MARCO
Research and Innovation Action (RIA)

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 730272.

Start date: 2016-11-01 Duration: 24 Months

Case Study 4 Report: Wind & Solar Energy

Authors: Ms. Bay LISA (DTU), Ms. Kirsten Halsnæs, DTU
Summary

This case study explores how improved climate services for hydropower based electricity production in the Nordic countries can support a more efficient electricity market. The case study focuses on hydropower, since this source of renewable energy largely dominates the Nordic electricity market, and thereby market possibilities for wind energy and solar. The large hydropower reservoirs and production capacity, particularly in Norway, can serve to balance the more volatile production by means of other renewable energy sources, such as solar and wind power. Skillful seasonal forecasts are therefore important to forecast the inflow to the hydropower reservoirs; the amount of potential power production. However, not only production but also demand of electricity is highly weather and climate dependent. Demand is especially affected by temperature (due to demand of electrical heating and cooling), while hydropower production is directly linked to precipitation and snowmelt. According to various stakeholders in the renewable energy supply chain (hydropower producers, TSOs and researchers), decisions are taken based on historical data rather than forecasts. On this background, the case study demonstrates how improved climate service information for the Nordic electricity market can support both short- and longer-term market improvements, implying economic gains and climate risk reduction.
# Table of Contents

1 Executive summary ........................................................................................................... 3

2 Background .......................................................................................................................... 3
   2.1 Definition of the sector ................................................................................................. 3
       2.1.1 The Nordic and Baltic power market ................................................................. 3
       2.1.2 Climate Services in the context of Nordic electricity markets ......................... 6
       2.1.3 Nord Pool Spot Market ..................................................................................... 6
       2.1.4 Trading electricity at the financial markets ...................................................... 7
   2.2 Overview of the Sector Climate Risks ......................................................................... 8
       2.2.1 Hydropower production ..................................................................................... 9
       2.2.2 Wind power production .................................................................................... 9
       2.2.3 Solar energy production ................................................................................... 10
       2.2.4 Power consumption ......................................................................................... 10
       2.2.5 Value chain of electricity from renewable energy sources ............................. 10
   2.3 Similar sectors and regions ......................................................................................... 12

3 Characterising the market ................................................................................................ 14
   3.1 Stakeholder mapping ................................................................................................. 14
   3.2 Market quantification ............................................................................................... 16
       3.2.1 Producers .......................................................................................................... 16
       3.2.2 Transmission System Operators ..................................................................... 16
       3.2.3 Energy traders .................................................................................................. 17
       3.2.4 CS suppliers ...................................................................................................... 17

4 Climate Services: demand, supply and use .................................................................... 18
   4.1 Climate services demand (present) .......................................................................... 18
       4.1.1 Producers of electricity from renewable sources ............................................. 19
       4.1.2 TSOs’ use of climate services ......................................................................... 20
       4.1.3 Market traders .................................................................................................. 21
   4.2 Existing climate services supply .............................................................................. 21
       4.2.1 Meteorological institutes .................................................................................. 21
       4.2.2 Private consultancy companies ...................................................................... 22
       4.2.3 Research institutes .......................................................................................... 23
   4.3 Unmet needs ............................................................................................................... 23
   4.4 Empirical assessment ............................................................................................... 25

5 Framework Conditions ..................................................................................................... 28
   5.1 Governance ............................................................................................................... 28
       5.1.1 National framework .......................................................................................... 28
       5.1.2 European framework ....................................................................................... 29
   5.2 Finance ....................................................................................................................... 29
   5.3 Collaboration with CS Suppliers .............................................................................. 29
   5.4 Research and knowledge ......................................................................................... 30
   5.5 Decision making ....................................................................................................... 30

6 Conclusions ....................................................................................................................... 31

7 Bibliography ...................................................................................................................... 31

---

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No 730272
List of Figures

Figure 1. Electricity generation by source in 2015, percentage of total ................................................. 4
Figure 2. Share of electricity generation from various sources. Total in Nordic countries ......................... 4
Figure 3. Share of electricity generation by countries .................................................................................. 4
Figure 4. Hydropower reservoir level in the Nordic countries (2013-2017) .............................................. 5
Figure 5. Reservoir levels in the Nordic countries (2013-2017). (year-to-year variation) ........................... 5
Figure 6. Nord Pool Spot Market system prices ......................................................................................... 6
Figure 7. Surplus/deficit of electricity production ...................................................................................... 6
Figure 8. Overview of climate change risks and opportunities on renewable power conversion .............. 8
Figure 9. Projected impacts of climate change on electricity production .................................................. 12
Figure 10. Stakeholders in the renewable energy supply chain ................................................................. 14
Figure 11. CS suppliers on energy (incl. renewables) ................................................................................ 18
Figure 11. Total annual inflow (in TWh) to the Norwegian hydropower system ........................................ 26
Figure 12. Examples of seasonal forecast skill based on a simple statistical model ................................. 27
1 Executive summary

This case study explores how improved climate services for hydropower based electricity production in the Nordic countries can support a more efficient electricity market. The case study focuses on hydropower, since this source of renewable energy largely dominates the Nordic electricity market, and thereby market possibilities for wind energy and solar. The large hydropower reservoirs and production capacity, particularly in Norway, can serve to balance the more volatile production by means of other renewable energy sources, such as solar and wind power. Skillful seasonal forecasts are therefore important to forecast the inflow to the hydropower reservoirs; the amount of potential power production. However, not only production but also demand of electricity is highly weather and climate dependent. Demand is especially affected by temperature (due to demand of electrical heating and cooling), while hydropower production is directly linked to precipitation and snowmelt. According to various stakeholders in the renewable energy supply chain (hydropower producers, TSOs and researchers), decisions are taken based on historical data rather than forecasts. On this background, the case study demonstrates how improved climate service information for the Nordic electricity market can support both short- and longer-term market improvements, implying economic gains and climate risk reduction.

2 Background

The sectoral focus of the Danish renewable energy case study is on the Nordic hydropower production. Danish electricity production is highly integrated and interrelated with the Nordic electricity market, on which hydropower is by far the most dominating source of electricity generation. Denmark has no hydropower production and is as such to a very large degree price taker in this context. However, to ensure balance between demand and supply within and between borders, there is a need to forecast production in the whole Nordic power system, where hydropower is dominating. Improved climate services in terms of forecasts on hydropower production potential should lead to optimized balancing of supply and demand in both Denmark and in the Nordic as a whole. Thus, in this case study, we focus on how climate services can support more efficient markets for electricity from renewable energy sources in the context of Nordic electricity markets.

2.1 Definition of the sector

2.1.1 The Nordic and Baltic power market

Norway, Sweden, Finland and Denmark have since the early 1990s co-operated to secure their populations with electricity supply and to make use of power system resources in the most optimal way by bringing the individual markets together into a common Nordic market, the Nord Pool Spot market (Nord Pool ASA, 2004). Between 2010-2013, Estonia, Latvia and Lithuania joined the Nord Pool market. Figure 1 provides an overview of the present electricity production sources in the seven countries, and illustrate the share of
renewable energy (IEA Statistics, 2015). As illustrated below, renewable energy contributes as a major electricity source in all Nordic countries, with a share of about 50% in Denmark (mainly wind), about 65% in Sweden (wind and hydro), almost 99% in Norway (hydro), and about 30% in Finland (wind and hydro). In the Baltic countries the share of renewables are smaller. However, according to national plans, renewable energy will have an even larger part of the power supply system in the coming years.

![Figure 1. Electricity generation by source in 2015, percentage of total (EIA, 2015)](image1)

The importance of hydropower in the Nordic electricity production is demonstrated by figure 2, while figure 3 illustrates the electricity generation (in TWh) by country, highlighting the relative sizes of national market.

