

1. Nordic electricity supply and demand in a changing climate

1.1 Introduction

Climate change will have an impact on almost all sectors and systems including the electricity system at generation, transmission and demand levels. Changes in the seasonal and geographical patterns of energy supply and demand as well as increasing extreme weather events are key issues for the energy sector regarding the effort to avoid significant market disturbances (Nordisk Energiforskning, 2010).

The Nordic power system is dominated by hydro power. There is a correlation between precipitation levels and the cost of electricity on the Nordic power market. This is shown in Figure 1 below. The influence that hydro power has on the Nordic electricity market means that future changes in precipitation levels due to climate change will have a strong influence on future investments in power generating capacity.

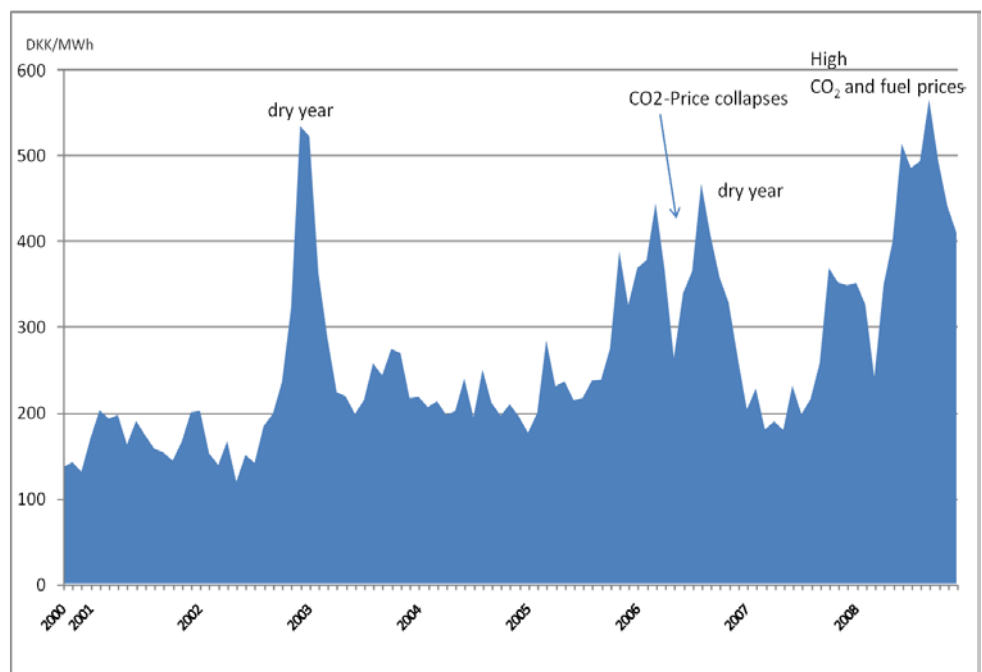


Figure 1: Correlation between, amongst other factors, precipitation and electricity prices in East Denmark 2000 - 2008.

Climate scenarios produced by IPCC and ENSEMBLES forecast higher levels of precipitation in the Nordic region in the future. Climate change is also expected to result in more extreme climate events, such as more severe droughts.

According to IPCC models, precipitation levels in Scandinavia and Finland are expected to increase by 10 % over the coming 50 years compared to the period 1961-1990. However, an increase in the frequency and duration of droughts and heat waves is predicted during the summer months. (Jørgensen, Christensen, & May, 2006).

The Norwegian Meteorological Institute and the Norwegian Water Resources and Energy Directorate determined a range of projections of the impact of climate change on Norway's hydrology for the periods 2021 – 2050 and 2071 – 2100. The models suggest a significant change can be expected in the seasonal distribution of runoff, with an increase throughout the entire country in the winter and decreases in the summer (Beldring & al, 2010).

