Nordic electricity supply and demand in a changing climate

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Summary

Global energy demand increases due to economic development in transition countries, such as India. This causes increasing demand for energy carriers, which should raise their prices. Fossil fuels will dominate global energy supply for many years. High energy prices make efficiency and energy conservation profitable. Biomass fuel use is expanding but land also produces food and raw material and climate change impacts upon biomass production. A dilemma is that the wealthy can pay more for automotive biofuel than the poor can pay for food.

Natural gas is used throughout Europe except the larger parts of Sweden, Norway and Finland. The European Union is becoming increasingly dependent on imported gas, primarily from Russia. Security of supply increases if less energy is needed. An issue is whether natural-gas expansion and carbon capture and storage (CCS) postpone the introduction of a sustainable energy system or if they are favourable transition technologies.

There are several studies on long term power supply and demand, which discuss issues such as if industry will consume more or less electricity, and reasonable wind-power expansion with respect to grid investments and balancing hydropower capacity. Phase-out of nuclear power influences electricity export possibilities. Electric cars may more or less replace fuel-driven vehicles. Combined heat and power (CHP) production is likely to expand. Electricity generation and use are thus linked to other energy forms, such as district heating and cooling.

District heating can decrease primary energy supply and reduce import dependency. District cooling saves electricity. Regional networks may be fed by many heat and cooling sources and match energy supply and demand, such as heat from solar panels, hot water for washing machines and cooling of rooms, food and water.

Demand for heating and cooling

Indoor cooling increases in Nordic countries and in countries with rising standard of living. Electric appliances supply more surplus heat in buildings. Keeping indoor temperature within a narrow interval requires energy for cooling or heating, more energy if more narrow.

Thick wall and attic insulation, windows with low thermal leakage and ventilation recovering heat can reduce heat demand significantly. EU requires substantially lower energy use for buildings in the future.

Cooling is normally produced using electricity but heat can be used to produce cooling in absorption machines. If the heat can be produced at low cost in a CHP plant, cooling can become a basis for electricity generation.

Industrial heat demand that occurs throughout the year is favourably served by plants that have low heat cost but large investments and therefore benefit especially from many utilisation hours a year, such as CHP plants, waste incineration or surplus heat from other industries.
Heating – Electricity and district heating as heat sources

Heat losses from European energy conversion, primarily power production, correspond to the heat demand in Europe. District heating can utilise such heat resources that else are wasted to provide space heating and hot water in dwellings, service facilities and industries.

District-heating systems supplied by, for example, biomass-fired CHP plants could gradually replace electric heating, especially in Norway. CHP (co-generation) plants, which produce heat and electricity, utilise fuels better than condensing power plants, where much fuel energy is wasted.

District heating can be a key to sustainable local energy systems and connect heat surplus and heat demand at various temperatures. Fuels may become too valuable for heat-only production. Almost all district heat may rather be by-products from production of other energy carriers, such as electricity and automotive biofuel, in polygeneration plants.

Waste volumes are increasing but need to be smaller in a sustainable society. Waste incineration may therefore partly be seen as a transition technology rather than a basis for a long-term system.

Heat can be recovered for repeated utilisation in industry and finally for space heating. More heat reuse within industries may reduce waste-heat supply to district-heating systems.

Solar heating may be less suitable for houses with district heating because when there is most solar radiation, district heating often comes from surplus resources, such as waste or waste heat.

To use high-quality electricity in a heat pump to obtain semi-quality heat may be inadequate from a comprehensive viewpoint. Heat pumps do often not cover the whole heat demand during cold days but are complemented by electric heating, which contributes to peak demand.

Electric cars as well as polygeneration plants that produce automotive fuel connect the stationary energy system with transport and increase the options for utilising biomass and achieving transportation. The quality of fuels should be utilised to produce much high-quality energy carriers, such as electricity and automotive fuels.

A changing demand

Switching from electric space heating, global warming and better insulated buildings reduce electricity demand and its seasonal variations. Switching from electric heating to district heating from a CHP plant decreases electricity demand and enables increased power generation. Swedish district heating use could increase by 25% if replacing all electric heating in non-rural areas.

At lower heat demand it is beneficial to have CHP plants with high electricity yield, which can produce much power with a small heat sink. District heating temperatures may be reduced, especially when low-energy houses dominate. Heat of lower temperatures may be utilised and a larger primary energy share can instead yield high-quality energy forms.
Heating or cooling in industrial manufacturing processes can be supplied by electricity, fuel, district heating or solar heat. The two latter can be supplemented by boilers to obtain desired high temperatures.

Nordic industry uses much electricity but should adapt to increasing electricity prices. Industrial electricity use can be substantially reduced through less operation of support processes, such as ventilation, outside working hours, which reduces electricity use during nights and weekends and increase the diurnal and weekly variations of electricity consumption.

**Electricity prices**

The electricity market price is basically decided by the highest marginal production cost among the power plants in operation. Now, coal-fired condensing power plants normally are *marginal* plants. Natural gas may in the long run be the marginal fuel for electricity generation, first at low and then at ever higher demand levels. Occasions with renewable electricity as marginal production may occur in systems with much wind power.

A reduced number of emission allowances should raise carbon-dioxide (CO₂) costs and electricity prices. But increased renewable and nuclear capacity and predicted increased precipitation should reduce future electricity prices. Electric cars would increase electricity demand and prices. Increased transmission capacity levels out electricity prices among regions.

Electricity prices at 45-50 euro/MWh at euro 20 per ton of CO₂ and USD 30-50 per barrel of crude oil follows from the efficiency of condensing plants, the CO₂ from coal and the oil-coal price relationship during 2007-2008.

**Long term scenarios for the Nordic power system**

This report presents an analysis of how climate change may influence electricity generation in the Nordic region during 2020-2050. Climate scenarios developed by IPCC and ENSEMBLES indicate increased precipitation in the Nordic region in the future. The Nordic electricity system is dominated by hydropower and changes in precipitation should influence future investments in power production. Political targets related to climate change will channel investments towards CO₂ neutral electricity generation capacity and lower final demand.

The objective of this analysis is to show how changes in precipitation may influence future investments in generation capacity in the Nordic region. 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. (Currently a wet year is defined as having at least 12 % more precipitation than a normal year.)

ii. There will be greater fluctuations in weather patterns in the future with extreme climate events, such as drought, occurring more often than in the past.

iii. Power production in the Nordic region must be fossil fuel free by 2050.

