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SOMMARLÄSNING

Nordic Energy Technology Perspectives (NETP)

- Summary and Extract

Profu (responsible for Chapter 3)

IVL (responsible for Chapter 7)

NEPP report

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Nordic Energy Technology Perspectives (Nordic ETP)

Nordic Energy Technology Perspectives is the first ever regional edition of the IEA's renowned global publication Energy Technology Perspectives*. While based on the same global scenarios to limit average temperature increase to 2°C, the Nordic edition includes an even more ambitious Carbon-Neutral Scenario, exploring how the Nordic countries can achieve their national emission reduction targets for 2050.*

The Carbon-Neutral Scenario calls for a complete decarbonisation of Nordic electricity generation. Improvements in grid infrastructure will be important in facilitating this, and with the right pricing in place, the Nordic region could achieve annual electricity exports of 50 to 100 TWh over the longer term. Existing Nordic hydropower resources can play an increasingly important role in regulating the North European power system.

Achieving the required 7% drop in energy demand between 2010 and 2050 requires significant energy efficiency improvements in buildings, industry and transport. Average energy use per square meter in buildings must drop by 35% from current levels. The necessary reductions in industrial emissions rely on Carbon Capture and Storage (CCS).

Transport will require the greatest emission reductions of any sector, to just an eighth of its current level by 2050. To achieve this, sales of electric vehicles must double every year for the next decade. Biofuels will underpin freight transport, accounting for half of energy use in all Nordic transport in 2050.

The region could become a net importer of biomass, highlighting the need to secure a sustainable supply and the potential for Nordic technology development in the area.

The project is a cooperation between the IEA, leading research institutes from Sweden, Denmark, Finland, Iceland and Norway, Nordic Energy Research and the Nordic Council of Ministers. ***NEPP has been the Swedish partner in the Nordic ETP working and reference group.***

A near complete decarbonisation is possible – but very challenging.

In the IEA global 2°C Scenario, energy-related CO_2 emissions in the Nordic region must be reduced by 70% by 2050 compared to 1990. But the Nordic countries have set their ambitions higher, aiming for even deeper cuts, and for some countries, a carbon-neutral energy system by 2050. These ambitions are operationalised in the Carbon-Neutral Scenario, in which energy-related CO_2 emissions are reduced by 85%. The remaining 15% are assumed to be offset by international carbon credits. The Nordic countries are in a strong position to establish a low-carbon energy system, thanks to rich renewable energy resources and relatively progressive policies already in place.

To realise the Carbon-Neutral Scenario, Nordic electricity generation needs to be fully decarbonised by 2050. Wind generation needs to grow quickly and alone accounts for 25% of electricity generation in 2050. This will increase the need for flexible generation capacity, grid interconnections, demand response and storage. Total investment required in the power sector is equal to some 0.7% of cumulative GDP over the period.

All industrial sectors must contribute. Energy efficiency and carbon capture and storage (CCS) will be vital to achieve the necessary emission reductions. By 2050, the overall energy intensity of the Nordic economies falls by some 60% from 2010 levels. This requires industrial use of fossil fuels to be cut in half and relies on CCS for further cuts. Current uncertainty over national positions on CCS must be resolved for this to happen.

CO_2 emissions associated with the buildings sector must be reduced by 80% by 2050. Widespread retrofits of older building stock will be necessary to achieve the necessary energy efficiency improvements. In the short term, policies should focus on improving building shell performance and on requiring best available technologies for space heating and cooling.

Transport sees the most dramatic drop in emissions of all end-use sectors, from 80 MtCO2 in 2010 to some 10 MtCO2 in 2050. This will require limiting growth in transport demand, substantial technology cost reductions, securing a sustainable biofuel supply and intelligent modal shifts.

Improved fuel economy provides the majority of transport emission reductions through 2030, with biofuels and electric vehicles more important in the longer term. By 2050, average fuel consumption of new cars must decrease to about 3 L/100km, down from 7 L/100km in 2010. Plug-in hybrid and battery electric vehicles must reach 30% of total sales in 2030 and 90% in 2050. Long-haul road freight, aviation and shipping remain dependent on high energy density liquid fuels even in 2050, resulting in an increased use of biofuels.

An interconnected European energy system

A highly interconnected European energy system will facilitate decarbonisation and could offer large economic opportunities for the Nordic countries.

- Decreasing costs for low-carbon electricity generation, coupled with a reinforcement of grid interconnections, could make the Nordic region a major net exporter of electricity. The Nordic region could achieve annual exports in the range of 50 TWh to 100 TWh over the longer term.
- The Nordic hydropower resource will be increasingly valuable for regulating the North European power system. An increasingly efficient and flexible Nordic power grid could enable a quicker decarbonisation of the European energy system. Transmission capacity needs to be strengthened in order to facilitate this.
- Supplying the region’s growing demand for biomass will rely on a well-functioning international market. In the Carbon-Neutral Scenario, bioenergy use increases by two thirds to become the largest energy carrier. This highlights an opportunity for research in sustainable biofuels to increase domestic production.

Five central challenges

The Nordic ETP identifies five central challenges that the countries face in a carbon-neutral energy system.