These predicted changes will have an impact on electricity production levels from hydro electric plants and the wider issue of balancing the electricity system. As the Nordic electricity market is heavily based on hydro production, such changes will have an impact of the entire Nordic market and the development of other electricity production units. (Nordisk Energiforskning, 2010)

1.2 Outline and aim of the analysis

In a study by Mo, Wolfgang & Styve (2010) it is anticipated that all Nordic countries, with the exception of Finland, will increase their net export by 2020 to continental Europe. The study indicates that the Nord-Pool electricity spot prices will fall in all countries due to increased precipitation. The price reduction in Denmark, however, is relatively small compared to the other Nordic countries due to its strong connection to the European market and lack of hydro power generation. The fall in electricity prices is made on the assumption that there will be no dry or drought years, which would otherwise have an impact on hydro electricity costs.

Although increased precipitation levels are expected, there is potential for extreme weather events to occur that could create uncertainties in the NordPool market, such as drought years with low levels of precipitation. This analysis considers the possible effects that an increase in precipitation coupled with occasional, extreme weather events may have on the future Nordic power system. Two scenarios are presented, a reference scenario and a low final demand scenario. The scenarios illustrate how higher average levels of precipitation may influence the development of the Nordic power system from 2020 to 2050 and whether occasional ex-

treme weather conditions in the form of prolonged droughts could potentially pose a serious stress factor for an increasingly hydro dominated power system. The low demand scenario analyses whether increased energy efficiency can play a role in developing a power system that is more robust in withstanding the effects of extreme climate events.

1.2 Assumptions in the analysis

In order to analyse how expected changes in precipitation may influence investments in the future two scenarios were developed with all parameters being equal except for changes in final demand. The scenarios run from 2020 to 2050. It is assumed that all existing EU and national policy goals for reduced energy use, CO₂ emissions and integration of renewables have been implemented and achieved in the Nordic countries by 2020.

The two scenarios aim to highlight the effect extreme climatic events such as drought could have on an increasingly hydro dominated power system. The expected increase in precipitation between 2020 and 2050 will result in hydro becoming even more dominant in the Nordic power system than is presently the case. This could ultimately result in a reduced security of supply due to a lack of diversity in the electricity supply industry. This lack of diversity could result in the power system becoming more sensitive to changes in precipitation and result in price volatility in years with low levels of precipitation.

1.2.1 Hypotheses for scenarios

The analysis is based on three hypotheses;

- i. The current definition of a wet year in the Nordic power system will represent a normal year from 2020 due to increased precipitation as forecasted in climate scenarios for the region,
- ii. there will be greater fluctuations in weather patterns in the future with extreme climate events, such as drought, being more severe and occurring more often than in the past,
- iii. power production in the Nordic region must be fossil fuel free by 2050

Expected future changes in climatic conditions in the Nordic region are represented in the scenarios by assuming that in the period 2020 to 2050 there will be 12 % more precipitation annually than in a current day normal year. Climate change is expected to result in more extreme climatic events occurring more regularly. In order to represent this in the scenarios, four drought years are included between 2020 and 2050. One year in ten is presumed to have severe and prolonged droughts. These are included in the scenarios in order to test the robustness of the power system under a changing climate. It is assumed that a drought year in the

scenarios has the same level of precipitation as a current day dry year. At present a dry year is considered to occur when precipitation levels are a maximum of 88 % of a normal year. In the scenarios used in this analysis the level of precipitation for a drought year is considered to be the same as for a current day dry year. This results in a drought year having approximately 20 % less precipitation than a normal year in the scenarios. This represents an extreme climatic event in the scenarios.

The inclusion of drought years provides an indication of the investments required to maintain security of supply for end consumers in an electricity system optimised for higher levels of precipitation, but with an increased risk of extreme climate events. The drought years are assumed to occur in 2021, 2031, 2041 and 2049.

In the analysis the assumption is made that the Nordic countries will have fossil fuel free electricity sectors by 2050. This is reflected in the scenarios through a gradual limitation being placed on the use of fossil fuels from 2020 until no fossil fuels are allowed in 2050. This is done in order to assess the viability of an electricity sector based on renewables and CO₂ neutral technologies.