The Balmorel electricity market model was used for the analysis. Balmorel is a partial equilibrium model that assumes perfect competition in the electricity and CHP sectors.
The model optimises investments in generating capacity subject to technology and policy constraints to meet end-user demand, which is assumed 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.

To analyse the effects of changes in precipitation and the phasing out of fossil fuels in the power sector, the three hypotheses were incorporated in the Balmorel model as constraints and two scenarios with different demand levels were developed. More frequent occurrences of extreme weather conditions were represented in the model by four drought years between 2020 and 2050. The inclusion of drought years provides an indication of the investments required in a system optimised for higher levels of precipitation, but with increased risk of extreme climate events.

Input data are based on the assumption that all EU and national policy goals for reduced energy use and CO₂ emissions and integration of renewables have been achieved. Demand data for the model are based on recent projections from the Danish Energy Agency and ENTSO-E.

Nuclear capacity is used throughout the period. CCS is introduced at larger scale in 2040. Electricity prices in normal years are doubled in Denmark but only increased by 25% in Norway during 2020-2050. In drought years, increased biomass and natural gas generation substitutes the shortfall in hydropower production, which results in higher electricity prices. Prices in drought years are from 2030 about 50% higher than in normal years.

A low demand scenario was developed with 10 % reduction in electricity consumption every ten years in all countries from 2020 to 2050. Besides this, a 40 % reduction in demand for electric heating in Norway and Sweden due to improved insulation and switching to district heating and heat pumps was included until 2050. The resulting demand in 2050 is 250 TWh instead of the 400 TWh in the reference scenario. Required wind power capacity is much smaller. Electricity prices are lower than in the reference scenario due to hydro and nuclear power covering a larger portion of demand. In the drought years, the electricity price is much lower than in the reference scenario, especially towards the end of the studied period as the need for expensive generation is much less. But Danish dry-year prices are high if bottlenecks remain.

A fossil fuel free power system optimised to higher levels of precipitation will experience markedly higher prices in drought years. The impact of drought years on electricity prices can be reduced substantially if ambitious energy efficiency initiatives are implemented.

**Scenario conclusions**

The expected increases in precipitation in the Nordic region will result in greater levels of reliance on hydropower 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 hydropower production that could be exported to continental Europe if additional transmission capacity connecting the two systems was built. Increased interconnections to continental Europe would provide additional markets for hydropower, increase security of supply in drought years, provide increased harmonization of wind power in continental Europe with hydropower in the Nordic region and play an important role in reducing greenhouse gas emissions in Europe.
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Foreword

This study was made in the project “Climate and Energy Systems: Risks, Potential and Adaptation” (http://en.vedur.is/ces), which is an integrated, regional project under Nordic Energy Research. The project attempts to demonstrate the effect of climate change on renewable power production and the stability of the Nordic power system.

Impacts on renewable energy sources in a changing climate is an important issue in the Nordic region with its large amount of hydropower production, development of wind power and potential for bio-energy. Uncertainty about the future of renewable resources in a changing climate can have wide reaching effects on the power supply.

Some renewable resources may increase their productivity in the future, but a greater reliance on a few renewable resources may make the Nordic power system more sensitive to occasional extremes such as drought, floods and storms. Changes in the geographical positioning of production units can also create new challenges for the power system, as will changes in demand.

This analysis provides long term scenarios that give an indication of how a changing climate can influence power production from renewable resources as well as the demand for electricity in the Nordic region. These scenarios build on the medium term scenarios developed in the project and have a horizon from 2020 to 2050.

Ea Energy Analyses (Denmark) and Optensys Energianalys (Sweden) have made the long-term scenarios using the Balmorel energy modelling tool. The report also outlines general development in the energy system that influences energy supply and demand.
1. Important issues for the development of the Nordic power system

1.1. Fuel supply and demand

Global energy demand increases significantly due to the economic development in transition countries, such as China, India and Brazil. This causes an increasing demand for energy carriers, which should raise their prices. The fossil fuels oil, coal and natural gas now dominate global energy supply and will be the most important energy sources for several years to come. Higher energy-carrier prices make new efficient technologies, energy conservation and renewable energy utilisation more profitable. Biomass fuels are used in the small-scale for cooking stoves etc. especially in developing countries but to a rapidly growing extent biomass is also used for large-scale energy applications, such as heat, electricity and automotive fuel production, primarily in industrialised countries.

Land is desired to serve needs for food and raw material and more and more also energy. Plants also serve as carbon dioxide (CO₂) absorbers. Fruitful soil is a limited resource. There is competition between using land for food, raw-material and energy-carrier production. It is disputable, how fierce this competition is. Different cultivated plant species may also complement each other in synergetic combinations. But pressure on land use should increase with growing demand for renewable energy. Plants and products that give the best income are preferred. Biomass could supply one-half of present global primary energy (Haberl et al, 2010). Climate change impacts upon biomass production and, thus, biofuel supplies. The impact varies among the regions of the world. Certain products may become more scarce. How agriculture and forestry use will develop and influence starvation, timber prices, energy supplies, etc. is still unknown. However, a dilemma is that a wealthy European car owner is willing to pay more for automotive biofuel than a poor African person can afford to pay for food. The biomass fuel market is getting more global and supplies, demand and prices will be directly and indirectly influenced by climate change. Biomass prices are likely to increase significantly due to the much larger demand for automotive biofuel and other biomass-based energy carriers.

Natural gas

Natural gas supplies in Western Europe are declining and the European Union is becoming increasingly dependent on imported gas, primarily from Russia, which has large reserves (e.g. BDEW, 2008). Russia has exercised its power as energy supplier toward Ukraine, which has damaged also more western countries. Gas transfer capacity will be increased through a new pipeline in the Baltic Sea directly from Russia to Germany. Russia has this far not used gas supply for political pressure directly on Central or Western Europe but that a single supplier dominates gas supply is not desirable for technical, economical and political reasons. To secure energy supply, multiple energy carriers from many different sources are desirable. A reduction of energy demand can help increasing security of supply because less energy is needed.

Natural gas is used throughout Europe except the larger parts of Sweden, Norway and Finland. The Swedish natural gas grid covers only the South-Western part of the country. There are plans for expanding the grid to Stockholm and industrial sites in central Sweden. As with other solutions obviously not sustainable in the long run, an issue is whether natural gas is a favourable transition fuel or if a larger use locks energy supply into a system that postpones the introduction of more long-term favourable alternatives.
The same issue can be raised concerning coal-fired power plants with carbon capture and storage CCS, which largely do not emit CO₂ but store it primarily underground.

