant by addressing minimum and maximum water level in hydropower plants.

There might have been a difference in technological capabilities and competence. However currently NVE (2018) is predicting the limited potential for solar power in Norway. The informants might different perception about the opportunity with solar power, instead of having different believes on hydropower. Moreover, there is potential that increased electrification will create increased consumption giving less need for pumped-storage. Therefore, these developments can influence more on them than competence and technological capabilities.

The organisations have similar values by orienting towards renewable energy and objectives to provide their owners with profits. This is very likely to form the main objective of pumped-storage. The utilities address that the aim is to make profits out of the technology. The profits come through utilizing the process of pumping and producing. Figure 6.5 illustrates a weekly operation in correlation with spot prices. With periods of high prices, water is used as a hydropower plant. In the low prices periods, the pump is activated to lift the water up to higher reservoirs (Moser et al., 2015).

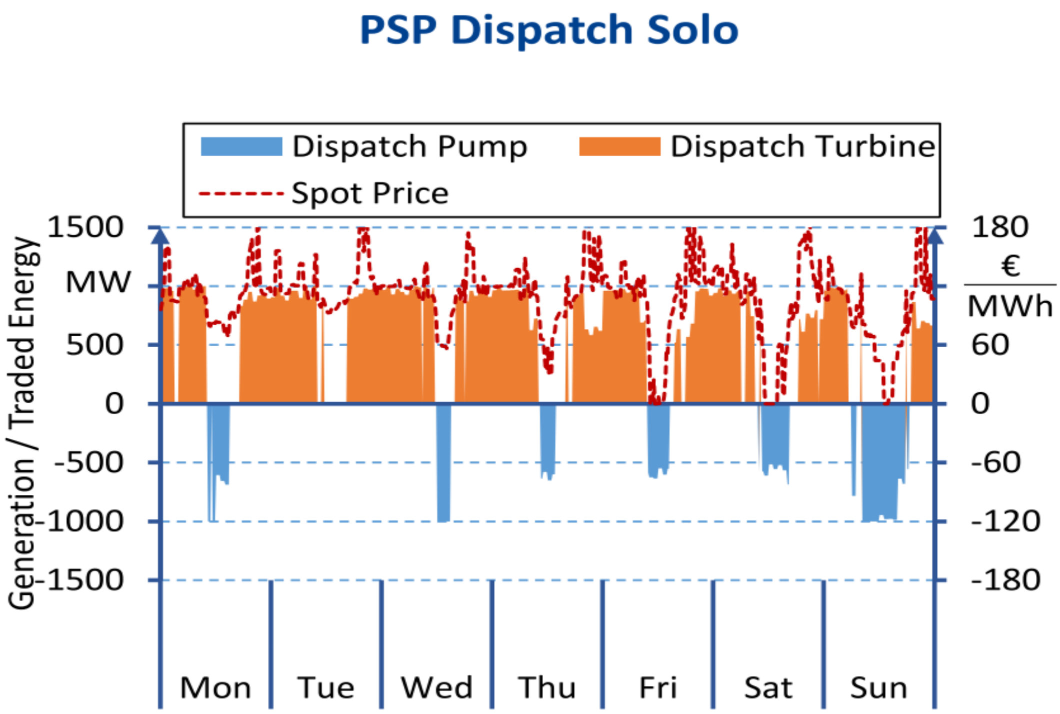


Figure 6.5: The dispatch of a Norwegian pumped-storage *(Moser et al., 2015, p. 52)*.

# 7. Conclusion

The thesis suggests that the likelihood of building a Norwegian pumped-storage, which can support intermittent wind and solar, is feasible under certain circumstances. The technology is needed to support increased intermittency from renewable energy. The technology has the potential to cover similar needs both for European states and domestic support. For European, more specific for Germany, the Norwegian pumped-storage is used in periods with a surplus with a large dispatch of solar and wind power. The pumped-storage will support the surplus by creating additional demand through pumping, This will increase the energy trade and allow more renewable energy into the system. (Moser et al., 2015). In Norway, the technology is needed in a scenario with increased development of renewable solar and wind. In surplus periods from wind and solar energy, there is a need to create additional consumption, else it would lead to overproduction.