Nuclear power capacity remains unchanged throughout in both scenarios.

1.2.2 Electricity consumption in the scenarios

This analysis focuses on the role lower demand for electricity can play in producing a more robust power system that is less sensitive to climatic changes and extreme events in a future with increased uncertainty about weather conditions. Demand data in the reference scenario are based on the most recent projections from the Danish Energy Agency (2010) and ENTSO-E (2010). For years without projections, demand is extrapolated at the latest available rate of change. Table 1 below shows the final electricity demand for the Nordic countries used in the reference scenario.

Table 1: Electricity consumption (TWh) in reference scenario, 2020 - 2050

	2020	2030	2040	2050
Denmark	31.7 TWh	34.2 TWh	36.6 TWh	40.7 TWh
Finland	84.4 TWh	83.1 TWh	81.7 TWh	80.4 TWh
Norway	120.2 TWh	124.2 TWh	128.6 TWh	133.1 TWh
Sweden	138.8 TWh	139.4 TWh	139.9 TWh	140.5 TWh

In the low final demand scenario it is assumed that ambitious energy savings targets are implemented in the Nordic region that result in a reduction in final electricity consumption of 10 % every 10 years in each of the Nordic countries.

In Sweden and Norway it is assumed that further savings are implemented for spatial heating in households. A reduction in electricity con-

sumption for spatial heating in Norway and Sweden of 40 % is assumed due to conversion of conventional electric heating to heat pumps, substitution of electric heating with district heating and improved insulation. The final demand for each country in the low demand scenario is shown in Table 2 below.

Table 2: Annual electricity consumption in low demand scenario

	2020	2030	2040	2050
Denmark	31.7 TWh	28.5 TWh	25.6 TWh	23.1 TWh
Finland	84.4 TWh	76.0 TWh	68.4 TWh	61.5 TWh
Norway	120.2 TWh	104.2 TWh	86.6 TWh	68.8 TWh
Sweden	138.8 TWh	120.7 TWh	100.9 TWh	81.0 TWh

1.2.3 Future trends in demand – the basis for the low final demand scenario

The low final demand scenario is inspired by two publications. The first is a report by Dansk Energi Analyse and Viegand & Maagøe (2010) on energy efficiency in Danish industry that concluded that the potential for energy savings in 2010 is greater than in 1995 due to technological developments. The second report, World Energy Outlook 2009, identified energy savings as the component with the most potential for reducing greenhouse gas emissions in the energy sector.

Energy savings can be expected to occur in two ways; passively due to increasing winter temperatures resulting in lower demand for space heating and actively through energy savings initiatives in industry and household sectors.

Higher ambient air temperatures will result in a decrease in energy demand in the residential and commercial sectors for space heating in the autumn, winter and spring. Average annual electricity demand in the Nordic region is expected to decrease by 2 – 2.5 % already by 2020 due to increases in temperatures, with a relatively larger reduction in winter months than summer months (Mo, Wolfgang, & Styve, 2010).

There is substantial potential for reducing electricity use in the Nordic region (Henning and Trygg, 2008). Simple initiatives in industry such as reducing the operation of industrial support processes, such as ventilation, outside of working hours has the potential to reduce electricity consumption considerably.

Electricity consumption is likely to be significantly reduced due to a shift from direct electric heating to district heating (Fidje, 2010). District-heating systems supplied by, for example, biomass-fired CHP plants could gradually replace electric heating, especially in Norway, which would increase non-hydro electricity supply and reduce electricity demand. Swedish district heating use could increase by 25% if replacing all electric heating in non-rural areas. The implementation and expansion of

combined heat and power plants in the Nordic region will provide an alternative to electric heating in communities. District heating can be a key to sustainable local energy systems and connect heat surplus and heat demand. Surplus industrial heat can also be recovered for repeated utilisation in industry and finally for space heating.

EU requires substantially lower energy use for buildings in the future. Thick wall and attic insulation, windows with low thermal leakage and ventilation recovering heat can reduce heat demand significantly. Better insulated houses reduce the impact of high and low outdoor temperature.