![Figure 2. Share of electricity generation from various sources. Total in Nordic countries (based on EIA, 2015)](image2)

![Figure 3. Share of electricity generation by countries (based on EIA, 2015)](image3)
From the figures, the major role of hydropower is clearly seen. The Nordic hydropower-based electricity production is so dominant (hydropower accounted for 55% of total power generation in 2015, see figure 2) that this electricity source has a major role in the Nordic power market. This implies that the hydropower supply is dominating the electricity prices at the market. The storage capacity in hydropower reservoirs enables the utilities to supply electricity when prices are particularly favorable. At the same time, all other electricity suppliers have to a large extent to take the prices as given. Evidently, climate service information on hydropower production potentials are very important for a wide range of electricity suppliers and market stakeholders within the Nordic region.

The year-to-year variation in hydropower reservoir influx can amount to ±20 TWh. This is a significant amount of energy, compared to, e.g., the total Danish annual electricity consumption of less than 40 TWh (Nord Pool ASA, 2004). The hydropower reservoir levels and hence the production capacity is thus highly affected by large variations in inflow. The reservoir levels are shown in figure 4 and 5. In the period 2013-2017, hydropower reservoir levels varied ±10 TWh from mean level with 2015 showing above average level during summer and 2013 experiencing low reservoir levels during both spring and summer time. Since hydropower production dominates the Nordic market, variation in hydropower production capacity is one of the main causes of seasonal variations in prices on the Nord Pool spot market (Nord Pool ASA, 2004). Conversely, the inter-annual variations in other renewable energy sources such as wind power are relatively small compared to variations in hydropower.

![Figure 4](image1.png)  
**Figure 4.** Hydropower reservoir level in the Nordic countries (2013-2017). Weekly mean level (solid line) and standard deviation (dashed line). Source: Nord Pool Spot.

![Figure 5](image2.png)  
**Figure 5.** Reservoir levels in the Nordic countries (2013-2017). (year-to-year variation). Source: Nord Pool Spot.
2.1.2 Climate Services in the context of Nordic electricity markets

Setting Nordic electricity market prices depend to some extent on climate services, since forecasts provide important information to producers on supply and demand as well as to traders on when and how much to buy and sell to which price. As temperature affect heating and cooling demand, and precipitation and wind affect whether power plants are producing to full capacity, supply and demand balancing are largely affected by weather conditions: when energy production exceeds what is expected, this will influence prices down and vice versa. Thus, the more correct forecasting of supply and demand, the more stable prices. As an example, in the summer 2013 less precipitation than normal came. Furthermore, the energy stored as snow was also lower than normal, which both contributed to a lower maximum reservoir level than normal (see Figure 5). Due to this hydrological situation, prices increased by 22% from 2012 to 2013. The highest price occurred in April, when temperatures were low (see figure 6). This happened because low temperatures led to a higher consumption, but also to a delayed melting of snow to the reservoirs (see Figure 5). When the temperature increased and the spring thaw arrived, prices dropped again (NordREG, 2014; figure 6).

![Figure 6. Nord Pool Spot Market system prices. Source: Nord Pool Spot.](image1)

![Figure 7. Surplus/deficit of electricity production. Source: Nord Pool Spot](image2)

2.1.3 Nord Pool Spot Market

The Nord Pool Spot is the market place for short-term trade in electric power contracts for physical delivery, primarily servicing the players at the wholesale market for electricity (Nord Pool Spot, 2014). Nord Pool Spot covers Denmark, Finland, Sweden, Norway, Estonia, Latvia and Lithuania. The customers on the Nord Pool Spot are both producers, retailers, and traders. Furthermore, large end-users of electricity trade on the Nord Pool Spot market to buy their electricity directly from the wholesale market instead of the retail market (Nord Pool Spot, 2014).
On the Nord Pool Spot, trading with contracts happens both at a day-ahead market and an intraday market, which means that electricity is bought and sold hourly (Nord Pool Spot, 2014). The wholesale markets provide key price signals, which affect the choices of producers and consumers, as well as investment decision in production facilities and infrastructure (NordREG, 2014).

The electricity spot prices are volatile due to several factors: electricity cannot be stored efficiently and demand for electricity is uncertain and inelastic (Deng & Oren, 2006). As the production of power from renewable energy sources increases, the need for adjusting short-term balancing of supply and demand will grow. Furthermore, when electricity production is increasingly based on production from renewable energy sources, electricity spot prices will be even more volatile, due to the volatile nature of renewable electricity production compared to production from traditional fossil-based electricity.

Since electricity is non-storable, it has to be consumed when it is produced, and supply and demand must balance at all time. This had led to a transparent market in terms of demand, available generation capacity, and the cost of generation (Füss et al., 2015). But it also implies that spot prices are determined on the basis of balancing demand and supply instantly, without the possibility to store electricity/withhold some from the market for ‘better times’ based on forward-looking information, e.g. an expected outage (Füss et al., 2015).

In general though, the ability of the Nordic and Baltic power system to store energy in hydro reservoirs has a cushioning effect on prices. Inflow of water to the reservoirs during summer and in periods with low demand can be stored and used in the wintertime with less inflow and higher demand. Figure 7 depicts the difference between production and consumption (2013-2017; the colored lines represent the different years and uses the same legend as in figure 6). It shows that the gab is varying with up to ±400 GWh, which is a relatively low number compared to the total amount of produced electricity. As a comparison, the German price structure is more variable than the Nordic, due to the high share of wind power in Germany (NordREG, 2014).

### 2.1.4 Trading electricity at the financial markets

Long-term trade of electricity in the Nordic market is a financial product on Nasdaq OMX (NordREG, 2014). The financial products are futures, forwards and options, with contracts having a time horizon up to ten years, covering daily, weekly, monthly, quarterly and annual contracts (Nord Pool, n.d.a).

Electricity forward and futures contracts represent supply contracts between buyers and sellers, where the supplier is obliged to supply a certain amount of power at a pre-determined price to buyers, who are obliged to buy this amount of power at the pre-determined price (Deng & Oren, 2006).

There is no physical delivery for financial electricity contracts. However, in the financial market, participants can secure prices for future purchases or sales of electricity (NordREG, 2014). Financial contracts are in this way used for price hedging and risk management. The large Swedish energy company, Vattenfall, report that they continuously hedge future electricity generation through sales in the forward and futures markets. Spot prices therefore only have a limited effect on Vattenfall's earnings in short-term (Hall & Dohler, 2016). The financial market gives important price signals to hydropower producers on how to dispose the energy stored in their reservoirs. When trading electricity, traders have to know how the market will be at each point in
time. Thus price forecasts based on historical data, not considering important forward-looking information, will have substantial pricing errors leading to financial losses (Füss et al., 2015).

The present limited precision of forecasts is reflected in how traders or speculators increase their gains on the energy trading market. Here traders on the wholesale and financial markets can gain high market returns at high risk. In 2013, the volume traded on the financial market was 4.7 times the volume of the physical market (NordREG, 2014), implying a large interest in these financial products.

Market participants are becoming more aware of the importance of risk hedging in the electricity market through long-term futures and forward contracts (Deng & Oren, 2006). The risk posed by climate change to the renewable energy sector is described in the next section. This highlights the need for improved climate forecasts for both producers and grid operators, but also traders and others in the value chain to ensure future security of supply.

2.2 Overview of the Sector Climate Risks

Climate change is expected to have significant impacts on renewable energy sources with respect to both their production potential and the climate-related risks. These impacts are expected to increase over time with a changing climate. Climate service information on future change and variability in renewable energy sources are therefore important for future electricity markets. Figure 8 provides an overview of risks and opportunities of hydropower, wind power and solar energy production potential.

![Figure 8. Overview of climate change risks and opportunities on renewable power conversion in the Nordics (based on Troccoli, 2014)]
As shown in figure 8, renewable power production is affected both by gradual changes in climate over decadal to longer time frames as well as to extreme weather events, which might be intensified and more frequent with time. Detailed impacts are described below.