Natural gas use for power and heat production is expected to increase at the expense of coal. An advantage with natural gas compared to coal, biomass and other solid fuels is that it more easily can be used in plants with a high electricity yield, that is, combined cycle plants with a gas turbine and a steam turbine. These plants could produce only electricity or be combined heat and power (CHP) plants where the heat also is utilised. Natural-gas-driven condensing power plants without heat recovery may, due to their higher electricity output and lower CO₂ emissions, be more profitable than coal-fired condensing plants at high fuel prices and CO₂ costs.

1.2. Demand for heating and cooling in a changing climate

Since way back in history, we have heated our homes during the cold seasons and let mild air in through the windows during summer nights. But we have also adapted our clothing to the achievable room temperature. Now, comfort requirements are increasing. We do not want to dress to keep warm and we don't want to be sweating. The demand for indoor climatisation through cooling is increased in Nordic countries but also in transition countries with rising standard of living. At the same time, electric appliances supply more and more surplus heat in buildings. In addition, global warming raises the outdoor temperature. These factors increase the demand for cooling. The trend of better insulated houses, on the other hand, reduces the impact of high as well as low outdoor temperatures.

Keeping indoor temperature at a certain level or within a narrow interval requires energy for cooling or heating. The narrower the accepted interval is, the more energy is needed. But an attempt to achieve the perfect indoor climate may require an unsustainable level of energy supply. Sustainability may require a broader temperature interval to be accepted. We can probably not economically and environmentally afford to spend a lot of energy on completely avoiding sweaters and sweat. We may have to stand, for example, +17 or +26°C at certain occasions. That could be a sustainable indoor comfort interval.

Energy demand for space heating can be much lower in refurbished and new buildings than in the average house today. Energy conservation measures can reduce energy use without decreasing indoor climate comfort. Thick insulation can be used for walls and attic and, primarily for new houses, toward the ground. Windows can have multiple panes separated by inert-gas-filled spaces and covered by low-emitting layers to minimise thermal leakage while still transmitting solar radiation. In buildings with controlled ventilation, heat can be recovered from the outgoing air and supplied to the incoming air through heat exchangers. Together these measures may reduce the heat demand (including hot tap water preparation) by one-half in existing buildings. But introducing a new ventilation system in an already built house means a more extensive refurbishment than upgrading insulation and windows because ducts etc. must be installed. Energy conservation measures increase investment costs by general refurbishment of existing buildings and by construction of new houses but should become more and more profitable due to increasing energy prices. EU also requires substantially lower energy use for buildings in the future. In Sweden, there are, for example, many multi-family buildings that were built during the 1960s and 1970s that now need renovation, which should include improvement of the energy standard.
Cooling is normally produced by electric refrigeration machines. More cooling would mean higher electricity demand, especially at high outdoor temperature. In regions with much cooling and hot climate, electricity demand therefore usually has its peaks on hot summer days.

But electricity demand need not increase with cooling supply. Heat can be used to produce cooling in absorption machines. The heat may, for example, be produced in a CHP plant. In that case, cooling, instead of consuming electricity, serves as a foundation for electricity generation. The heat from a CHP plant can be used for heating in winter and for absorption cooling in summer. It increases the plant’s annual utilisation time, power production and profitability. The heat may be supplied directly from the CHP plant to the absorption unit or through a district-heating network.

But the relation between heat input and cold output (coefficient of performance, COP) for absorption cooling machines is poor. Therefore, the heat cost must be much lower than the electricity price to make absorption cooling profitable compared to conventional compression cooling. Today, it is primarily heat from waste incineration that is used but expected higher electricity prices can make absorption cooling expand. If CHP heat is used, a higher electricity price also makes the heat cheaper due to revenues from sales of simultaneously produced power.

In total, there are two opposite trends concerning electricity use for cooling. Electricity consumption increases due to higher cooling demand but it can decrease through deployment of absorption cooling.

**Industrial heat demand**

In industries, there is demand for space heating and hot water like in other buildings. But there are also manufacturing processes that need heat in various forms, for example, for melting, drying and heating of goods. Such heat demand may also to a larger extent be covered by heat from a CHP plant or other sources in a district-heating system.
The heat demand in industrial processes does normally not depend on outdoor temperature but rather on working hours. Depending on process and industry, demand may occur only intermittently during daytime on weekdays or more or less continuously throughout the year. The more the demand has the latter character, the better it can serve as an outlet for heat from a CHP plant. It may also be served by other plants that have rather low heat cost but require large investments and therefore benefit especially from many utilisation hours a year, which shorten pay-back time. It could be heat from waste incineration plants, with or without electricity generation, or surplus heat from other industries.

Industrial processes require different temperatures. In some cases, high-temperature steam is needed whereas other demand can be satisfied with heat at low temperature. The steam and heat can be supplied by a CHP plant, yielding less or more, respectively, electricity per unit of thermal energy. Waste incineration and, even more, industrial surplus heat are more suitable for demand at lower temperatures.

1.3. Heating – CHP and electricity as heat sources

Heat losses from European energy conversion, primarily power production, correspond to the heat demand in Europe (Ecoheatcool, 2006b). District heating can utilise such heat resources that else are wasted and can reduce the environmental impact of energy supply.

District heating covers 10% of the total heat demand in households, service and industry in the countries of EFTA (Norway, Iceland, Switzerland, Liechtenstein) and EU. Sixty percent of this heat are produced in CHP plants (Euroheat, 2007). There are also industrial co-generation plants that produce electricity as well as heat or steam for manufacturing processes. In the European Union, Norway, Iceland, Switzerland and Croatia, 530 TWh of district heating are annually delivered in 5 000 district heating systems. Sixty percent of this heat are supplied to households, whereas industry and service each consumes 20% of the district heating (Ecoheatcool, 2006a, b).

Countries with high shares of district heating are Denmark, the Baltic countries, the Czech Republic, Sweden, Poland and Finland but in the large countries France, the UK and Germany, the district-heating fraction of heat supply is low (Euroheat, 2007).

Among Nordic countries, district heating is least developed in Norway due to historically abundant hydroelectricity supplies. There is a large potential in developing modern Norwegian district-heating systems supplied by CHP plants and gradually replacing electric heating.