An important issue when discussing demand is the use of electricity for transport. This may become an important factor in the future Nordic energy system that results in increasing final demand for electricity. However the degree to which electric cars will become an integrated part of the energy system is still unclear. In the scenarios described in this analysis consumption from electric cars is not included.

1.2 Methodology in the analysis of scenarios

The analysis was carried out using the Balmorel electricity market model. Balmorel is a partial equilibrium model that assumes perfect competition in the electricity and combined heat and power sectors. The model optimises investments in generating capacity subject to technology and policy constraints to meet end-user demand, which is considered to be inelastic. The model consists of a number of electricity regions divided by transmission bottlenecks. Balance of supply, demand and net exports are maintained in each region. The model minimises costs at full foresight to obtain optimal operation including generation for specific or aggregated plants, consumption of fuels, emissions, losses, international transmission etc.

The model determines a least-cost solution for covering the electricity and district heating loads hour by hour with the given energy production system. Thereby the model simulates the detailed dispatch of the production units, taking into account:

- Electricity and heat demand;
- Technical and economic characteristics for each kind of production unit, e.g. capacities, fuel efficiencies, operation and maintenance costs, fuel prices, ramping rates, and start-stop costs;
- Environmental regulation;
- Transmission capacities between regions and countries.

The model version applied in this study includes data for the Baltic and Nordic countries as well as Germany. Production patterns within these countries as well as power exchange between the countries are simulated

by the model. For more information on Balmorel refer to www.balmorel.com.

1.3 Results

In the reference scenario electricity consumption in the Nordic region increases from 375 TWh in 2020 to 400 TWh in 2050, whilst in the low final demand scenario reduces total demand in the Nordic region to from 375 TWh to 250 TWh in 2050. This can be seen in Figure 2 and Figure 3 below.

Generation from nuclear power remains constant throughout both scenarios at 110 TWh annually. Production from hydro power plants increases from 245 TWh to 265 TWh annually in a normal year in the reference scenario. In the the low demand scenario generation from hydro power decreases to 200 TWh by 2050. Hydro production in dry years is approximately 30 % lower than in a normal year in the reference scenario, but only 5 % lower in 2050 in the low final demand scenario.

The short fall in dry years in both scenarios is made up by production from biomass fired thermal plants. In 2049 production from biomass in the reference scenario is 56 TWh whilst in a normal year for the period represented by 2050 it is 50 % lower. In the low demand scenario production from biomass is only 19 TWh in 2049, which is only 10 % lower than in 2050.

The greatest difference between the two scenarios is the level of wind power in the system and net exports between dry years and normal years. In the reference scenario large investments in wind power are made in Sweden and Norway by 2030 to meet increasing demand and reduced levels of fossil fuels. The synergy between wind and hydro production becomes more important for ensuring security of supply in dry years towards 2050. In 2030 Sweden has 6,000 MW of wind capacity and Norway 4,000 MW. These increase to 8,000 MW and 7,000 MW respectively in 2050. Danish wind power capacity remains constant at 4,000 MW from 2020 to 2040. Between 2040 and 2050 capacity increases to 10,000 MW in order to replace decommissioned fossil fuel production in Denmark and Germany. Increased precipitation and hydro capacity allows for greater wind power penetration in the Nordic grid to meet growing demand in an uncertain climate. In the low final demand scenario there is no wind in Norway and Sweden, capacity in Denmark is reduced to 6,000 MW and capacity in Finland is halved to 2,000 MW.