2.2.1 Hydropower production

Research studies have concluded that hydropower systems in the Nordic countries will be strongly affected by projected climate change (Chernet et al., 2013; Thorsteinsson & Björnsson, 2012). Projected climate change can change the hydrological cycle of hydropower production. Higher temperatures will lead to less snow coverage. With a smaller snow coverage and a predicted higher amount of precipitation will result in an increased river flow during winter, but to a lower during summer, where the inflow from melting snow will be smaller. This also lead to a shift towards earlier flow peak from snowmelt and lower peak volumes in the future (Gimbergson, 2017).

Both total runoff and the timing affects hydropower production, thus an increasing climate variability is likely to affect hydropower production potential, even with no change in annual runoff.

In general, the potential for hydropower production is projected to increase in the Nordic region towards the end of the 21st century (Bonjean Stanton et al., 2016). With an increasing hydropower production, the energy market and the balancing of produced electricity from other renewable sources is likely to be increasingly dependent on variations in hydropower and as well as other climate impacts affecting this sector.

Hydropower production performance also depends on several other factors such as operation strategies, reservoir design and dam safety, and distribution of flood and droughts, which are all factors that are vulnerable to climate change and climate events. A Nordic study by Thorsteinsson & Björnsson (2012) showed that climate change might significantly affect dam safety and flood risks, which is very likely to influence future design and operation of hydropower plants.

2.2.2 Wind power production

Since climate change can affect average wind speeds, wind power production is also sensitive to climate change. Increasing average wind speeds would in general lead to increased wind power production, whereas decreasing average wind speeds would decrease wind power production (Lemaitre, 2013). In the Nordic region, annual wind electricity generation is projected to increase in the near-term to the end of 21st century. Furthermore, electricity generation is projected to increase in summer months (Bonjean Stanton et al., 2016). However, an increase in average wind speed might also mean an increase in strong/extreme winds. Strong winds can lead to periods where the wind turbines are stopped, or even lead to a higher risk of destruction of the turbines (Lemaitre, 2013), thus periods with lower wind power generation. Therefore, information on
extreme or strong wind speeds is important for the structural design of wind farms, as well as for the planning, operation and maintenance of the wind farms (Thorsteinsson & Björnsson, 2012).

2.2.3 Solar energy production

Especially cloud cover and temperature are important factors influencing the performance of solar energy production. Gradual changes in cloud cover can influence solar energy production potential, but while photovoltaic cells and solar water heaters can produce electricity despite a certain degree of cloud cover, concentrated solar power systems need full sunlight to be able to produce electricity (Lemaître, 2013). As part of a Nordic project on solar power plants (called NorthSol), research partners at Luleå University of Technology (LTU) investigated how the power grid in Scandinavia could be challenged by large installations of photovoltaic power. They found that one passing cloud could cause a big drop in production, resulting in rapid voltage variations (Nordic Energy Research, 2016). In addition, solar power production is affected by temperature. In general, increasing temperatures will lead to a decrease in power production, since higher temperatures have a negative impact on the efficiency of solar power production: When the temperature drops by 20°C, energy production rises by about 10 per cent (Nordic Energy Research, 2016). The risk of extreme events, such as storms and heavy precipitation, increase the risk of destruction of the solar energy production equipment (Lemaître, 2013).

2.2.4 Power consumption

Climate variabilities do not only affect power generation, but also power consumption. Historically, electricity prices have been low in the Nordic electricity market, because of the high share of hydropower combined with nuclear power (NordREG, 2014). This has led to a large share of houses heated by electricity, especially in Norway and Sweden (NordREG, 2014). For this reason, the demand for electricity is especially affected by variations in temperature, which is a main price driver in the Nordic countries (NordREG, 2014). Cold temperatures raises heat demand, while warmer winter temperatures decrease the demand for heating (Golombek, Kittelsen, & Haddeland, 2012).

2.2.5 Value chain of electricity from renewable energy sources

It is seen from the table 1 below that climate risks and opportunities in the renewable energy sector does not only affect the production and the consumption of power, but several factors throughout the value chain identified in this case study. Changes in the production will affect other economic sectors indirectly, such as the manufacture of turbines, pumps, solar cells and other equipment for the construction of new production capacity. Changes in the production will also affect the necessity of repair of existing equipment along with installation of equipment. In addition, climate change poses a risk to the transmission and distribution of power. The energy grids are challenged by changes in seasonal and regional consumption patterns, but also physical effects of extreme weather events (European Commission, 2013). The increasing share of renewable
energy challenge the grid operation even further, since the integration of these sources requires a new level of balancing due to their volatile production. Transmission lines in coastal areas or as off-shore installations will be affected by sea level rise, changes in the ocean currents and coastal erosion. The sea level rise will lead to an increase in the effect of storm surges posing a higher risk to the energy infrastructure (European Commission, 2013). Damage from extreme events to the energy transmission and distribution infrastructure can potentially have wide economic consequences (European Commission, 2013).

An analysis of the different sub-sector activities dependency on Climatically Sensitive Infrastructure and Systems (CSIS) can be found in Annex 8.

Table 1: Value chain analysis of electricity from renewable energy sources

<table>
<thead>
<tr>
<th>Input Supply</th>
<th>Production</th>
<th>Trading</th>
<th>Transport</th>
<th>Processing</th>
<th>Consumption</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natural resources (precipitation, wind and solar radiation)</td>
<td>Production of electricity (D 35.11)</td>
<td>Trade of electricity (D 35.14)</td>
<td>Transmission of electricity (D 35.12)</td>
<td>Repair of machinery and equipment (C 33.1)</td>
<td>Household consumption</td>
</tr>
<tr>
<td></td>
<td>Manufacture engines and turbines (C 28.11)</td>
<td></td>
<td>Distribution of electricity (D 35.13)</td>
<td>Installation of machinery and equipment (C 33.1)</td>
<td>SME consumption</td>
</tr>
<tr>
<td></td>
<td>Manufacture of pumps (C 28.13)</td>
<td></td>
<td></td>
<td></td>
<td>Large customer consumption</td>
</tr>
<tr>
<td></td>
<td>Manufacture of construction (C 28.92)</td>
<td></td>
<td></td>
<td></td>
<td>Exports</td>
</tr>
<tr>
<td></td>
<td>Construction (F)</td>
<td></td>
<td></td>
<td></td>
<td>Imports</td>
</tr>
</tbody>
</table>

Note: NACE Rev. 2 codes in brackets
2.3 Similar sectors and regions

The use of climate services is not only important to hydropower production in a North European context. In 2015, the share of electricity from renewable energy sources was about 30% in Europe (Eurostat, 2017), where the largest renewable energy sources were hydropower and wind power (14% and 13% of total primary energy production respectively) (Eurostat, n.d.). Figure 9 below shows how projected impacts of climate change will affect the renewable energy producers in Europe differently.

From Figure 9 it appears that hydropower is projected to increase in Northern Europe, but projected to decrease in Western, Southern and Eastern Europe by the end of the 21st century. The use of climate services is therefore equally relevant in the renewable energy sector in other European regions, i.e. underpinning management and operational decisions. Box 1 and box 2 presents two sector cases from France. The first case is of the French TSO, which shows a high use of climate forecasts to cope with future climate change. The second case of a large French power producer show what climate services are needed to improve forecasting for producers.

Box 1. Similar sector case 1: Use of climate services by the French TSO, Réseau de Transport d’Électricité

France is an interesting case, since cold spells have a particularly significant impact on the French electricity system (RTE, 2016;a). France has a high use of electric domestic heating, leading to a high sensitivity to cold weather. The French TSO, Réseau de Transport d’Électricité (RTE), estimates that for each temperature drop of one degree centigrade, demand will increase by up to 2,400 MW,
which is equivalent to the amount of power consumed in central Paris (RTE, 2016;a). Temperature sensitivity is currently much higher in France than other European countries. France alone accounts for almost half of total temperature sensitivity in Europe (RTE, 2014). Meeting demand under such circumstances therefore hold a high priority for the national TSO. RTE finds the best possible estimate of winter-related risks, by using different weather scenarios supplied by Météo-France (RTE, 2016;a).