- **Energy efficiency improvement remains a priority policy area**. Policies to ensure rapid and sustained energy efficiency improvements will be necessary in all scenarios, especially in buildings and industry.

- **Infrastructure development will be a critical policy challenge**. The significant need for new infrastructure in electricity grids and generation will not only pose technological and financing challenges, but will also require social acceptance.

- **Carbon capture and storage (CCS) plays an important role, especially in industry**. Progress in this technology has been slow and uncoordinated between countries. Governments must scale-up policy action for this technology to realise its full potential.

- **Bioenergy will be the single largest energy carrier in 2050, raising questions over its supply**. The Carbon Neutral Scenario projects a net import of bioenergy to the Nordic region, making sustainability criteria all the more important.

- **Nordic co-operation is a prerequisite to reducing the cost in achieving the scenarios**. Regional co-operation in infrastructure development, RD&D and in strategies for transport and CCS would offer significant benefits.

Chapter 3

Power Generation and District Heating

The development of the power and district-heating systems is central to the Nordic decarbonisation pathways. An almost fully decarbonised Nordic power and district-heating sector could be achieved by 2040.

Key findings

- ***Nordic countries have already implemented policies and drawn up long-term political objectives*** *that support the continued expansion and development of both these sectors.*
- ***The Nordic region's technological strengths have led to the greater use of various sources of power*** *including hydropower, wind power, efficient biomass use, co-generation[1], geothermal and nuclear power.*
- ***The region is endowed with substantial sources of renewable energy, and technological advancement has meant that renewables can expand significantly*** *and strengthen their position within the Nordic energy mix. Wind power competitiveness is strengthened in all scenarios, as advanced technological learning world-wide reduces the cost of investment. The scenarios also reveal an increased use of nuclear power, mainly in Finland.*
- ***Traditional power consumption is stagnant, but new demand from electrification could drive overall power consumption especially on the road to decarbonisation.*** *Low-carbon electricity via electrification is crucial for reducing emissions in sectors such as transport and buildings.*
- ***The Nordic power markets and regulatory set-up are well developed and integrated in the region.*** *This can facilitate efficient trading opportunities in power and balancing services, which are particularly important for decarbonisation.*
- ***The Nordic power grid, with the exception of Iceland, is highly interconnected internally and with Continental Europe.*** *In all scenarios, the Nordic region becomes a major net exporter of electricity to Continental Europe and the United Kingdom. This export is driven by higher electricity prices in surrounding regions. However, in order to facilitate export, transmission capacity needs to be strengthened.*
- ***Increased volumes of variable power generation (e.g. wind power) highlight the regulating and capacity issues.*** *Nordic hydropower will be increasingly valuable in the regulation of the North European power system.*
- ***District heating will continue to play a central role in transforming the Nordic energy system away from fossil fuels and towards lower carbon dioxide (CO_2) emissions.*** *Future expansion will, however, be limited due to a high market share and a decline in demand for heating in buildings.*
- ***The synergies among the district-heating system, power generation, the municipal waste management system and industrial energy systems are significant.*** *Efficient co-generation, waste incineration with heat recovery (and co-generation), and the use of industrial waste heat will all facilitate these synergies and are increasingly used.*

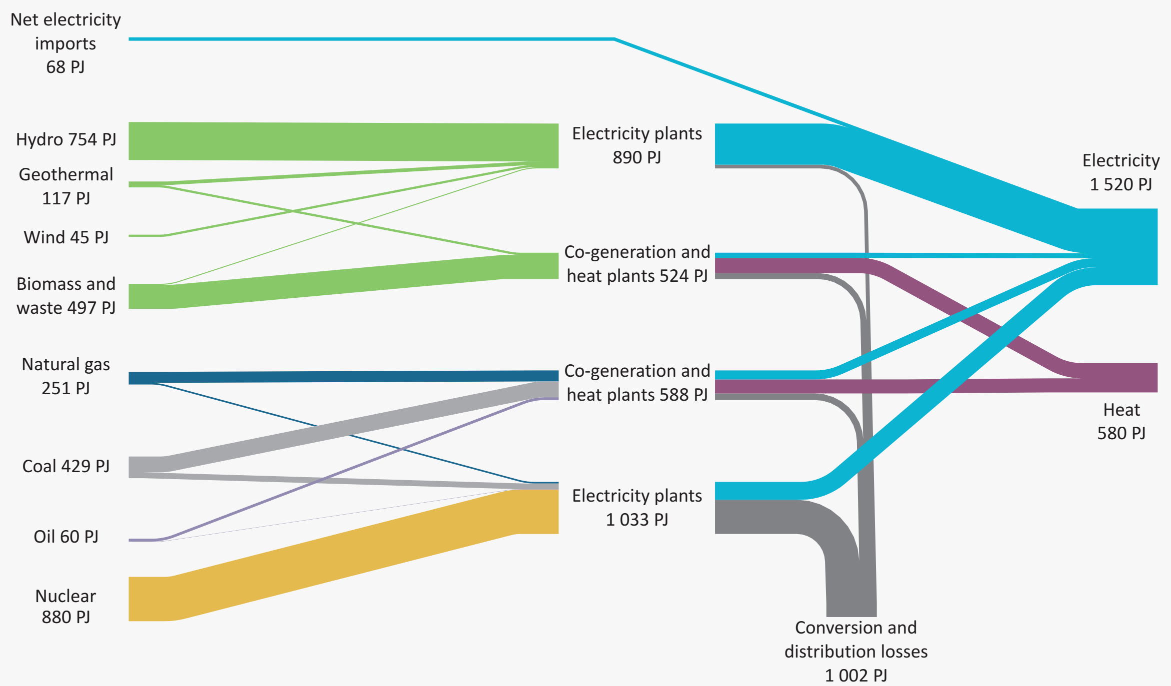
1 Co-generation refers to the combined production of heat and power (CHP).