District heating can play a key role in sustainable local energy systems. The networks of hot-water pipes can connect heat surplus and heat demand. In the future, fuels may be too valuable to only be used for heat production. Almost all heat supply to a district-heating system may rather be by-products from production of goods or other energy carriers, such as electricity and automotive biofuel. A local district-heating system may be integrated with other district-heating networks and with industrial steam systems. Energy flows between connected systems may increase.
Figure 2. Combined district-heating and electricity production on a cold winter day in Linköping, Sweden

District-heating systems can comprise a multitude of plants that supply heat and facilities that need heat:

• Biomass-fired CHP plants with heat-rich output and natural-gas-driven CHP plants with electricity-rich output
• Waste incineration plants that produce heat and, possibly, some electricity
• Industrial plants or other facilities with surplus heat at various temperatures
• Polygeneration plants that produce automotive fuel, electricity, cooling and by-product goods, and consume and produce, respectively, heat at different temperature levels
• Dwellings, service facilities and industries with demand for space heating, hot water and cooling of rooms, food and water
• Industrial sites with manufacturing processes that require thermal energy with various qualities and temporal variations

Boilers producing heat only, fired by biomass or even fossil fuel, are likely to be needed also in the future as a complement to cover the very peak demand and as a reserve by malfunction and overhauling of the main heat supply.

CHP (co-generation) plants, which produce heat and electricity, utilise fuels to a much larger extent than condensing power plants, where one-half to two-thirds of fuel energy is wasted. Rising fuel prices and CO₂ costs increase the electricity generation cost in condensing power plants, which should stimulate the expansion of CHP plants.

Table 1 shows, as an example, the installed Swedish capacity for CHP production with renewable fuels. In many plants, several fuels can be used. For these plants, the capacity
fraction that can use biomass and waste, respectively, is included in the table. The major part of the industrial cogeneration is based on by-products from pulp manufacturing, such as black liquor. The 2009 figures are based on Svensk Energi (2001-2008), Svensk Fjärrvärme (2007), Wiberg (2007) and Energimyndigheten (2009).

Table 1. Swedish renewable CHP capacity (MW electricity)

<table>
<thead>
<tr>
<th></th>
<th>2009</th>
<th>2020</th>
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<tbody>
<tr>
<td><strong>District heating systems</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Biomass</td>
<td>1 340</td>
<td>2 100</td>
</tr>
<tr>
<td>Waste</td>
<td>340</td>
<td>600</td>
</tr>
<tr>
<td><strong>Industrial cogeneration</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Biomass</td>
<td>990</td>
<td>1 100</td>
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The predicted capacity for 2020 is based on the Swedish energy agency’s forecast for Swedish CHP production (Stem, 2009) and assumed operation. Annual utilisation times are here supposed to be longer than today due to better profitability of electricity generation. The CHP production is assumed to be larger than in the forecast because the latter only considered policy instruments planned in 2008.

Waste is one fuel for boilers and CHP plants. Waste volumes are increasing but should be smaller in a sustainable society. The EU waste management hierarchy states that waste should primarily be prevented, then reused, subject to material recovery or energy recovery and, as a worst alternative, disposed (in landfills or through incineration without energy recovery). Reuse and material recycling should increase. Waste incineration may therefore partly be seen as a transition technology rather than a basis for a long-term system. But there should always be waste fractions that preferably are taken care of by incineration.

Figure 3. Fuel resources: wood and waste

**Surplus heat**

Surplus industrial thermal energy can have various temperatures and pressures. The higher these are, the more purposes the energy can be utilised for. High quality forms, such as high-pressure steam, can be used for electricity generation and industrial processes but lower quality forms may only be useful for space heating. Heat can be
recovered for repeated utilisation in industrial processes, in for example pulp and paper mills, and finally for space heating.

Thermal energy can, thus, be used in sequence for several purposes from steam with high temperature and pressure, which is required for certain industrial processes and which can generate electricity, via low pressure steam with lower temperature, suitable for other manufacturing processes, and heat that can be used for hot water and space heating, to low-temperature waste heat, which needs upgrading with a heat pump to be useful.

To use the thermal energy efficiently, the quality of all flows should be utilised. That may mean that more heat than today is reused within an industry or in a cluster of industries there one plant produces heat that another plant can use in an industrial ecologic system, whose total thermal output only consists of real waste heat that cannot be used for other purposes than space heating and hot water. This may reduce waste-heat supply to district-heating systems in the future. Co and poly-generation plants and industrial-ecology systems may also exist without district heating if there is outlet for the useful heat within the systems. For certain purposes, a lower energy quality than now used may be sufficient (e.g. heat instead of steam). Low-temperature heat might better be wasted because to use high-quality electricity in a heat pump to obtain semi-quality heat may often be inadequate from a comprehensive viewpoint.

**Poly-generation plants**
Poly-generation plants that produce automotive fuel establish stronger links between the stationary energy system and transport, like electric cars also do. These technologies increase the number of options for utilising an energy resource, such as biomass, and covering an energy service demand, such as transportation.

The energy quality of fuels should, like for thermal energy, be utilised to produce as much energy carriers as possible with as high energy quality as possible, that is, that can be used for many purposes and transformed into several desired energy forms. Such versatile energy carriers are electricity and various automotive fuels, which can drive engines. As by-products can also be produced; goods, heat and cooling.

In total, more electricity is likely to be produced from biomass, in co-generation and poly-generation plants.

**Switching energy carrier for heat supply**
Space heating can be supplied in several ways. Often, there is a water-filled radiator in each room fed from a waterborne system of hot water pipes, which can comprise a whole house or be separate for every apartment in a multi-family building. Such a system can be supplied by various devices and it is relatively simple to install new equipment that uses another energy source. Common heat sources are boilers, run by electricity or fuel, heat pumps, district heating and, emerging, solar panels. Electric heat pumps in buildings normally utilise low-temperature heat in ground, outdoor air or exhaust air from ventilation. But electricity is also used for space heating by electric resistance panels or electric storage radiators. (The latter include material that only slowly gets cooler when power is switched off.) When using such devices it is more difficult to switch to another energy source because in most cases a hot-water-pipe system must be installed. A stove firing, for instance, firewood or wood pellets is sometimes used as complement to the main heat source and may occasionally reduce, for example, the electricity demand for
heating. Solar heating and heat pumps using outdoor or ventilation air may also be installed to complement other heating and reduce the need for external energy supply. Solar heating may be less suitable for houses with district heating because when there is most solar radiation, district heating in many systems comes from surplus resources, such as waste heat or waste incineration.

Hot tap water is mostly prepared by the same energy source as the space heating but sometimes electricity or solar heating is used for tap water and something else for space heating. Domestic hot water demand has large diurnal but small seasonal variations.

An electric boiler may be replaced by an electric heat pump or any of the other heating devices that can be connected to a waterborne heating system, such as a wood-pellets-fired boiler. Electric panels and storage radiators may also be switched to other heat sources provided a heat distribution system is installed.