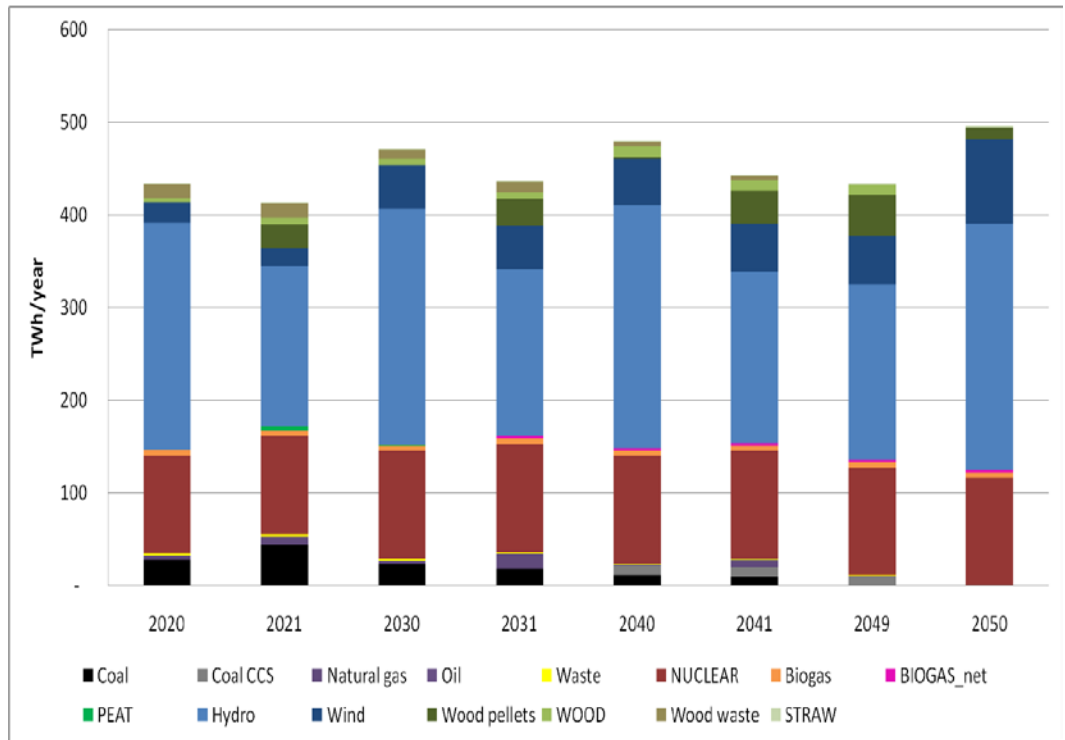


Figure 2: Electricity production in reference scenario

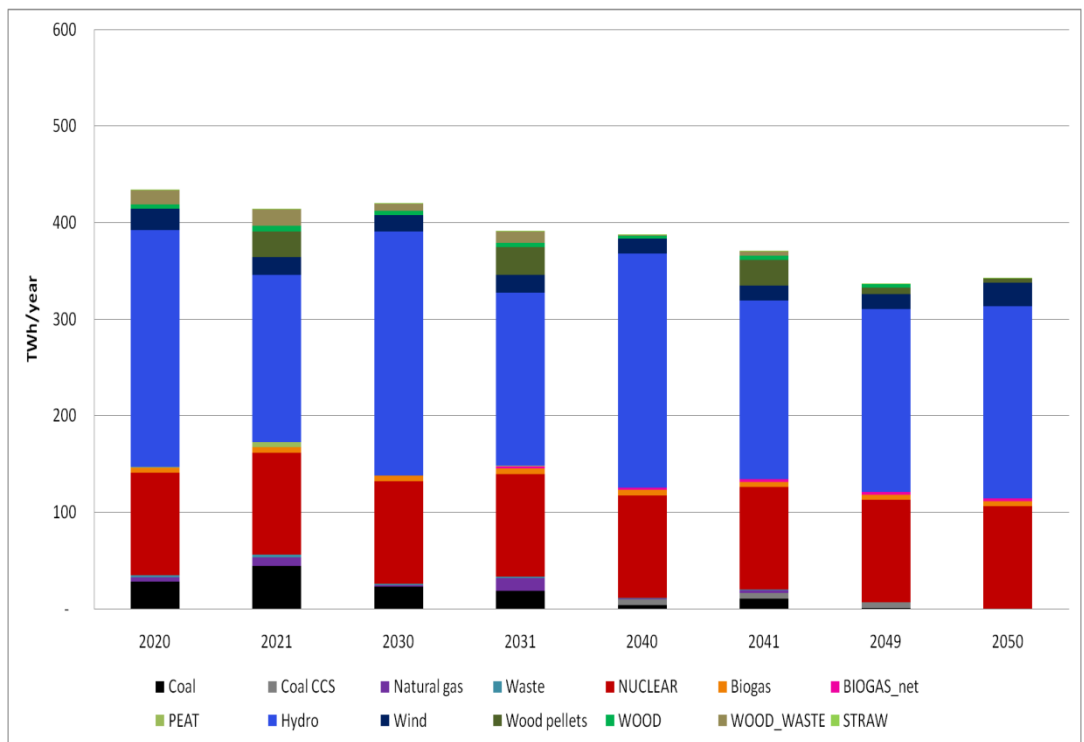


Figure 3: Electricity production in low demand scenario

Net exports are only reduced by 10 % in dry years compared to normal years in the low final demand scenario, whilst in the reference scenario exports are reduced by 75 % in dry years compared to normal years. The major influence of reducing final demand is lower average annual prices in normal and dry years. There is, however, higher price volatility between normal and dry years with differences being more than 50 % in the low demand scenario. Increased levels of precipitation in combination with a lower final demand gives markedly lower electricity prices in all the Nordic countries with the exception of Denmark. Prices in Denmark are lower, but the lack of domestic hydro power reduces the downward pressure on electricity prices due to bottlenecks in the transmission system. If investments in transmission capacity were included in the scenarios this price differential would be reduced as would price differentials in the reference scenario. Annual average electricity prices for the two scenarios are shown in Figure 4 and Figure 5 below.