Since weather forecasts are limited to a few days, RTE worked with Météo-France experts who created a reference framework for temperatures (including 100 scenarios generated with a model developed by the Météo-France research center) to predict future network development needs. The climate models are designed to simulate the climate by calculating the average value and distribution around the average of parameters like temperatures, wind, sunlight, etc. The data represent climate situations, which can create constraints for the power system, such as cold spells and heat waves. From this, RTE has a set of 100 series of climate variables on an hourly basis, coherent at a European level, to use in assessing the impact of weather contingencies on the power system at the European, national or regional scale (RTE, 2014).

Box 2. Similar sector case 2: Use of climate services by the French power producer and distributor, EDF group.

Renewable energy account for about 17% of total electricity production in France, where hydropower production is the largest accounting for 10.8% of total electricity generation (61% of renewable energy production) (RTE, 2016;b). The largest French electric power producer and distributor, Electricité de France (EDF), identifies in their paper from 2007, two main problems with the climate models available: First of all, the spatial resolution of the model outputs are too coarse, making it difficult to integrate into existing operational models. Secondly, the precipitation forecasts of the models are known to have very little skill (García-Morales & Dubus, 2007). Since the benefits of improving the hydropower production management is high, it is worth investigating all positive improvements regarding forecasts for the EDF Group (García-Morales & Dubus, 2007). Probabilistic seasonal forecasts could be valuable for EDF; e.g. forecasting showing anomalies in the lowest 15% percentile in the autumn, would allow management to react by lowering the power production in the concerned hydropower plants, given that the probability in the forecast is strong and reliable (García-Morales & Dubus, 2007). Importantly, according to EDF, knowing that a forecast is not reliable in a given location or for a specific date is also valuable information (García-Morales & Dubus, 2007).
3 Characterizing the market

3.1 Stakeholder mapping

In the Nordic, the users of climate services in the renewable energy electricity market include many stakeholders dealing with both power supply and demand: from power generation, transmission, sale and trade, to the use of electricity. Figure 10 provides an overview of the different stakeholders involved in the renewable energy supply chain.

![Stakeholders in the renewable energy supply chain](image)

Figure 10. Stakeholders in the renewable energy supply chain.

In the renewable energy supply chain (see Figure 10), producers generate electricity, which are sold on the wholesale market. Here both producers, retailers, traders, brokers and large consumers trade electricity contracts. The national Transmission System Operators (TSOs) are responsible of balancing supply and demand and ensuring security of supply. They are thus responsible for the large grid infrastructure supplying power to society. Retail companies sell power to smaller consumers, and the Distribution System Operators (DSOs) are responsible for the local power grid (e.g. for households). Hence, many stakeholders are involved in the energy supply chain. The stakeholders vary from large entities operating on national or international level to smaller private companies. Their use of climate services as well as potential use or unmet needs are therefore also varied. The importance of climate services in three first links in the supply chain (producers, market traders and TSOs) are elaborated on in Table 2 below.
<table>
<thead>
<tr>
<th>Decision-making /Management/Operations</th>
<th>Input to forecasting models</th>
<th>CS components</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Producers of electricity</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plan production (hourly/daily/seasonal)</td>
<td>Daily/hourly consumption</td>
<td>Temperatures</td>
</tr>
<tr>
<td>Management of storage/reservoir capacity</td>
<td>Seasonal variations in consumption</td>
<td>Precipitation (what type – snow/rain)</td>
</tr>
<tr>
<td></td>
<td>(daily/hourly + geographically specific)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Production capacity (time scales and geographically specific)</td>
<td></td>
</tr>
<tr>
<td>Trade electricity short term</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Trade/hedge long term</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Investment decisions on new production capacity</td>
<td>Reservoir capacity</td>
<td>Snow melt (timing)</td>
</tr>
<tr>
<td>Risk assessment of risk from extreme events (destruction of production equipment)</td>
<td>Daily/hourly production from hydro/wind/solar/etc.</td>
<td>Wind</td>
</tr>
<tr>
<td></td>
<td>Production both local/national and cross-border</td>
<td>Solar radiation</td>
</tr>
<tr>
<td>Adapting to climate change</td>
<td>Electricity spot prices</td>
<td>Cloud cover</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Extreme weather events</td>
</tr>
<tr>
<td><strong>Transmission System Operators</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Balancing daily/hourly demand and supply</td>
<td>Daily/hourly consumption</td>
<td>Temperatures</td>
</tr>
<tr>
<td></td>
<td>Seasonal variations in consumption</td>
<td>Precipitation (what type – snow/rain)</td>
</tr>
<tr>
<td></td>
<td>(daily/hourly + geographically specific)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Production capacity (time scales and geographically specific)</td>
<td></td>
</tr>
<tr>
<td>Grid investments</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Risk assessment of grid operation</td>
<td>Reservoir capacity</td>
<td>Precipitation (quantity)</td>
</tr>
<tr>
<td></td>
<td>Daily/hourly production from hydro/wind/solar/etc.</td>
<td>Snow melt (timing)</td>
</tr>
<tr>
<td></td>
<td>Production both local/national and cross-border</td>
<td>Wind</td>
</tr>
<tr>
<td></td>
<td>Electricity spot prices</td>
<td>Solar radiation</td>
</tr>
<tr>
<td></td>
<td>Grid capacities national and cross-border</td>
<td>Cloud cover</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Extreme weather events</td>
</tr>
<tr>
<td>Adapting to climate change</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Financial market traders</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Buy/sell decisions (futures contracts /forward contracts/other financial products)</td>
<td>Future demand/supply</td>
<td>Temperatures</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Future production capacity</td>
<td>Precipitation (what type – snow/rain)</td>
</tr>
<tr>
<td></td>
<td>Daily/hourly consumption</td>
<td>Precipitation (quantity)</td>
</tr>
<tr>
<td></td>
<td>Seasonal variations in consumption</td>
<td>Snow melt (timing)</td>
</tr>
<tr>
<td></td>
<td>(daily/hourly + geographically specific)</td>
<td>Wind</td>
</tr>
<tr>
<td></td>
<td>Production capacity (time scales and geographically specific)</td>
<td>Solar radiation</td>
</tr>
<tr>
<td></td>
<td>Reservoir capacity</td>
<td>Cloud cover</td>
</tr>
<tr>
<td></td>
<td>Daily/hourly production from hydro/wind/solar/etc.</td>
<td>Extreme weather events</td>
</tr>
<tr>
<td></td>
<td>Production both local/national and cross-border</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Electricity spot prices</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Grid capacities national and cross-border</td>
<td></td>
</tr>
</tbody>
</table>
3.2 Market quantification

3.2.1 Producers

In 2016, the total production of hydropower in Nordic and Baltic countries amounted to 231.2 TWh (EIA, 2015). Table 3 presents the largest hydropower producers in the Nordic countries.

<table>
<thead>
<tr>
<th>Hydropower producers</th>
<th>Number of hydropower plants</th>
<th>Generation in 2016 (TWh)</th>
<th>% of total</th>
<th>Capacity (MW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Statkraft</td>
<td>350</td>
<td>61.2</td>
<td>26%</td>
<td>15747</td>
</tr>
<tr>
<td>Vattenfall</td>
<td>100</td>
<td>34.8</td>
<td>15%</td>
<td>NA</td>
</tr>
<tr>
<td>Fortum</td>
<td>160</td>
<td>20.7</td>
<td>9%</td>
<td>4650</td>
</tr>
<tr>
<td>E.ON Sweden</td>
<td>210</td>
<td>15.5</td>
<td>7%</td>
<td>5409</td>
</tr>
<tr>
<td>E-CO Energi</td>
<td>NA</td>
<td>13.0</td>
<td>6%</td>
<td>3350</td>
</tr>
<tr>
<td>Adger Energi</td>
<td>49</td>
<td>8.1</td>
<td>4%</td>
<td>NA</td>
</tr>
<tr>
<td>PVO</td>
<td>12</td>
<td>2.0</td>
<td>1%</td>
<td>528</td>
</tr>
<tr>
<td>Other generators</td>
<td>NA</td>
<td>75.9</td>
<td>33%</td>
<td>NA</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>231.2</td>
<td>100%</td>
<td></td>
</tr>
</tbody>
</table>

Sources: Vattenfall, n.d.; Statkraft (2016); E-CO (2017); Adger Energi (2017); Fortum (2017); Pohjalni Vojma (2016); NordREG (2014).