Recent trends

The Nordic electricity-supply system is characterised by a low share of fossil fuels and, thus, low emissions of CO_2 (Figures 3.1 and 3.2). Significant differences in production levels exist among the five Nordic countries. While Denmark and Finland still rely rather heavily on fossil fuels, electricity production in the other three countries is associated with very little or no CO_2 emissions (Figure 3.2). Hydropower is the largest supplier of capacity in the Nordic countries with around half of the total installed capacity.

The most diversified electricity generation system is found in Finland, while Norway relies almost exclusively on hydropower for its domestic production. Fossil fuels for electricity generation are important in Denmark and Finland. No emissions taxes are levied on electricity generation in the Nordic countries. Renewable electricity is, however, supported through different schemes. In Denmark and Finland, such schemes are mainly feed-in tariffs, while Sweden and Norway introduced a common market for electricity certificates at the beginning of 2012.

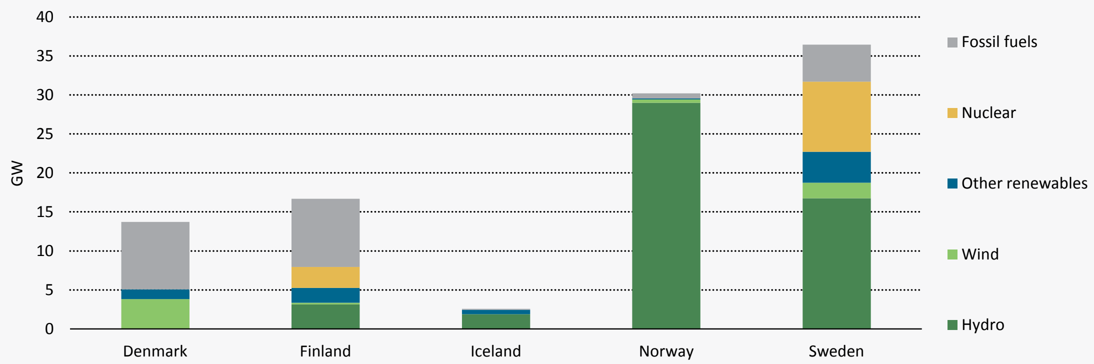
Figure 3.1 **Energy flows in the Nordic electricity and heat sector, 2010**



Notes: PJ = petajoules. Figures and data that appear in this report can be downloaded from www.iea.org/etp/nordic
Source: Unless otherwise noted, all tables and figures in this report derive from IEA data and analysis..

Key point *Nordic electricity generation and district heating is dominated by low-carbon fuels, with renewables and nuclear accounting for three-quarters of the fuel consumption of this sector.*

Figure 3.2 Electricity generation capacity by fuel type, 2010



Note: GW = gigawatt.

Key point *Nordic electricity generation is dominated by renewables. Significant differences exist among the five Nordic countries.*

Increased North European integration

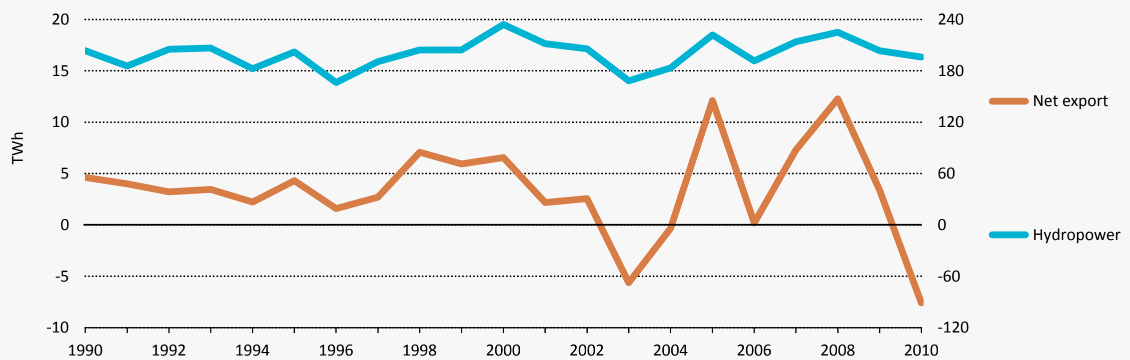
The European Union (EU) is striving towards an integrated European electricity market. Above all, this implies a market-orientated model that encourages the efficient trade of electricity among market players and across EU member states, and creates a basis for managing resources more efficiently. In addition, market integration could also generate incentives for investments by bringing prices more in line with the market. In recent years, several large-scale interconnector projects have already led to the increased integration of electricity markets in Northern Europe. Such investment projects are generally significant in size and have, in some cases, also been subject to public opposition.