Heat pumps do often not cover the whole heat demand during cold days because a ground heat pump with capacity to do that would be too expensive and the heat in outdoor and ventilation air is insufficient. Therefore, electric heating mostly complements heat pumps during cold days, which contributes to electricity peak demand.

**District heating demand**

Switching from electric heating to district heating from a CHP plant impacts upon the electricity system twofold; through decreased demand and increased generation enabled by the larger heat sink for co-generation. District heating supplied to consumers could increase by 25% if all electric heating in Swedish non-rural areas was switched to district heating.

New and refurbished houses with low heat demand are becoming more frequent. At lower heat demand it is more beneficial to have CHP plants with high electricity yield, which can produce much power with a small heat sink. If district heating originates from surplus heat it may be seen as wasted resources to reduce heat demand through, for instance, insulation. But buildings should be useful for decades to come without extensive refurbishment and during their lifetimes heat supplies may become more scarce.

New applications for district heating, such as absorption cooling and industrial heat demand, can replace heat demand lost through energy conservation and global warming. Water heating for washing machines and dishwashers can also be switched from electricity to district heating. In southern Europe, waste heat can be used for seawater desalination. In the long run when low-energy houses dominate the building stock, district heating temperatures may be reduced, heat of lower temperatures than today may be utilisable and a larger share of the input primary fuel energy can be transformed into high-quality energy forms, such as electricity and automotive fuel.

The seasonal variations of district-heating demand would decrease due to increased district-heating supply to absorption cooling, primarily in summer, and to non-outdoor-temperature dependent industrial processes. Smaller seasonal heat demand variations are also due to lower space heating demand, primarily in winter, as a result of warmer climate and better insulated buildings with heat recovery.
1.4. Power load profiles: changing demand due to climate and other factors

Electricity is a high-quality energy carrier, which primarily should be utilised for purposes where less valuable energy forms cannot be used, as examples, for lighting and machine operation. Electricity use for heating should decrease but the little heat supply needed in low-energy houses may be favourable to cover with electricity because the larger investments in more elaborated heating systems can be unprofitable due to short annual utilisation time.

Switching from electric space heating to other heat sources reduces electricity demand and the seasonal variations of electricity demand. Global warming, switching to heat pumps and reducing space heating demand through energy conservation has similar impact on the electricity demand. Increased use of electricity for cooling in summer can contribute further to a levelling out of the electricity demand levels of different seasons, but this impact may be alleviated by installation of heat-driven absorption cooling devices.

Industrial electricity demand is likely to decrease due to less manufacturing industry and expanding service business. Nordic industry was used to low electricity prices and uses much electricity (Elforsk, 2006). Nordic industry has had a comparative advantage to its competitors in the low electricity price. But the price difference is now gradually reduced. Electricity consumption should therefore decrease also due to the increasing electricity prices.

Newspaper pulp and paper mills have, for instance, high electricity demand and should, if possible, be situated where the electricity price is low and raw-material supply convenient. If owners of the even more electricity-intensive metal melting works would find more favourable electricity prices elsewhere, Nordic electricity demand would be reduced by 20 TWh a year (Elforsk, 2006). However, remote areas in Nordic countries with hydropower resources (such as Iceland) should remain among the most favourable locations in the world for aluminium melting works etc.

But Swedish small and medium-sized industries can reduce electricity use substantially (e.g. Henning and Trygg, 2008). This is probably the case also for other Nordic countries where electricity prices have been low. In continental Europe, less electricity is normally used by manufacturing (Nord-Ägren, 2002).

Electricity used in industries for the supporting processes lighting, ventilation and pressurised air can often be decreased through reducing operation to occasions when these services are necessary. Higher electricity costs, control systems and increased awareness among personnel would bring wasted electricity use, especially during non-working hours, to a minimum. Electricity used for space heating and hot water can, as in other buildings, be replaced by district heating, fuel or solar heat.

Less operation of industrial support processes, such as ventilation, outside working hours and less electric space heating reduce electricity use during nights and weekends and increase the diurnal and weekly variations of electricity consumption. At the same time, the seasonal variations in electricity demand for heating are decreased due to warmer climate and better insulated buildings. This trend may be emphasised by switching from electric heating to other energy sources and there would be less electric heating demand per heated floor area, especially in winter.
Electricity used for heating or cooling in manufacturing processes can also to a large extent be replaced by district heating, fuel or solar heat. District heating alone can only give moderate temperatures, whereas fuels can yield steam. But district or solar heating can be used to supply basic heat that is supplemented by boilers at site to obtain desired high-quality thermal energy. Heat and steam may also be supplied from poly-generation plants.

![Renewable energy sources: solar heat and wind power](image)

**Figure 4. Renewable energy sources: solar heat and wind power**

### 1.5. Electricity prices

The electricity price in the electricity market is basically decided by the short-range marginal cost for power production, that is, the highest electricity generation cost among the power plants that are in operation at the moment. Now, these so-called marginal plants are normally coal-fired condensing power plants.

Power plants with lowest operation costs are run in the first place and serve the base load, typically hydroelectric power plants and nuclear condensing power plants. The higher the electricity demand is, the more costly power production is dispatched. Therefore, the electricity price rises with the demand.

As natural-gas-driven combined cycle condensing power plants expand and old coal-fired power plants are shut down, natural gas may become the marginal fuel for electricity generation, first at low and then at ever higher demand levels. But this is a slow process. There is a lot of coal-based power production capacity that probably mostly will be marginal plants during the next decades. A phase-out of natural gas would occur even later and occasions with renewable electricity as marginal production in a large system are likely to be rare into a distant future. But wind power can be the marginal production source in a region at occasions with much wind, little demand and congestion in export capacity from the area.

#### Main factors that influence electricity prices

The electricity price in an area depends on the regional electricity generation costs, power production capacity, water supplies in dams, electricity demand, power transmission capacity between areas in the same or different countries and the electricity price in neighbouring regions.

Electricity generation costs depend on fuel prices, operational costs and policy instruments, primarily emission allowances and taxes as well as electricity certificates or feed-in tariffs. Coal-fired condensing power plants are the main price setters in the electricity market and their electricity generation costs mainly depend on the prices of
coal and emission allowances. Increased global demand is likely to raise fuel prices. Global coal reserves are much larger than oil supplies and coal prices only increase moderately with oil prices. But a certain coal price increase is most likely. CO2 emissions must be reduced and emission restrictions should be tightened, which would increase the price on emission allowances. In total, electricity generation costs in coal-fired condensing power plants should increase, which raises electricity prices.