The large hydropower producers on the Nordic energy market are large players on the market, they are often involved in energy production from several renewable energy sources, and also in the distribution and transmission of electricity.

3.2.2 Transmission System Operators

The Nord Pool is owned by the seven national transmission system operators (TSOs) as seen in Table 4, below. The TSOs are large national companies responsible for security of supply and balancing supply and demand (Kitzing et al., 2016). The TSOs are also responsible of operating the larger national grid infrastructure and cross-border grid connections.
### Table 4. Owners of the Nord Pool Spot.

<table>
<thead>
<tr>
<th>Country</th>
<th>Name</th>
<th>Shares of Nord Pool Spot</th>
</tr>
</thead>
<tbody>
<tr>
<td>Norway</td>
<td>Statnett SF</td>
<td>28.2 %</td>
</tr>
<tr>
<td>Sweden</td>
<td>Svenska Kraftnät</td>
<td>28.2 %</td>
</tr>
<tr>
<td>Denmark</td>
<td>Energinet.dk</td>
<td>18.8 %</td>
</tr>
<tr>
<td>Finland</td>
<td>Fingrid Oy</td>
<td>18.8 %</td>
</tr>
<tr>
<td>Estonia</td>
<td>Elering</td>
<td>2 %</td>
</tr>
<tr>
<td>Lithuania</td>
<td>Litgrid</td>
<td>2 %</td>
</tr>
<tr>
<td>Latvia</td>
<td>Augstsprieguma Tikls (AST)</td>
<td>2 %</td>
</tr>
</tbody>
</table>

*Sources: Nord Pool (n.d.b); Statnett (2012).*

#### 3.2.3 Energy traders

Financial trading with electricity is risky, and in Denmark currently only three companies specialised in trading electricity contracts exists: Nordic Power Trading, Danske Commodities and NEAS Energy A/S. Nordic Power Trading has a portfolio of almost 200 million DKK with a return of 15.48% in 2015 and 31.29% in 2016 (Nordic Power Trading, n.d.). According to the company: “The prices are influenced by the varying precipitation in Norway and Sweden, where electricity production is dominated by hydro power. The water level in lakes and rivers rise and falls, and we can create a return for our investors in both situations” [translated from Danish, Nordic Power Trading, n.d.].

Danske Commodities is an energy-trading company, trading power and gas across borders. In 2016, they had an equity of 623.6 million DKK and a return on equity of 32.2% (Danske Commodities, n.d.).

The third energy trading company is NEAS Energy A/S, trading electricity and gas on the European energy markets. They manage the trade of electricity for several market players, including energy companies, utilizes, producers of wind and solar power and CHP plants (NEAS Energy, 2017). In 2015, their equity was 435 million DKK and had a return on equity of 22.8% (NEAS Energy, 2015). Hence, these companies have much money invested in financial trading with electricity contracts.

#### 3.2.4 CS suppliers

According to the analysis of European climate services suppliers (as MARCO deliverable 3.1 and 3.2 (Cortekar, 2017a;2017b)), 168 organizations provide climate services to the energy sector (including renewables). Figure 11 shows how the climate service providers are distributed among the European countries. It should be noted that among the Nordic countries covered in this case study (marked with green), it appears that no climate services providers have been identified for Lithuania. The relative low amount of CS providers on energy within the Nordic countries (compared to e.g. France and Germany) is surprising, given that this case study has highlighted how widely different sorts of CS is used in the energy sector in the Nordic. However,
the deliverables 3.1 and 3.2 are evolving data sources on the market, and the list might therefore not be exhaustive.

In this case study, some suppliers not in the supplier database has been identified, e.g. the Norwegian Meteorological Institute, The Danish consultancy ‘Energy and Environment Data’ (EMD.dk) and Thomson Reuters. A further description of the most important climate service suppliers in the sector for renewable energy in the Nordic countries are described in more detail in section 4.2.

4 Climate Services: demand, supply and use

4.1 Climate services demand (present)

Climate services can be useful for planning and operation of the hydropower production sector for different time scales including:

1. Long term planning of power and energy system capacities and storage (decades)
2. Short term management and operation (daily and up to seasonal)
3. Strategies on electricity markets (daily to seasonal)
4. Adaptation and emergency response to extreme events (daily/weekly up to decades)

This section highlights some of the current CS demand and use in the renewable energy sector. We are in the following assessing the stated demand and supply of climate services for renewable energy electricity markets leading up to the identification of how the information could be improved.
4.1.1 Producers of electricity from renewable sources

Hydropower producers’ daily management, but also long-term investment decisions are affected by weather and climate variables. They depend highly on weather and historical data in their daily and weekly planning. Producers currently only use long-term climate services such as seasonal forecasts as indicators (e.g. more/less precipitation), however, as identified in various studies they would benefit from using relative accurate quantitative information for longer term planning. A main barrier is that the available seasonal forecasts are currently quite coarse or lack sufficient reliability or skill (Dessai & Bruno, 2015).

According to the EUPORIAS analysis of users’ needs, large state owned or private energy companies make use of historical data, observations and climate statistics (averages and tendencies of particular months) in many aspects of their planning and operations. These data are used for forecasting future demand, understanding the potential value of generation mix, improving optimization, developing new facilities, and understanding potential risks to assets from extreme events (Dessai & Bruno, 2015). The actual use of climate services in relation to these needs is, however, very limited and in particular historical data is the major information used, which is not reflecting future climate change.

In addition to historical data, the companies use weather forecasts (up to two weeks) to feed their operational models, e.g. to understand electricity demand. Demand for electricity based heating and cooling is especially affected by temperature changes, where warmer summer temperatures increase the demand for cooling, while warmer winter temperatures decrease the demand for heating (Golombek et al., 2012). On the demand side, the main parameters of interest are therefore temperature and cloud cover. On the production side, the main parameters include precipitation, wind and solar radiation (Dessai & Bruno, 2015).

For the planning of hydropower production, information on potential shift towards earlier flow peak from snowmelt and lower peak volumes in the future are important to plan for different seasonal regulation, e.g. to reduce the need to store large volumes of meltwater for the winter months (Gimbergson, 2017). The EUPORIAS survey notes that organizations responsible for mainly hydropower production only currently use seasonal forecasts as indicators of warmer/colder weather and not as quantitative information feeding into operational models. This is due to several barriers existing with the use of the current available seasonal forecasts. One of the barriers of using the forecasts is the opinion that they are temporally coarse, making it difficult to integrate into existing operational models and decision-making processes (Dessai & Bruno, 2015). Another barrier is the lack of reliability (/skill) and the reputational risk of using the seasonal forecasts.

In general, the large electricity producers apply:
- **Short-term weather forecasts** for daily and weekly operational models. To operate and manage generation capacities forecasts of wind speed, solar radiation, cloud cover and precipitation is used. To forecast demand, temperatures are the most important parameter.

- **Historical data** are used to forecast seasonal patterns. For hydropower generation management, storage of energy in terms of snow cover and inflow in terms of snowmelt and precipitation are important variables. Historical data are also used at the early stage of a project to set up a wind farm, to determine the geographic areas offering the best wind potential to produce electricity (Lemaître, 2013).

- **Seasonal forecasts** are mainly used as indicators (e.g. more/less precipitation) and not as quantitative information due to barriers, such as lack of reliability and skill.