During years of high precipitation, the Nordic countries have exported electricity to Continental Europe, and when precipitation has been low they have acted as net importers. The co-variation between the annual production of hydropower in Nordic countries and electricity trade with Continental Europe is clearly visible in Figure 3.3.

Traditionally the abundant hydropower resources in Iceland, Norway and Sweden have implied relatively low electricity prices. This has been beneficial for the electricity-intensive industry and has also led to a high share of electric heating in the heating market. Since the beginning of the 1990s, however, the Nordic electricity markets have been integrated into one single market known as Nord Pool Spot (Chapter 2).

This single market has been further interlinked with other Northern European electricity markets, which has meant that, although some differences in electricity prices still remain in Northern Europe, the prices are gradually being brought in line. In general, power prices are higher in Germany, for example, than in the Nord Pool Spot area (Figure 3.4).

Figure 3.3 Co-variation of hydropower in Denmark, Finland, Norway and Sweden with net electricity exports to Continental Europe

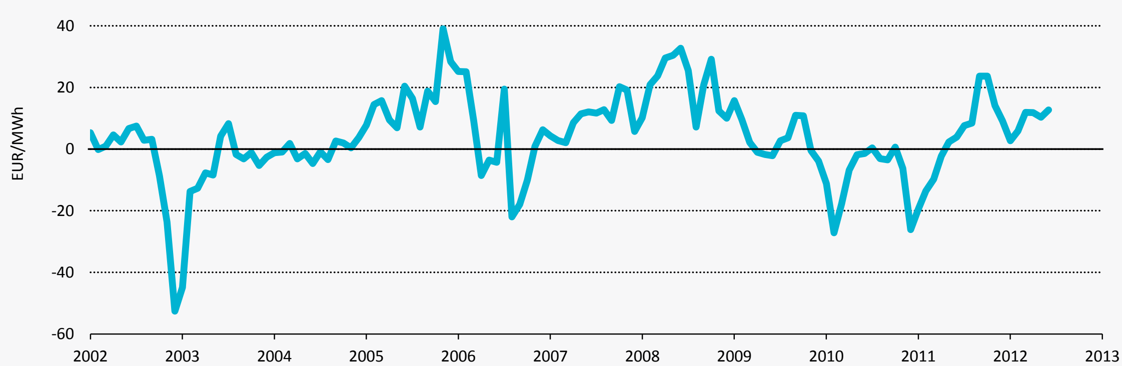


Notes: TWh = terawatt hour. Imports to Finland from Russia are not included in this chart.
Source: EUROSTAT, 2012.

Key point *There is a strong interrelationship between annual variations in Nordic hydropower and annual variations in net exports to Continental Europe.*

During certain periods, especially during winter, prices are (sometimes considerably) higher in the Nordic countries. Hence, the increased integration with Continental Europe does, generally, exert an upward pressure on electricity prices for Nordic consumers. For the region's electricity-intensive industry, this reduces their competitive advantage.

Figure 3.4 Monthly wholesale electricity price differences between the German market (EEX) and the Nord Pool Spot system



Note: EUR/MWh = euros per megawatt hour (nominal prices). A positive number in the figure means that prices are higher in Germany than in the Nord Pool Spot area.
Source: Energinet,2012; Nord Pool Spot, 2012.

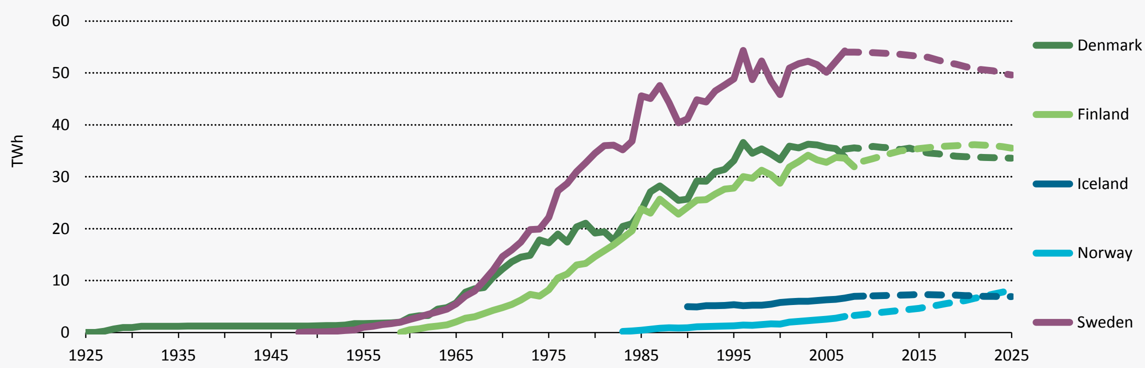
Key point *Wholesale electricity prices are generally higher in the German market than in the Nordic market. This price difference drives cross-border trading.*

District heating in the Nordic countries

The market share for district heating is typically high in the Nordic region, but there are differences among the countries. In 2009, the share of district heating in heat demand for the residential, services and other sectors accounted for: 47% in Denmark; 49% in Finland; 92% in Iceland; 6% in Norway; and 55% in Sweden (Euroheat & Power, 2011).