The Norwegian utilities Lyse, Statkraft and Agder Energi believe that about pumped-storage need to be profitability by taking advantage of differences in power prices. In the short-term, the transmission cables that are connecting to Europe have the potential to create larger differences by integrating with a power dispatch with fluctuations. This can be increased price differences in Norway making it profitable to taking advantage of differences between low and high power prices. However, the utilities are uncertain if there are enough systematic and large differences to make the technology profitable since there is a need for a large upfront investment and energy are lost through the pumping phase. While for Skagerak Energi the technology it needs to be profitable, but the future consumption level will also determine the need for the technology.

Concerning future developments, the paper suggests that future attractiveness of pumped-storage from the Norwegian utilities. Depends on the development of the European energy transition and the price differences created by the integration of the cables in 2021. These developments will have the potential to make pumped-storage profitable. In the future, the volatility has the potential to increase with more cable, but more network improvements in Europe might be a barrier that reduces the power price difference. This development can give challenges for the utilities if they have plans to build pumped-storage.

The decisions taken by the Norwegian utilities might have implications on the developments in Germany. It, the country need storage technology and Norway was a feasible solution to support intermittency. But limited willingness from Norwegian utilities and struggles from Norwegian politicians and customers. Reduces the likelihood for Germany to benefit from a massive expansion of pumped-storage, but in a smaller scale with support to the gas storages could the feasible scenario for pumped-storage, but it depends on the future price volatility fro Norwegian utilities.

In Norway, there is a potential future challenge occurring with a future a trajectory towards increased solar power. In surplus periods there might be a need for a pumped-storage to cope with the intermittency of solar power. Then the technology is used to create additional consumption. However, The increased consumption also has the potential to come from other feasible solutions such as increased electrification. Then there will be less need for a pumped-storage used for domestic support.

A suggestion for further research is to investigate the need for a domestic pumped-storage. The aim of the research might be to identify the need for a pumped-storage to support increased wind and solar development in Norway. Pumped-storage can be needed to support intermittency if there is not enough consumption in Norway to cope with the surplus of wind and solar power. It could explore different scenarios with increased prosumers in Norway, the electrification and transmission cable capacity.

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# Appendix

## A1. List of interviews

| Interview | Position | Interview situation | Date | Place | Duration |
|---|---|---|---|---|---|
| Agder Energi | Senior advisor | Face-to-Face | 06.05.19 | Kristiansand | 51 min |
| Lyse | Leader | Face-to-Face | 02.05.19 | Stavanger | 40 min |
| Skagerak Energi | Leader | Telephone | 13.05.19 | X | 35 min |
| Statkraft | Production planer(former leader) | Face-to-Face | 20.05.19 | Oslo | 31 min |