### 4.1.2 TSOs’ use of climate services

Interviews with employees in the Danish TSO (Energinet) conducted in the MARCO project found that Energinet uses climate services for several purposes: “We use climate data in a variety of respects. In relation to our operation of the grid, we use forecasts for sun and wind. (...) We also use climate data in the form of time series for wind power and solar cells production and time profiles for heating throughout the year.” (Ander Bavnhøj Hansen, Senior Consultant at Energinet, personal communication, April 24, 2017). According to Lasse Diness Borup, model developer at Energinet, the TSO does not directly account for precipitation and the expected electricity generation hereof: “Norway and Sweden who have a lot of hydropower, are accounting for expected precipitation. And since we coordinate our revision planning with our neighbouring countries, this will have an impact on Denmark as well” (L. D. Borup, personal communication, October 10, 2017).

Thus, data used by Danish TSOs is forecasts based on historical data and they do not incorporate information on precipitation directly.

In general, the national TSOs apply:

- **Historical data** to forecast peak load of a particular day, as well as general patterns months.

- **Short-term weather forecasts** for operational models. To understand demand, temperatures are the most important parameter. Temperature is also important for determining the capacity of high voltage lines. Other used parameters are wind, solar radiation and cloud cover. For hydraulic forecasts, precipitation is used. Forecast on extreme events (such as strong winds, icing, etc.) are important for maintenance teams to act fast (Lemaître, 2013).

- **Long-term climate change projections** for managing future assets.
4.1.3 Market traders

The limited precision of the forecasts used by producers and TSOs are reflected in how another stakeholder at the market – traders - increase their gains on the energy trading market. Investors trading electricity futures, a financial instrument to hedge prices and risk, use weather and climate forecasts to make gains on the financial market. The small case study of a Danish investment company, Nordic Power Trading, shows that a limited precision of forecasts in the renewable energy market can lead to increasing gains on the energy trading market (as found in WP4 case study on renewable energy). Nordic Power Trading is a Danish electricity investment company, who trades with electricity contracts (Nordic Power Trading, n.d.). The company manage to gain on forecasting weather conditions for electricity production and demand. Nordic Power Trading managed to gain a 31.29% return in 2015 and a 15.48% return in 2016. In a webcast, Bjarne Walbech says that they are using external models, but also models they have developed on their own, where they include factors such as solar radiation, wind, temperature and precipitation (Walbech, 2017). The use of weather data from the world's meteorological institutes in combination with risk management and pricing models have led to their market returns (Nordic Power Trading, n.d.). As mentioned in section 3.2.3 other energy-trading companies specialized in energy trading are getting high returns as well. Due to the competitive nature of the business, there are no available information on the specific type of climate services used. However, the large return on investments signal a good use of climate and weather data.

4.2 Existing climate services supply

Suppliers of climate services are the meteorological institutes, climate services centers, research institutes and private consultancies.

4.2.1 Meteorological institutes

The meteorological institutes in Norway (met.no)/The Norwegian Water Resources and Energy Directorate (NVE), in Sweden (SMHI) and in Finland (ilmatieteenlaitos.fi) all provide seasonal forecast products for hydropower producers operationally, whereas the climate service centers located at met.no and SMHI provide climate projections and other relevant information of use within the hydropower sector. In general, these forecasts are based on the operational seasonal forecasts product provided by The European Centre for Medium-Range Weather Forecasts (ECMWF), which are then bias-corrected before serving as input into a spatially distributed hydrological model used to generate an ensemble of realizations (e.g., Olsson et al., Hydrol. Earth Syst. Sci., 20, 659–667, 2016). Both in Sweden and Norway, the meteorological institutes license access to a climate information tailored for the hydropower sector.

Efforts using the same kind of methodology as the Nordic meteorological institutes is currently explored and/or prototyped in no less than four projects under the Copernicus Climate Change Service:
Case study: Renewable Energy Sector

- SWICCA - Service for Water Indicators in Climate Change Adaptation (coordinated by SMHI)
- eDGe - End-to-end Demonstrator for improved decision-making in the water sector in Europe (coordinated by NVE)
- Clim4Energy – Providing climate service products tailored for the energy sector
- ECEM - European Climatic Energy Mixes

Notably, eDGe introduces a multi-model hydrological ensemble using many climate models and many hydrological models to address the issue of uncertainty and provide improved seasonal and centennial forecasts.

4.2.2 Private consultancy companies

A limited range of additional services aimed at the hydropower sector are similarly offered by different semi-commercial vendors. SINTEF Energy Research (Trondheim, Norway) have developed a market simulation model based on for, e.g., stochastic dual dynamic programming (SDDP), to support hydro scheduling in competitive electricity markets (e.g. Larsen et al., Energy Procedia 87, 189 – 196, 2016), where information/forecasts/projections of, e.g. wind and hydropower, is drawn from time series data. A similar SDDP tool and associated services are offered by Thomson Reuters Point Carbon (Canadian, but situated in 20+ European countries), who have developed a system based on 23 regional models (Dahl Jensen et al, Energy Procedia 87, 19 –27, 2016). In their implementation, the SDDP-based market model is fed by input from the network of hydrological models, which are again forced by a combination of historical observations and actual forecasts of snowmelt. Thomson Reuters provide information for up for 52 weeks ahead using this approach.

‘Energy and Environment Data’ (EMD) is a renewable energy service company in Denmark. The consultancy company delivers comprehensive data on wind to the industry and to wind turbine developers. For this purpose, EMD has developed commercial software packages, which can be used when designing and planning renewable energy projects, but also for the daily operation and management phase (EMD, 2016). As an example, EMD provide web-based software services that can be used by wind turbine operators to check the performance of their equipment. They have also developed a trading software, with data on both power supply and demand, but also heat data to enable the user to calculate the optimal electricity bid prices and quantities at different electricity markets (EMD, 2016). According to Niels-Erik Clausen from DTU Wind Energy, the EMD data is based on historical wind data, and climate forecasts have not yet been integrated in the company’s portfolio of software support tools (N. Clausen, personal communication, October 9, 2017).
4.2.3 Research institutes

Several research institutes develop and use weather and climate information as part of climate services to different CS users (as also identified in MARCO deliverable 3.1 and 3.2). In Denmark, e.g. DTU Wind Energy\(^1\) supplies wind data to several customers. One user is Energinet (the Danish TSO), who is provided with wind projections to manage the transmission system (N. Clausen, personal communication, October 9, 2017). According to the EUPORIAS survey on CS user needs, research institutes most often supply historical data to help users understand inter-seasonal values and to forecast the probability of extreme events (Dessai & Bruno, 2015). Niels-Erik Clausen from DTU Wind Energy confirms in a short interview the use of historical data. According to N. Clausen, “forecasts of wind data for climate change are not used today in the planning of wind energy projects. Instead, historical data is used” (N. Clausen, personal communication, October 9, 2017). As an example, DTU Wind Energy provide data for the planning of new wind projects on extreme wind (for design of wind turbines construction) and data on mean wind (for calculating profitability of wind turbines investment). He mentioned that climate projections on wind and other renewable energy sources have been used in research projects, but that the wind projections are subject to great uncertainty (N. Clausen, personal communication, October 9, 2017).

4.3 Unmet needs

This section is based on findings from literature review and from the EUPORIAS project work package 12\(^2\), which provide a valuable insight to users’ needs of seasonal to decadal climate predictions for European energy sector. The interviews were conducted in several European countries, however none Nordic countries. Anyhow, we find the findings relevant and representative for Nordic countries and thus this case study.

From the interviews conducted as part of EUPORIAS, an organization responsible for electricity production (mainly hydropower), seasonal forecasts state that it would be very helpful to know more about future conditions in the next 1 to 3, even to 6 months in terms of precipitation (rainfall) and temperature. Here precipitation would be the most important variable for production, combined with snowmelt, and temperature is important for predicting electricity consumption, the combination of the two would be useful (Dessai & Bruno, 2015, p. 36). Another organization (a research institute working nationally) also mentions the value of predictions on longer term: “For me it’s interesting to know whether the next six months would be dry or wet because what happens very often (...), we use water as much as possible and then, just when

---

\(^{1}\) DTU Wind Energy: The Technical University of Denmark, Department of Wind Energy.