A market share of 50% can be considered high, particularly because district heating is not suitable for some parts of the heating demand. District heating is therefore a mature business in all of the Nordic countries except Norway, which means potential for growth is limited. The majority of buildings in energy-dense areas are already connected to district heating and, therefore, conversion of existing buildings to district heating provides only limited potential for expansion. In Norway, market penetration of district heating is much lower as the country has traditionally relied on electric heating.

Figure 3.5 **Development of district heating in the Nordic countries and estimates for the coming decade**

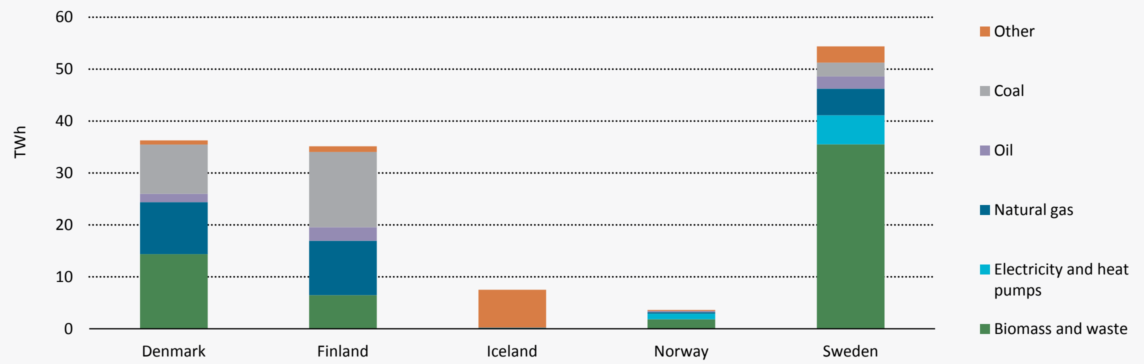


Note: TWh = terawatt hour.
Source: Nordic Energy Perspectives, 2010.

Key point *Most Nordic countries experience stagnating district-heating demand, but use in Norway may continue to grow.*

District-heating production systems vary significantly among the five Nordic countries, but there are also certain similarities. Significant differences are also found within a given country. The choice of energy resources depends largely on local conditions such as availability of different energy sources and energy infrastructure. Biomass and/or municipal waste are major sources of renewable energy in all Nordic countries, except Iceland where geothermal energy dominates. The domination of these energy sources is not only the result of available natural resources but can also be partly explained by policy measures. Some of these countries have very diverse district-heating supply systems (Figure 3.6).

Figure 3.6 Energy supply composition for district heat produced in 2009



Note: "Other" includes industrial waste heat.
Source: Statistics Finland, 2012; Danish Energy Agency, 2012; Swedish Energy Agency, 2012; Statistics Norway, 2012; Euroheat & Power, 2011.

Key point *Production of district heat is diversified, with significant differences between countries.*

Finland's district-heating production is diverse and composed of a large share of fossil fuels. The use of biomass and peat is, however, increasing. A highly diversified production with a large share of fossil fuels is also found in Denmark although biomass and waste incineration is also becoming increasingly present. Biomass and an increasing share of waste incineration dominate Swedish district-heating production. Norwegian district heating relies heavily on waste incineration with significant contributions also from electric heating (particularly electric boilers and heat pumps). In Iceland, all district heat is produced from geothermal sources.

Large shares of the heat are produced in co-generation plants. In Denmark and Finland, 75% of all district heating comes from co-generation. This is considered to be one of the most important success factors of district heating, as the high overall efficiency leads to the low cost of heat generation. In Sweden, the share is much lower at 40%. As mentioned above, national policy measures have had a large impact on the development and can explain the differences among countries.

These large shares of district heating in Nordic countries have been reached through fundamentally different regulatory regimes. Denmark and Norway rely, to a large extent, on detailed regulation. In Denmark, municipal energy planning is responsible for assigning certain areas to district heating and other areas to natural gas heating, with a possibility of making collective energy distribution systems mandatory. In Norway, a concession for district heating (*i.e.* a company is given an exclusive permit to conduct district-heating operations in a certain area) is mandatory for plants with more than 10 megawatts (MW) of maximum heat loads. Municipalities may decide on mandatory connection to the district-heating system for new buildings provided there is a concession for the district-heating system. In Finland and Sweden, the development of district heating is less dependent on regulation and more directly related to its competitiveness on the heating market.

The future of district heating – saturation, increased competition and possible growth markets

The use of district heating is still increasing, but there are signs that this is occurring at a much slower pace. Factors that will influence the future use of district heating include:

Decreases in demand

- Increased energy efficiency in buildings.
- Conversion to other heating alternatives, *e.g.* heat pumps.
- Warmer climate due to increased green house effect.

Increases in demand

- District heating to new customers, both through conversion of existing buildings and for new buildings.
- Heating demand due to more efficient new household appliances.
- New markets for district heating.