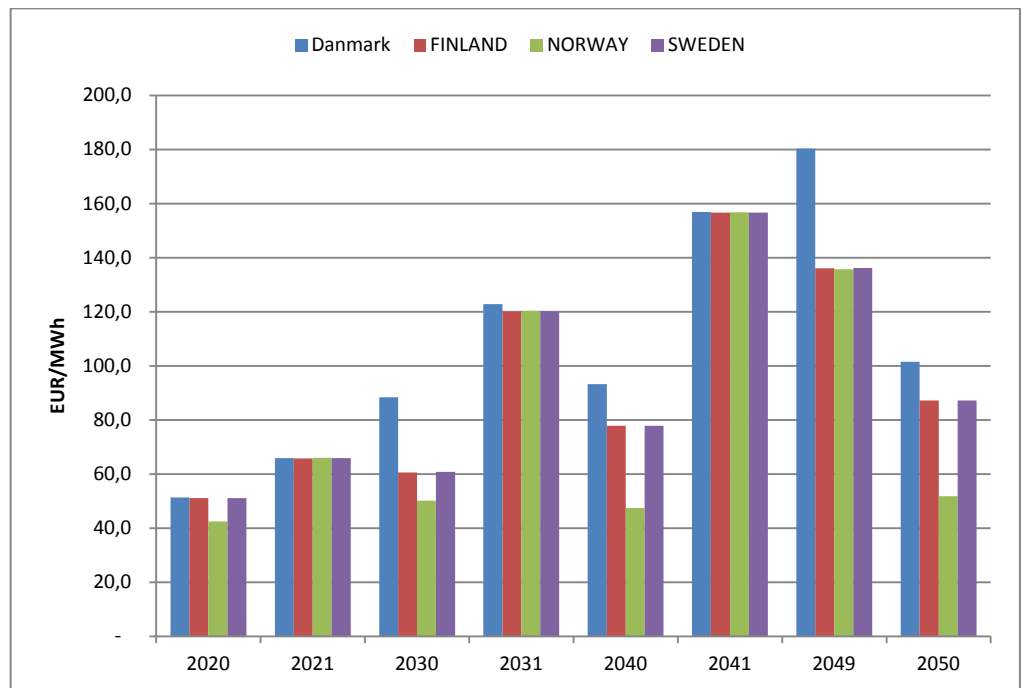


Figure 4 Average annual electricity prices in reference scenario

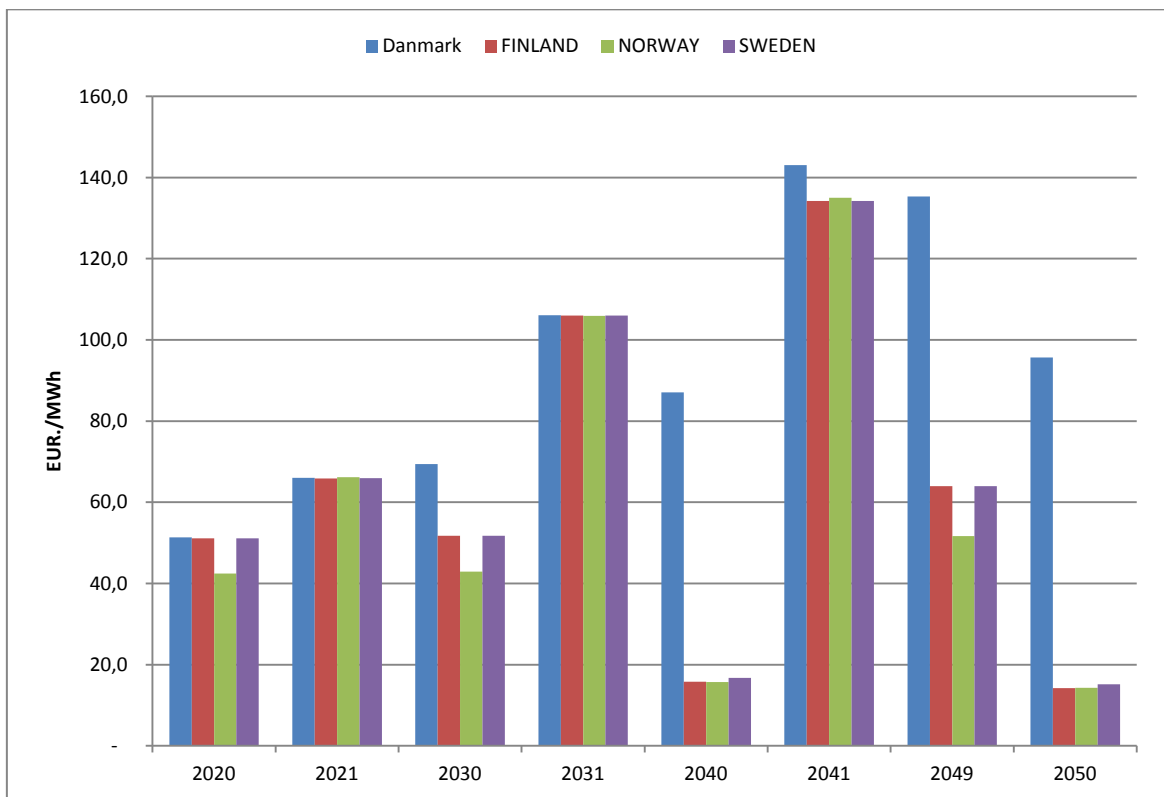


Figure 5 Average annual electricity prices in low demand scenario

1.4 Conclusions

The expected increases in precipitation in the Nordic region will result in greater levels of reliance on hydro power in the Nordic power system. Forecasted demand levels could result in the Nordic power system becoming increasingly vulnerable to extreme weather conditions such as prolonged droughts, which would result in higher average electricity prices in both normal years and drought years. Reducing final demand for electricity could play an important role in making the Nordic power system more robust in an uncertain and changing climate.

The low demand scenario potentially provides a minimum of 65 TWh extra hydro production that could be exported to Europe if additional transmission capacity connecting the two systems were built. Increased interconnections to UTCE would provide additional markets for hydro power, increase security of supply in drought years, provide increased harmonization of wind in Europe and hydro in the Nordic region and play an important role in reducing greenhouse gas emissions in Europe.

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