Higher power production capacity means a larger offered electricity supply, which should reduce electricity prices. EU goals include increased renewable electricity production, which is stimulated by feed-in tariffs and electricity certificates. These should bring about new power production capacity; partly wind power plants with low operation costs, which should reduce electricity prices. Swedish nuclear policy now allows new reactors with higher capacity to replace the existing ones. If this option is fully used, Swedish nuclear electricity supply could be doubled in the 2020s. It would substantially influence the electricity market and is likely to reduce electricity prices because short-range marginal costs for electricity from condensing plants are lower for nuclear than for coal.

Precipitation and stored water in dams significantly influence the electricity generation in hydropower plants. In Sweden and, even more, in Norway, where hydroelectric power is dominant, water supplies influence electricity prices substantially even if their importance were much larger in the former technically and economically isolated national power systems. During a dry year, the offered hydro electricity supply is much smaller than for a wet year. Climate changes increase precipitation, which puts more hydro electricity on the market and lowers the electricity price. Hydropower dams also serve as energy storages, which level out electricity prices between different occasions. Water that is not used at one occasion can be used at another time instead of more costly generation. The water has a value that transfers electricity prices between various occasions.

Electricity demand depends, among other things, on economic situation, material standard of living (number of electric appliances, etc.), how electric heating and cooling develops and to which extent electric or hybrid cars are introduced. There are demand variations during days and nights, between weekdays and weekends and among seasons due to working hours, holidays, use of electric lighting (depending on number of daylight hours), use of electric cooling and heating (depending on outdoor temperature), etc. The more energy services that are desired to be covered by electricity, the higher is the demand, and thus the electricity price. This must be regarded by the trade-off among various candidate automotive prime movers, such as electricity and biofuels.

Increasing power transmission capacity within and between countries levels out electricity prices among different regions. When transmission capacity is not used at all or fully utilised, smaller changes in electricity production or consumption in an area does not influence the region beyond the bottleneck. When the changes in power supply or use are large enough to alter the regional electricity price to such an extent that transmission is desired to increase from zero or decrease from full capacity utilisation, there is interplay between electricity generation, use and prices in the two areas.

Increasing transmission capacities between the hydro-nuclear Swedish-Norwegian power system and the surrounding more coal-based system emphasizes the electricity price setting by coal condensing plants and raises Nordic electricity prices.
**Future electricity prices**

The Swedish energy agency assumed that emission allowances cost Euro 30 per ton of CO$_2$ and oil costs USD 90 per barrel until 2030. The predicted average Swedish electricity price is SEK 470 per MWh throughout the period (Stem, 2009). One SEK equalled euro 0.10 in 2010.

Two German studies indicate base load electricity prices between 45 and 50 euro/MWh at a CO$_2$ price of 20 euro/ton and crude oil prices at USD 30-50 per barrel during 2015-2020. All prices increase slightly during the period (EWI, 2007, UBA, 2008). Another German study predicts a lower electricity price for 2015 and that base load electricity can cost less than 50 euro/MWh in 2020 even if the CO$_2$ price is close to 40 euro/ton and the crude oil price exceeds 60 USD/barrel (BDEW, 2008).

Electricity prices at 45-50 euro/MWh at euro 20 per ton of CO$_2$ and USD 30-50 per barrel of crude oil follows from the CO$_2$ amount released by coal incineration, the efficiency of coal-fired condensing power plants and (Kohlenstatistik, 2009) the oil-coal price relationship during 2007-2008. But 40 euro per ton of CO$_2$ and a crude oil price of 60 USD/barrel should, based on the same relationships, rather result in a price of electricity from coal-fired condensing plants at 70 euro/MWh, and electricity from gas-fired combined cycle condensing plants would be even more expensive at these CO$_2$ and oil prices.
2. Review of some studies on long term energy supply and demand

In this section, some studies on energy supply and demand in the future are reviewed. The studies comprise Nordic countries, Germany or Europe and most of them focus electricity but supply and use of electricity is linked to other energy forms, such as district heating and cooling.

2.1. A vision for European district heating & cooling toward 2050

A vision for the development of district heating and cooling in Europe via 2020 and 2030 to 2050 has been elaborated by the District heating and cooling plus (DHC+) technology platform, which consists of European district heating and cooling stakeholders (DHC, 2009).

According to the vision, district heating has expanded throughout Europe in 2020. District heating has doubled its share of the European heat market to 20%, which has decreased primary energy supply by 600 TWh and reduced European import dependency. One-fourth of district heating will be based on renewable sources, primarily biomass and waste, and polygeneration of heat, electricity and automotive biofuel has expanded. More industrial surplus heat, also at low temperatures, is utilised. All European DH systems perform as the best systems do now. District cooling covers 25% of the cooling demand in Europe in 2020, which saves 60 TWh of electricity a year.

In 2030, District heating and cooling infrastructures are fed with a variety of heat and cooling sources, such as excess heat from solar panels on buildings. Local energy resources are utilised in several ways. The interaction between various forms of energy supply and demand at different temperatures is optimised. District heating is around 2030 used instead of electricity in, for example, washing machines, tumble dryers and dishwashers. Electricity can be reserved for purposes where no other form of energy supply is possible, which reduces the need for replacing condensing power plants at the ends of their lifetimes.

In 2050, there are district heating and cooling networks with carbon neutral supply in most European towns. Local grids are interconnected to establish regional heating and cooling networks (DHC, 2009).

The study emphasises the means of district heating to utilise resources that are difficult to use for other purposes and to avoid consumption of more valuable energy forms, such as fuels and electricity. But for the vision to be realised, the awareness of district-heating benefits must be increased and its expansion facilitated.

2.2. The Swedish Energy Agency’s forecast until 2030

The Swedish energy agency has presented a forecast for Swedish energy supply and use until 2030 (Stem, 2009). The forecast is based on the policy instruments that were decided upon until 30 June 2008. Here, the main scenario is described.

Energy use in industry and, even more, for transport increases due to expanding manufacturing and foreign trade, whereas slightly less energy is used in dwellings and for service. In industry, more electricity is consumed and forest industry switches from fossil fuels to biomass fuels. Electric hybrid vehicles and diesel consumption increase. Energy
and electricity use for heating of buildings decreases. Oil and electric heating are replaced by heat pumps, district heating and biomass.

The EU and national goals of using about 50% renewable energy sources in 2020 should be achievable. The total energy supply would be almost 700 TWh in 2030 (6% more than now); thereof one-third is nuclear fuel.