Business development tends to follow an S-shaped curve. In the context of district heating, the volume of energy sold relates to the penetration rate. When, or if, the level at which all customers have district heating is reached, the volume is bound to remain at the same level or decline due to improved energy efficiency and substitution of local solutions (*e.g.* heat pumps). The European Union has ambitious targets for energy efficiency improvements by 2020 and this will probably affect the demand for heat and, therefore, also district heating. Such a development for district heating is schematically illustrated in Figure 3.5 above, where the historical development of district heating is combined with a recent outlook. The market share for district heating is expected to grow, but at a much slower pace than has previously been the case.

District heating is often a competitive alternative for new buildings, assuming that the heat sources are available close to the potential customer. However, volumes are limited in the short term largely because of the construction rate of new buildings and because of the often very small heating demand in these buildings. Passive houses (ultra-low-energy buildings), energy-neutral buildings and low-energy buildings are concepts that are often discussed, and increasingly being built. District heating is constantly competing with other heating alternatives, with heat pumps, in both new and existing buildings, acting as the main competitor.

In Denmark, with its tradition of municipal energy planning, the strong focus on CO_2 emissions could spur greater use of district heating if areas previously designated for natural gas heating are converted to district heating.

As the growth of district heating in its traditional markets starts slowing down, it is natural to intensify efforts to identify and exploit new markets. Examples of new markets could include: underground heating (*e.g.* streets and pavements), absorption cooling, household appliances (*e.g.* washing machines, dryers and dishwashers), greenhouse heating, heating for industrial processes, and heating for refining fuels (*e.g.* drying). Increased investment in variable renewable energy production, such as wind power and small-scale run-of-river hydropower plants, could also generate new opportunities for district-heating systems, which could be used to balance fluctuating and unpredictable electricity production. Large-scale electric boilers or heat pumps could use “excess” electricity to produce district heating.

Co-generation will continue to be important as a means to reduce CO_2 emissions and transform the energy system towards more renewables. Co-generation is further discussed in the technology spotlight later in this chapter.

Scenario results

The power and district-heating sectors have been analysed for the 4°C Scenario (4DS), 2°C Scenario (2DS) and Nordic Carbon Neutral Scenario (CNS). For the latter scenario also two variants have been considered: the Carbon Neutral high Bioenergy Scenario (CNBS) and the Carbon Neutral high Electricity Scenario (CNES) (see Chapter 1 for scenario definitions). Key scenario assumptions for the power sector are summarised in Annex C. The scenarios for Denmark, Finland and Sweden incorporate the 2020 targets of the National Renewable Energy Action Plans (NREAP) for renewable electricity generation. Electricity generation from renewables in these three countries combined will be 162 TWh by 2020 (ECN, 2012).

All scenarios also include calculations based on the common electricity certificates currently existing in Norway and Sweden, which aim to increase the electricity production from renewables by 2020. Expansion of nuclear capacity is limited to 6.4 gigawatts (GW) of new reactors in Finland. While in Sweden, maximum nuclear capacity has been limited to the current capacity of 9.3 GW, which includes the replacement of existing reactors. New coal plants, with and without carbon capture and storage (CCS), have only been included for Finland. In addition, the scenarios also assume that Danish coal-fired power generation, even with CCS, will be phased out by 2030.

The assumptions on existing and new transmission lines are summarised in Table C.4 in Annex C. Compared with the 4DS, the 2DS, CNS and CNBS assume a 2 GW increase in export capacity to Continental Europe. The CNES assumes additional options for expanding transmission capacity within the Nordic region as well as to neighbouring countries.

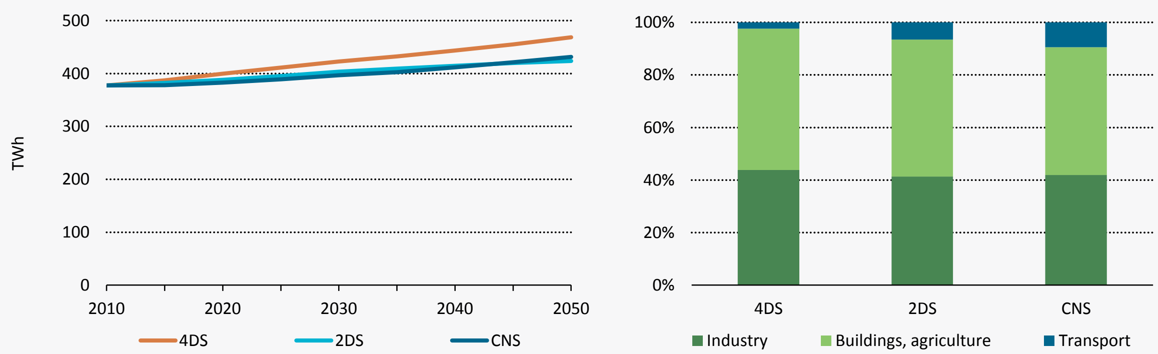
Two variants of the ambitious CNS targets for reducing CO_2 emissions are considered in the power sector:

- *Carbon Neutral high Bioenergy Scenario*: This scenario variant assumes lower import prices for biofuels (bio-ethanol, biodiesel) compared to the CNS, 2DS and CNES. As the assumed domestic biomass potential in the Nordic region of around 1 600 petajoules (PJ) by 2050 is already almost fully utilised in the CNS, the option of cheaper biofuel imports provides the possibility to free up some of the domestic biomass use for other purposes (*e.g.* electricity, heat generation). In the long term, imports of solid biomass (*e.g.* as a product similar to coal) could be another option. This option has not been considered in the analysis as a large part of the biomass in this scenario is needed in liquid form for the transportation sector.
- *Carbon Neutral high Electricity Scenario*: Compared to the other scenarios (4DS, 2DS, CNS, CNBS), the constraints imposed on new capacity additions in cross-border capacity among the Nordic countries and for trade with Europe have been further relaxed. In the CNES, no constraints have been imposed on additional investment in transmission lines within the Nordic region, whereas the capacity with neighbouring countries has been limited to 16.5 GW.

Electricity demand

In the 4DS, final electricity demand in the Nordic region increases by more than 20% over the next four decades. This increase is mainly driven by industry, which is responsible for half of the growth in electricity demand (Figure 3.7). Final electricity demand in the 2DS and the CNS is characterised by two counteracting trends: more efficient use of electricity in the industry and buildings sectors on one hand, and on the other the electrification in the transport sector and to a lesser extent also increased electricity use for CCS in some industrial sub-sectors. Overall, final electricity demand in these scenarios in 2050 is 8% lower than in the 4DS.

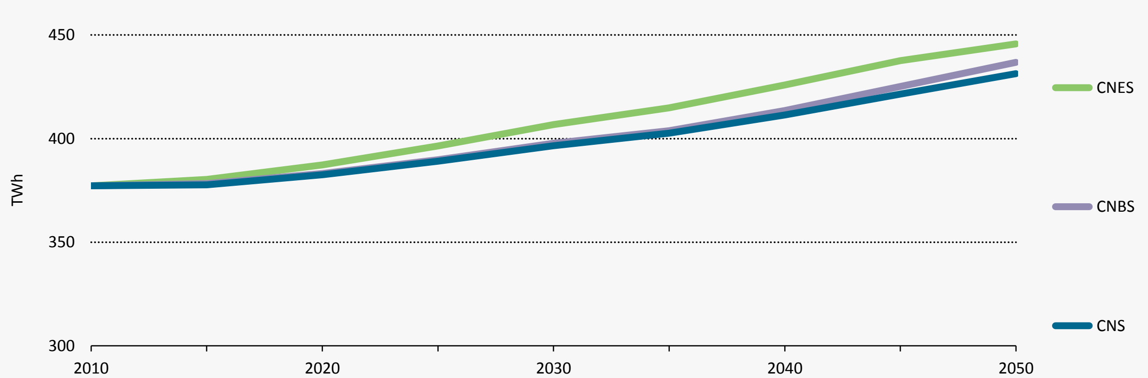
Figure 3.7 Development of final electricity demand (left) and its breakdown by sector in 2050 (right)



Key point *Final electricity demand grows in all three scenarios, but saving measures in industry and buildings halve the growth in the 2DS and CNS compared to the 4DS.*

In the two variants of the CNS, final electricity demand is slightly higher than in the CNS. The increase is largest in the CNES, with demand in 2050 exceeding that of the CNS by 3%. This additional electricity demand is mainly driven by the buildings sector, and to a lesser extent by the transportation sector. Options for further electrification in the transportation sector, beyond the levels already reached in the CNS, are limited.

Figure 3.8 Final electricity demand by scenario

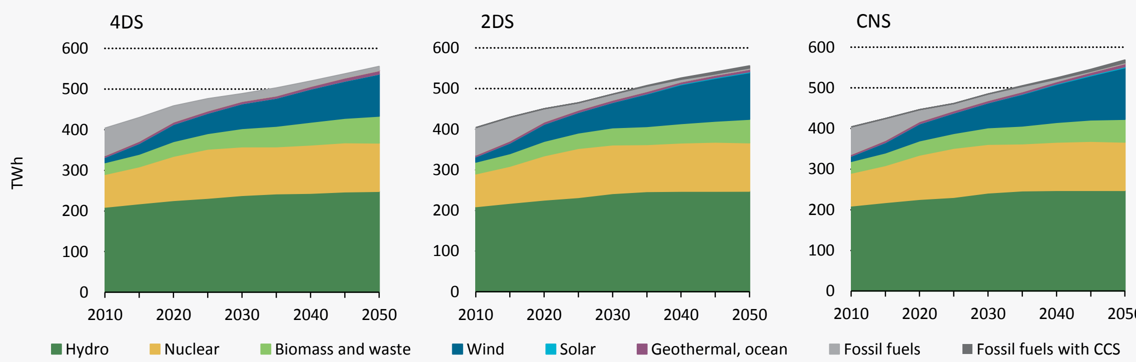


Key point *The CNES has a modest increase in electricity demand compared to the CNS.*

Electricity generation and trade

Wind power, hydropower and other renewable sources of power generation increase over time in the 4DS, 2DS and CNS (Figure 3.9). Wind power accounts for the lion's share of that increase and generates around one-fifth of total generation in the 4DS by 2050. In the 2DS, the overall share of renewables is much larger, increasing from around 60% in 2010 to almost 80% by 2050 (Figure 3.10). Increased volumes of variable production from wind will highlight issues related to capacity and regulating power. Nordic hydropower will, therefore, become increasingly valuable to regulate the electricity systems in Northern Europe.