## A2. Interview guide

# Intervjuguide

| | |
|---|---|
| Samtykke<br>-Samtykke til bruk av lydopptak<br>-Samtykke til deltakelse, | Informantens rettigheter<br>-når som helst trekke seg,<br>-trenger ikke svare på spørsmål,<br>-kan få innsyn i registrert informasjon<br>-få slettet eller rettet på informasjon<br>-rett til å sende klage. |
| Informasjon om prosjektet | Premisser<br>- Norge har sesongbaserte pumpekraft.<br>- Pumpekraftverk som løsningen til økende fornybar energi i utlandet og muligens innenlands<br>- Har vært tidligere vært sendt en konsesjonssøknad |
| Hoveddel 1 Oppfattelser | Hvilke muligheter kan et pumpekraftverk gi for bedriften?<br>Hvordan passer teknologien med bedriftens verdier og rolle i samfunnet?<br>Hvordan kan pumpekraftverk integreres i deres vannkraftverk?<br>Hvordan er dagens regleringer tilrettelagt for pumpekraft? |
| Hoveddel 2 Betingelser | Ser du for deg at pumpekraftverk er en del av Norges fremtidige energisystem?<br><br>Hvilke betingelser er nødvendig?<br><br>Hvordan forholder bedriften seg strategisk til betingelsene?<br><br>Hva tenker du om en eventuell motstand?<br><br>Er vannkraft/pumpekraftverk den beste løsningen for å støtte varierende energikilder i Tyskland. Hva tenker du om andre løsninger?<br><br>Hvordan evaluerer du økt mengde av vind og sol i Norge og muligheten for pumpekraftverk? |
| Avslutning | Oppsummering, har jeg forstått deg riktig<br>Er det slik at..<br>Er det noe du vil legge til? |

## A3. Cover letter

**Forespørsel om intervju.**
Jeg arbeider for tiden med en masteroppgave om muligheten for pumpekraftverk i Norge som støttefunksjon til økende fornybar energi i Norge og utlandet. Formålet er å undersøke om det er gjennomførbart å bygge pumpekraftverk i Norge. Undersøkelsen bruker The Multi-level perspective, The Triple embededdeness Framework og ulike forretningsstrategier som teoretisk rammeverk. Intervjuet vil han en varighet på 45 til 60 minutter og danner grunnlaget for en Masteroppgave i studieprogrammet Energi, miljø og samfunn ved Universitetet i Stavanger (UiS), der instituttet for medie- og samfunnsfag er behandlingsansvarlig for prosjektet.

Utvalget består av ledere i ulike elektrisitetsselskaper og deres syn på mulighetene for et pumpekraftverk. Datainnhentingen baserer seg på dokumenter og intervjuer. Intervjuet vil bli tatt opp på bånd dersom du godkjenner dette, og informasjon blir kun brukt til oppgavens formål, og behandlet konfidensielt og i samsvar med personvernregelverket. Lydopptaket kommer til å bli slettet etter at oppgaven er ferdig. Informasjonen fra intervjuene er det kun undertegnede og veileder som har tilgang til, og blir lagret i UiS sitt IT- system og følger UiS sine personvernregler. Når masteroppgaven avsluttes den 14. juni, blir all data anonymisert.

**Forespørsel om deltakelse.**
Der er frivillig å delta på intervjuet, og dersom du takker ja kan du når som helst trekke deg fra undersøkelsen, uten å måtte oppgi grunn helt frem til prosjektets slutt. Hvis du ønsker å trekke deg, vil alle opplysninger om deg bli slettet.

Så lenge du kan indentifiseres i datamaterialet har du ulike rettigheter, som å få innsyn i dine registrerte personopplysninger, få rettet eller slettet personopplysninger, få utlevert en kopi av dine personopplysninger, og har rett til å sende klager til personvernombudet eller datatilsynet om behandlingen av personopplysninger. Min rett til å behandle dine personopplysninger kommer fra ditt samtykke om deltagelse i undersøkelsen. I tillegg har Norsk senter for forskingsdata AS (NSD) vurdert at behandlingen av personopplysninger i prosjektet er i samsvar mer personvernregelverket. Hvis du ønsker å vite mer om prosjektet eller ønsker å benytte deg av dine rettigheter, ta kontakt med:

- Uis student, Christer Ersdal Munthe på telefonnummer 48209303, eller epost c_e_munthe@hotmail.com, eller veileder Professor Oluf Langhelle på epost oluf.langhelle@uis.no.
- NSD- Norsk senter for forskningsdata AS, på epost (personvernombudet@nsd.no) eller på telefon: 55582117.

Med vennlig hilsen

| | |
|---|---|
| Christer Ersdal Munthe | Oluf Langhelle |
| Student | Professor |