\(^{2}\) Through a systematic literature review, workshop with relevant stakeholders, in-depth interviews (14 from the energy sector) and a broader survey (Dessai & Bruno, 2015).
it’s nearly too late, everyone says, “Be careful. We have to use less water because there’s no water in the reservoir." Now for me I think it would be useful to know one year beforehand [if] next year is going to be dry and then to save water a year rather than just one month before.” (Interview in energy sector. From EUPORIAS, 2015, p. 40). For seasonal forecasts to be beneficial for the end-user, they have to be sufficiently skill and be tailored to a decision-making context (Torralba et al., 2017).

Traditionally, wind forecasts have been limited to short timescales from hours to days. However, when planning longer term factors such as expected energy yield and maintenance requirements have fed into the assessment of the economic feasibility of a wind farm (Torralba et al., 2017), as well as in the hydropower sectors. In the wind sector these have often been based on historical data and for short time periods only (Torralba et al., 2017). Thus, there is a need for long-term climate information. The RE sector need to move beyond historical climatological information and focus more on climate predictions. The gap between weather forecasts and climate change predictions needs to be filled (Torralba et al., 2017).

A hydropower producer state that they would like to know the daily distribution of precipitation for the first month. Furthermore, it would be useful to know the type of precipitation during wintertime (rain or snow) together with its distribution (EUPORIAS, 2015, p. 36). Another private energy company working with energy generation see a potential in the use of seasonal forecasts (mainly precipitation) to manage water reservoirs better. “For us to have more reliable information for the next 3-4 months will be very important to help manage the water in a better way, considering those two situations (...): optimizing the electric generation, and obviously putting all the social conditions and all the social restrictions, so from the water supply to the other usages of water, in an optimal way” (interview in energy sector by Dessai & Bruno (2015) p. 37).

Especially seasonal forecasts suffer from systematic errors, which makes them useless to the end-user unless they are post processed in some way. The climate science community is aware of this problem and see this as a main challenge for enabling a better use of climate predictions (Torralba et al., 2017). Organizations in the energy sector find information on uncertainty important for understanding the provided climate data and are aware that uncertainty is unavoidable (Dessai & Bruno, p. 32). Some of the interviewed energy organizations stated that they compare several forecasts from different suppliers to reduce uncertainty. Furthermore, the authors find that many organizations (n=31) prefer receiving information on the uncertainty of the data as numerical estimates to be able to quantify uncertainty, integrate it in existing models or produce graphics on their own (Dessai & Bruno, 2015, p 32). Reliable probabilities on the uncertainty are expected to be part of the decision-making processes. A prediction has little value without an estimate on its quality. Quantification of the uncertainty is one of the most important aspects for minimizing financial risk and a successful development in the industry. From a user perspective, improving
reliability is fundamental, since this says something about the trustworthiness of the predictions (Torralba et al., 2017).

The liberalization of the electricity markets has introduced new financial risks, increasing the risk of substantial losses especially for the sellers of forward contracts (Füss et al., 2015). This increases the demand for new and better tools for predicting spot market prices. When trading electricity spot and derivatives contracts, traders have to know how the market will be at each point in time. Thus, price forecasts based on historical data, not considering important forward-looking information, will have substantial pricing errors leading to financial losses (Füss et al., 2015).

4.4 Empirical assessment

In order to illustrate the potential of seasonal forecasts to stakeholders, a prototype climate service based on statistical modelling of observed hydrological to hydropower systems from Norway was developed as part of the case study. This methodology has large similarities to the approach used by SINTEF Energy Research for providing services to the hydropower sector. Seasonal forecasts of 1-6 months inferred from the statistical model were compared to more advanced climate service prototypes delivered by Copernicus Climate Change Services projects SWICCA and eDGe. Overall, a simple statistical approach was found to provide seasonal forecasts of hydrological inflow to the Norwegian hydropower system of roughly similar spread and precision as these more advanced tools, and thus to provide a reasonable approximation of the current state-of-the-art.

As indicated above, Norway is the main producer of hydropower in the Nordic region, and about 99% of the electricity produced in Norway stems from hydropower. The Norwegian Water Resources and Energy Directorate (NVE) maintains a database of 82 observed time series, representing 100% of the hydrological inflow to the Norwegian hydropower system (more information can be found in NVE-rapport 7-2008 by Holmqvist and Engen: “Utvalg av tilsigsserier til Samkjøringsmodellen”). In the following we will assess the potential and skill of climate services for the hydropower sector based on this dataset.
Figure 12. Total annual inflow (in TWh) to the Norwegian hydropower system. The red full lines indicate decadal averages (e.g. 1970-1979) whereas the red dashed lines indicate the standard deviations.

Decadal prediction

Figure 12 depicts the total annual inflow to the Norwegian hydropower system, based on measurements from 82 representative stations selected by NVE. As indicated in the figure the average annual production from hydropower is around 130 TWh, with interannual variations in the power production ranging from less than 100 TWh/year to 170 TWh/year. It is further evident that the inflow has increased significantly (due in particular to increases in water originating from increased spring melting and increased precipitation), causing an increase in the hydropower production.

As discussed above decadal predictions are relevant for long-term planning of energy production and in some cases also trading. Figure 12 shows the mean annual inflow (full red lines) as well as standard deviations (dashed red lines) for each decade since 1960. While the mean annual inflow is seen to rise, increases from one decade to the next are irregular, and the picture is dominated by high inter-annual variability. Since climate models have not in general included information about natural variability at decadal scales there have been limitations in the climate services provided at decadal scale despite its usefulness.
Seasonal forecasts

Figure 13 illustrates the potential skill of our prototype climate service for the hydropower sector, based on a simple statistical ARIMA model. Results are here shown for the period 2013-2015 to allow for comparison with Nord Pool Spot (see above). The black curves indicate water measurements at two of the Norwegian stations, whereas the red curves designate 1-6 month predictions based on applying the statistical model to the observed time series. As seen from the figure the seasonal forecasts up to 6 months reflects well the general behaviour of both time series, however, the model is unable to predict the full extent of the spring melt, which may be essential to practitioners and traders. This performance is roughly similar to state-of-the-art climate services provided by various suppliers to the hydropower sector, and suggests also, in this case, that there is a potential for improving current market offerings. Moreover, to add value to users, currently available forecast models must significantly outperform seasonal forecasts used in our illustrative example.
5 Framework Conditions

5.1 Governance

5.1.1 National framework

The electricity trade is expected to increase in the Nordic area in the next decades because of the ambitious climate policy goals of the countries, where a fast penetration of renewable energy is a key component (Summary of Nordic Energy Commission Reports, 2017). The countries have already today utilized almost all the available hydropower potential with its associated storage possibilities, and the expansion of renewable electricity sources in the Nordics will therefore to a large extent be covered by fluctuating sources like wind and solar power. A high share of these sources in the systems will require extensive electricity trade to balance the system. E.g. in the case of Denmark, more than 60% of the total electricity production is expected to be covered by wind energy in 2030, which will require extensive international trade (Summary of Nordic Energy Commission Reports, 2017).

The national plans for renewable energy expansion are not supported by very detailed official climate risk and adaptation plans for the sectors. Denmark has no climate change adaptation plan for the energy sector. Norway has a national plan with a brief coverage of the energy sector (Det Kongelige Miljødepartement, 2013). According to the national plan, projected loads in different types of extreme weather have to be taken into account when the Norwegian power grid is designed and upgraded (Det Kongelige Miljødepartement, 2013), and all TSOs are expected to incorporate risk and vulnerability assessments in their planning (Det Kongelige Miljødepartement, 2013). Sweden has a more detailed plan including future projections of hydropower potentials developed in 2017 (SOU, 2007). Limited research on adaptation to climate change in Nordic electricity grid companies exists, e.g. a study by Inderberg & Løchen (2012). This study investigates how climate change adaptation among Swedish and Norwegian electricity grid companies are affected by factors such as national regulations, culture and experience with weather events. The study shows how some companies are more focused on the economic efficiency than overall resilience in the system due to national regulatory framework. The authors found that the Swedish companies focused on a balance between economic efficiency and a robust grid network, because of the Swedish national framework conditions (Inderberg & Løchen, 2012). This shows how the strong Swedish national framework focusing on adaptation as well has resulted in grid companies investing more in adaptation measures than e.g. Norwegian companies (European Commission, 2013).