Twelve TWh of automotive biofuel (mainly ethanol), 19 TWh of waste and 120 TWh of other biomass-derived fuels will be used in 2030. The total biomass use for energy purposes is 30% larger than now. The use of district heating increases by 10% and the domination of biomass and waste as main fuels becomes even more manifest.

Combined heat and power (CHP) production is doubled, largely through biomass and especially in CHP plants that produce district heating but also through industrial cogeneration. Nuclear capacity is also increased. Wind power is expected to expand significantly during the next ten years but then to maintain an annual generation of 7 TWh. However, Swedish electricity consumption will increase very little, which enables an electricity export of 25 TWh during 2030 (Stem, 2009).

This study does not pretend to outline a sustainable energy system but rather a forecast of the situation that is brought about by current economic trends and existing policy. The results emphasize that stronger instruments are required to achieve a more sustainable system.

### 2.3. A Scenario for 2030 by The Swedish Academy of Engineering Sciences

The Royal Swedish academy of engineering sciences outlines an energy system for Sweden in 2030 that the group considers sustainable (IVA, 2009). Extensive energy conservation will take place, especially in buildings, but total Swedish energy demand will be maintained or slightly increasing until 2030 due to economic and popular growth.

Much less fossil fuel is used in 2030. Oil will only be used in industry and air, sea and long-distance-goods transport. Biomass will produce more electricity and heat. District heating will expand and help utilise more industrial waste heat. Hydroelectric capacity will have some expansion until 2030 due to modernisation and new plants. Nuclear capacity is maintained or increased. There will be more distributed generation, whose surplus will be fed into the grid. Wind, wave and solar power production will increase.

Concerning wind power, IVA finds a production of 15 TWh in Sweden in 2020 reasonable with respect to power grid investments and balancing hydropower capacity. This is half the level, Swedish Government aims at facilitating. Domestic and international transmission capacity will be increased to help balancing fluctuating wind power production.

Electricity demand may increase slightly until 2030. Efficient electric and hybrid cars (600 000 cars using 1.5 TWh of electricity in 2020) will be used for personal transport. It would reduce oil dependence and carbon dioxide (CO₂) emissions substantially. In the long run, all private cars should be electric and they would annually consume 10-15 TWh of electricity (IVA, 2009).

This study emphasizes the role of electricity for a carbon neutral energy system but is, on the other hand, very sceptic to an extensive wind power capacity expansion.
2.4. **Effective use of wind power in Denmark**

Energinet.dk developed a scenario for the effective use of wind power in Denmark. The scenario is based on the assumption that there will be 6700 MW of installed wind power in Denmark in 2025 and shows how this, along with deployment in neighbouring countries, can be used efficiently. The scenario includes the introduction of heat pumps in district heating systems and for other space heating. Heat pumps supply 15% of the total heat demand in the district heating sector and 50% of space heating demands outside of district heating areas. Fifteen percent of the total road transport sector is based on electric cars.

The results of the scenario are that Denmark moves from being a power exporter to a gross importer of electricity. Total power consumption increases by 7 TWh annually but CO$_2$ emissions are reduced by 5 Mt/year and total energy use in Denmark is reduced by 24 TWh annually. This results in a total saving of DKK 2.5 billion per year. (One DKK equals 0.13 Euro) If increased interconnector capacity to neighbouring states is introduced, CO$_2$ emissions are reduced by a further 1 Mt annually and total savings increase to DKK 4 billion annually.

2.5. **German ministry for environment’s *Leitstudie 2008***

The German ministry for environment has presented a scenario that is meant to reflect a possible and realistic development, especially concerning the expansion of renewable energy sources (BMU, 2008). Here, the main scenario (Leitszenario) of the study is reflected.

The goal that renewable energy should cover 20% of the total energy demand in 2020 would not be quite fulfilled in Germany but 30% of the electricity will be renewable. One-half of German electricity comes from renewable sources in 2030 and 90% in 2050. Nuclear power is phased-out completely during the 2020s. New coal-fired power plants will be built but the new gas-based electricity generation capacity would be much larger and mainly be due to CHP plants.

CHP and district heating expand considerably and play significant roles in reducing CO$_2$ emissions due to high conversion efficiency. But heat demand will be 20% lower in 2020 and one-half of present level in 2050. By that time, 50% of the heat is supplied through renewable energy carriers. Energy use for transport is 30% lower in 2050. 20% of automotive fuels could be biofuels.

Due to more efficient energy utilisation, German primary energy use in 2050 is almost 50% lower than now, and it consists to one-half of renewable energy. Coal use is cut by 90% and gas consumption by one-half. German energy import is 40% of the present level, which increases security of supply, and CO$_2$ emissions are 80% lower. Without nuclear phase-out, less renewable energy would be used and less CHP capacity would be installed and CO$_2$ emissions cannot be reduced by 80% (BMU, 2008).

The scenario reflects an optimistic development where emission and efficiency goals basically are met but it requires a substantial restructuring of energy supply and use.
2.6. German energy industry’s energy concept for 2030

The German Bundesverband der Energie- und Wasserwirtschaft has presented scenarios for the development of the German energy system until 2030 (BDEW, 2008). Here some common trends for the scenarios are described.

There is much more renewable electricity generation in 2030, especially from wind power (maximum 45 GW in Germany) and biomass. By strong wind and low demand, Germany would export electricity. Phased-out German nuclear power would, on the other hand, partly be replaced by imported nuclear electricity.

Coal-fired condensing power stations are used less but there is some expansion of gas-fired combined cycle condensing plants. Carbon capture and storage (CCS) will in Germany primarily be applied to lignite-fired plants due to its cost (by moderate CO₂ prices) being lower than for hard coal because lignite open-cast mines that already exist today can still be used in 2030. Heat demand decreases slightly and less gas is used for heating in 2030, but gas-fired CHP plants with high electricity-to-heat output ratios have replaced old coal-fired ones (BDEW, 2008).

In this study, coal and nuclear power are emphasised as the basis for power supply. There are also substantial investments in renewable electricity generation but the report shares wind-power scepticism with the Swedish IVA (2009) study.
3. **Long term scenarios for the Nordic power system**

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 (Nordisk Energiforskning, 2010).

The Nordic power system is dominated by hydropower. There is a correlation between precipitation levels and the cost of electricity on the Nordic power market as shown in Figure 5. The influence that hydropower has on the Nordic electricity market means that future changes in precipitation levels due to climate change should have a strong influence on future investments in power generating capacity.

![Figure 5. Electricity prices in East Denmark 2000 - 2008 and their correlation to precipitation and other factors (One DKK equals 0.13 Euro).](image)

Climate scenarios produced by IPCC (2007) and ENSEMBLES (http://ensembles.eu.metoffice.com) 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 that a significant change can be expected in the seasonal distribution of water runoff, with an
increase throughout the entire country in the winter and decreases in the summer (Beldring et al, 2010).

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

Infrastructural investments in the power sector generally have technical and economic lifetimes of 20 years and longer. This means that many investments made in the near future will function under a changing climate and be affected by shifting patterns of supply and demand. Previously it has been possible to make investment decisions in the power sector based on past experiences. There is, however, no historical data available for investments made in a changing climate.

3.1. 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 have increased their net electricity export to continental Europe by 2020. The study indicates that the NordPool 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 continental market and lack of hydropower generation. The fall in electricity prices is made with the assumption that there will be no dry or drought years, which would otherwise have an impact on hydro-electricity costs.

The aim of this analysis is to give an indication of possible consequences of climate change for renewable power production in the Nordic region. 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 extreme weather conditions in the form of prolonged droughts could potentially pose a serious stress factor for an increasingly hydro dominated power system. The scenarios are intended to provide an indication of how robust the future Nordic power sector may be in dealing with occasional climate events, such as drought, if investments are optimised for increased precipitation scenarios. 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.

3.2. 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, carbon dioxide (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 electricity 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.

**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 normal year. Climate change is expected to result in more extreme climatic events occurring more often. 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. 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 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 the period in both scenarios. Swedish nuclear power capacity in 2020 is based on existing plants. Hydroelectric capacity expansion may take place in Norway but in Sweden and Finland only a small increase in hydropower capacity is assumed.
Electricity consumption in the scenarios

This analysis also focuses 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 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 2 shows the final electricity demand for the Nordic countries used in the reference scenario.

Table 2. Electricity consumption in reference scenario (TWh)

<table>
<thead>
<tr>
<th></th>
<th>2020</th>
<th>2030</th>
<th>2040</th>
<th>2050</th>
</tr>
</thead>
<tbody>
<tr>
<td>Denmark</td>
<td>31.7</td>
<td>34.2</td>
<td>36.6</td>
<td>40.7</td>
</tr>
<tr>
<td>Finland</td>
<td>84.4</td>
<td>83.1</td>
<td>81.7</td>
<td>80.4</td>
</tr>
<tr>
<td>Norway</td>
<td>120.2</td>
<td>124.2</td>
<td>128.6</td>
<td>133.1</td>
</tr>
<tr>
<td>Sweden</td>
<td>138.8</td>
<td>139.4</td>
<td>139.9</td>
<td>140.5</td>
</tr>
</tbody>
</table>

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 space heating in households. A reduction in electricity consumption for space heating in Norway and Sweden of 40% is assumed due to switching from 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 3.

Table 3. Electricity consumption in low demand scenario (TWh)

<table>
<thead>
<tr>
<th></th>
<th>2020</th>
<th>2030</th>
<th>2040</th>
<th>2050</th>
</tr>
</thead>
<tbody>
<tr>
<td>Denmark</td>
<td>31.7</td>
<td>28.5</td>
<td>25.6</td>
<td>23.1</td>
</tr>
<tr>
<td>Finland</td>
<td>84.4</td>
<td>76.0</td>
<td>68.4</td>
<td>61.5</td>
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<tr>
<td>Norway</td>
<td>120.2</td>
<td>104.2</td>
<td>86.6</td>
<td>68.8</td>
</tr>
<tr>
<td>Sweden</td>
<td>138.8</td>
<td>120.7</td>
<td>100.9</td>
<td>81.0</td>
</tr>
</tbody>
</table>

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 (IEA, 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 for space heating in 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, especially reducing the operation of industrial support processes (such as ventilation) outside of working hours, have the potential to reduce electricity consumption considerably. (See section 1.4 for details.)

Electricity consumption is likely to be significantly reduced due to a shift from direct electric heating to district heating (Fidje et al, 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. The implementation and expansion of combined heat and power (CHP) plants in the Nordic region will provide an alternative to electric heating in communities. (For further information, see section 1.3.)

Additionally, thick wall and attic insulation, windows with low thermal leakage and ventilation recovering heat are likely to reduce energy demand for heating buildings significantly. (See section 1.2 for details.)

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, electricity consumption due to electric cars is not included.

3.3. 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 supply system. Thereby the model simulates the detailed dispatch of the power production units, taking into account:

- Electricity and heat demand
- Technical and economic characteristics for each kind of power 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 Nordic and Baltic countries as well as Germany. Electricity 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.

3.4. 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, total demand in the Nordic region is reduced from 375 TWh in 2020 to 250 TWh in 2050. This can be seen in Figures 6 and 7.

Figure 6. Electricity production in reference scenario

Generation from nuclear power remains constant at 110 TWh annually throughout the analysed period in both scenarios. Production in hydropower plants increases from 245 TWh to 265 TWh annually in a normal year in the reference scenario. In the low demand scenario, generation from hydropower decreases to 200 TWh in 2050. Hydropower 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 shortfall in hydroelectricity during dry years is in both scenarios primarily made up by electricity production from biomass-fired thermal plants. In 2049, power production from biomass in the reference scenario is 56 TWh whilst in a normal year for this period, represented by 2050, it is 50 % lower. In the low demand scenario, electricity production from biomass is only 19 TWh in the dry year 2049, which is only 10 % higher than in 2050.
The greatest difference between the two scenarios is the level of wind power in the system and the change in 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 power production becomes more important for ensuring security of supply in dry years towards 2050. In 2030, Sweden has 6 000 MW of wind power 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 hydropower 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, no wind power is needed in Norway and Sweden, capacity in Denmark is reduced to 6 000 MW and capacity in Finland is reduced by one-half to 2 000 MW.

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 electricity prices in normal and dry years. There is, however, higher price difference between normal and dry years in the low demand scenario (more than 50 %). Increased levels of precipitation in combination with a lower final demand give markedly lower electricity prices in all the Nordic countries with the exception of Denmark. Prices in Denmark are lower, but the lack of domestic hydropower 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 for Denmark would be reduced as would the price differentials in the reference scenario. Annual average electricity prices for the two scenarios are shown in Figures 8 and 9.

Figure 8. Average annual electricity prices in reference scenario

Figure 9. Average annual electricity prices in low demand scenario
References


Dansk Energi Analyse and Viegand & Maagøe (2010) Energibesparelser i erhvervslivet, Copenhagen, Denmark, www.ens.dk