Private sector actors, including in the short-term TSOs and utilities and in the longer term also financial market traders, manage the electricity trade. Climate service Information about renewable electricity production potentials are not currently officially reported in relation to market surveys, but personal information from market agents confirm that historical climate service information is used internally by the parties involved.
5.1.2 European framework

The European Commission is by the staff working document “Adapting Infrastructure to Climate Change” (European Commission, 2013) and “Framework Strategy for a Resilient Energy Union with a Forward-Looking Climate Change Policy” (2015) aiming at increasing the climate resilience of energy infrastructure. The two documents provide strategical frameworks to climate resilience. In addition, the frameworks can guide the assessment of new existing technical infrastructure related to how resilient to current and future climate risks it is and the respective adaptation measures (European Environment Agency, 2016). The strategical directions and priorities of the European Commission for the energy sector is described in “Priorities for the energy sector in Europe 2020 and beyond – A blueprint for an integrated European energy network” (2011). However, the documents do not yet specify in what way the energy sector should adapt to climate change (European Environment Agency, 2016).

The European Network of Transmission System Operators for Electricity (ENTSO-E) is a network of electricity TSOs working together to improve legislation (e.g. the Ten-Year Network Plan), but also to improve operational cooperation among TSOs (e.g. through the “Regional Security Cooperation Initiatives (RSCI)) (Energinet, 2015).

5.2 Finance

Member States’ development of infrastructure resilient to climate change is funded by the EU Cohesion (or regional) policy under the programming period of the regional funds (2014-2020) (European Environment Agency, 2016).

Denmark has a ForskEL programme, which is a research, development and demonstration programme that funds external projects. The projects must with focus on electricity systems, develop solutions for an economically viable green transition of the energy system (Energinet, 2015).

5.3 Collaboration with CS Suppliers

The Swedish meteorological Institute SHMI offers extensive climate services to the energy sector and financial traders in terms of forecasts based on weather and hydrological models, historical data and custom made models https://www.smhi.se/en/services/professional-services/energy/products-for-trading-1.12623. The services also include longer term forecasts, which e.g. can be used in the assessment of wind energy investment projects. SMHI is the largest and most comprehensive supplier of climate services in the region. The Norwegian Climate Service Center at the Meteorological Office as well as the climate services at the Danish Meteorological Office do not offer specific sectoral climate service products rather than specific short-term weather forecasts, but tailor-made products can be demanded. There is no official information about costumer use of these climate services.

There seems to be a gap between the climate services offered in terms of weather and climate forecasts by the meteorological institutes, and what could be expected in terms of more specific needs of the market actors in the Nordic countries in terms of what could support more profitable market outcomes. However,
information about such needs and climate market intelligence by definition is confidential since it can provide a basis for extraordinary benefits.

5.4 Research and knowledge

There is very limited research on the climate vulnerability of electricity systems in the Nordic countries. The most comprehensive source is the study by Thorsteinsson, T., Björnsson, H. (2012) on Climate Change and Energy Systems: Impacts, Risk and Adaptation in the Nordic and Baltic countries. According to the Norwegian national adaptation plan, more research and knowledge are needed on “the hydrological impacts, climate-related challenges in the power sector, changes in the frequency of lightning, changes in sea level and storm surges, the frequency of storms and the effects of hurricane-force winds, icing on power lines, ice loads on dams and the effects of slide-generated waves on dams” (Det Kongelige Miljødepartement, 2013).

The research on the benefits of climate services in the energy sector has as well only been estimated by a few authors according to the comprehensive Risk Assessment as part of the MARCO project Work Package 4 (Skougaard Kaspersen, 2017). To the best of our knowledge, this research has not been conducted on Northern European level. For hydropower, Hamlet et al (2002) estimate an increase in annual net revenues of $153 million for Columbia River dams with perfect ENSO and PDO based stream flow forecasts, while Block (2011) find a $1-6.5 billion decadal net benefits for Ethiopian hydropower with perfect ENSO based precipitation forecasts. For wind-energy producers in Europe Roulston et al (2003) estimate a 100% increase in weekly income with medium-range forecasts (Skougaard Kaspersen, 2017).

5.5 Decision making

Several factors can influence the take up of climate services in relation to trade of renewable energy based electricity in the Nordic. These include:

- Documentation and a knowledge transfer of the potential economic benefits and losses by utilities and traders of considering climate predictions. Similarly, investment decisions on climate risks of renewable electricity production should be able to benefit from research and other knowledge generation.
- Development of tailor made products, which can help stakeholders to integrate climate services in their decisions.
- Trust and quality assurance procedures need to be established in relation to climate services for the sector. Climate services are e.g. in relation to investment projects integrated in feasibility studies as part of larger consultancy services, which do not include specific expertise on climate change issues.
- Climate service data should be available for a short- to medium time frame, and at a very detailed geographical level reflecting location of power production plants. In particular today’s data on offshore sites for wind parks are very uncertain.
• Creation of operational online interfaces, where users of the wind industry as proposed by Torralba et al. (2017), but also the hydropower and other stakeholders can explore probabilistic predictions and experts provide training.
• Interactions between the renewable energy community and the climate science community to enhance outcome and evaluate the performance of past predictions (Torralba et al., 2017).

6 Conclusions

In the Nordic electricity market, electricity from hydropower is dominating the market. Hydropower production has the ability to store large amount of energy and can thereby serve to balance the supply of electricity from fluctuating renewable energy sources like wind and solar power. Since hydropower is highly dependent on precipitation and thereby hydrological forecasts, climate services could potentially play a key role in the renewable energy sector.

The liberalization of the electricity markets has introduced new financial risks, especially increasing the risk for the sellers of electricity futures contracts. When trading electricity spot and futures contracts, traders have to know how the market and thus production and demand, will be at each point in time. This increases the demand for climate services to improve tools for the electricity market and prices.

The current use of climate service information is, however, limited. Stakeholders typically only use forecasts of renewable energy potential based on forecasts from historical data. Price forecasts based on historical data and not considering important forward-looking information will have substantial pricing errors leading to high financial risks. This is confirmed by the very high return of the Nordic financial power trading companies, specialized in trading electricity spot and futures contracts.

Risk assessment showed how sectors in other European regions, in this case France, are highly dependent on quality climate services, and that there is a need for better skill and reliability in the seasonal forecasts used in this sector. Interviews with stakeholders and literature review have highlighted that improved climate services could potentially be beneficial in several parts of the value chain, and especially to the largest market players, such as producers, TSOs and market traders. In addition, surveys have identified a demand from the power sector for improved seasonal forecasts, but relevant seasonal forecasts in terms of time and geographical resolution have not been easily available for the sector.

The performance of the prototype climate service developed in this case study suggests that there is a potential for improving current market offerings. Moreover, to add value to users, currently available forecast models must significantly outperform seasonal forecasts used in our example. This is an important step in increasing the uptake of climate services in the sector – an improvement of the products offered.
However, other factors such as research on climate service benefits and transparency and standardization of climate services help a more efficient uptake in the sector.

An increased uptake and improved climate services can lead to efficiency improvements in the electricity markets implying economic gains for both traders and producers and ensuring security of supply.
7 Bibliography


Cortekar, J. (2017a). Analysis of European Climate Services Suppliers. MARket Research for a Climate Services Observatory (MARCO), Deliverable 3.1.

Cortekar, J. (2017b). Analysis of European Climate Services Suppliers. MARket Research for a Climate Services Observatory (MARCO), Deliverable 3.2.


E-CO Energi (2017): http://www.e-co.no/English/E-CO_Energi/About_E-CO/