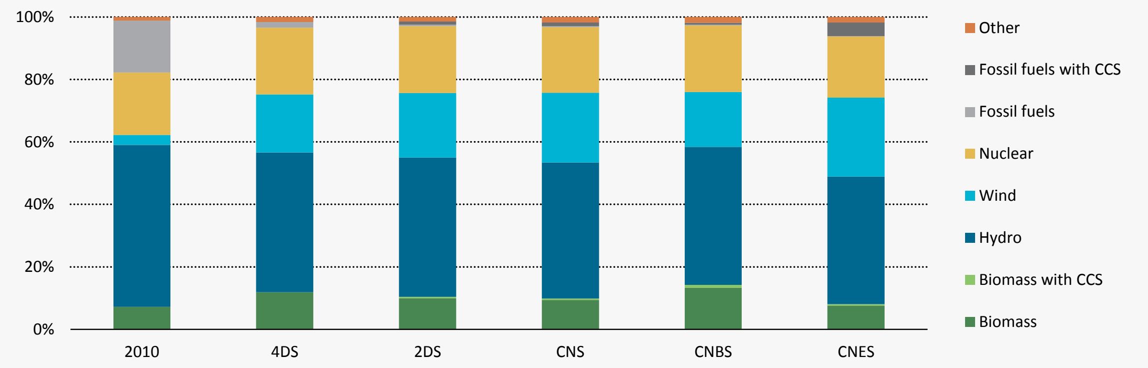
Figure 3.9 Nordic net electricity generation by scenario



Key point *Growth in electricity generation in all scenarios is covered by low-carbon electricity sources, mainly renewables.*

In all three scenarios, nuclear generation grows by more than 40% between 2010 and 2050, reaching a level of 120 TWh in 2050 (the growth is partly explained by low availability in Swedish nuclear power plants in 2010). This corresponds to 20% of the electricity generation. The expansion of nuclear energy is based on a capacity increase in Finland from the current level of 2.7 GW to 6.4 GW in 2050 as well as the capacity in Sweden, which remains the same as current levels. Conventional power generation based on fossil fuels, particularly coal, is reduced in all scenarios. In the 2DS, coal-fired power generation falls by 85%, gas-fired power generation is also drastically reduced by more than 90%. The remaining generation from coal-fired plants of 5 TWh in 2050 is entirely based on plants equipped with CCS. In 2DS, biomass CCS schemes become profitable by 2035, albeit on a rather small scale.

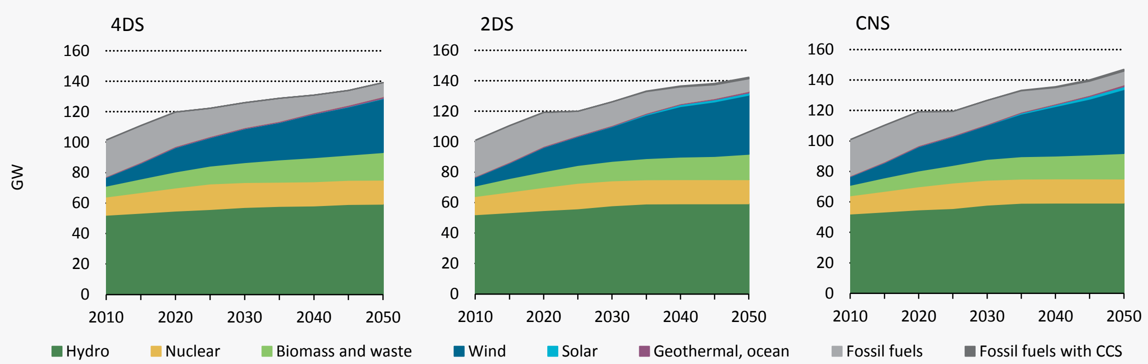
Figure 3.10 Electricity generation mix in 2050



Key point *Low-carbon electricity sources provide more than 90% of the electricity in 2050 in all scenarios, compared to an already high level of 83% in 2010.*

Electricity generation capacity in both the 4DS and the 2DS increases from around 100 GW to 140 GW in 2050 (Figure 3.11). Wind capacity, reaching almost 40 GW by 2050, is the main factor behind this capacity growth. This increasing share of variable electricity capacity in the power sector, reaching one-third in 2050, raises the issue of the system's flexibility to integrate these variable sources. Around 35 GW of the almost 60 GW hydropower capacity in the Nordic countries in 2050 can be considered as dispatchable. In addition, 8 GW of gas capacity (fired by natural gas or biogas) is still operational in 2050, but used only with low load, full hours to provide additional flexibility. The growing electricity trade within the Nordic region as well as with Continental Europe is an additional factor increasing the flexibility of the system and balancing variable wind generation. Demand-side management can be a further flexibility option, but has not been included in the quantitative analysis here.

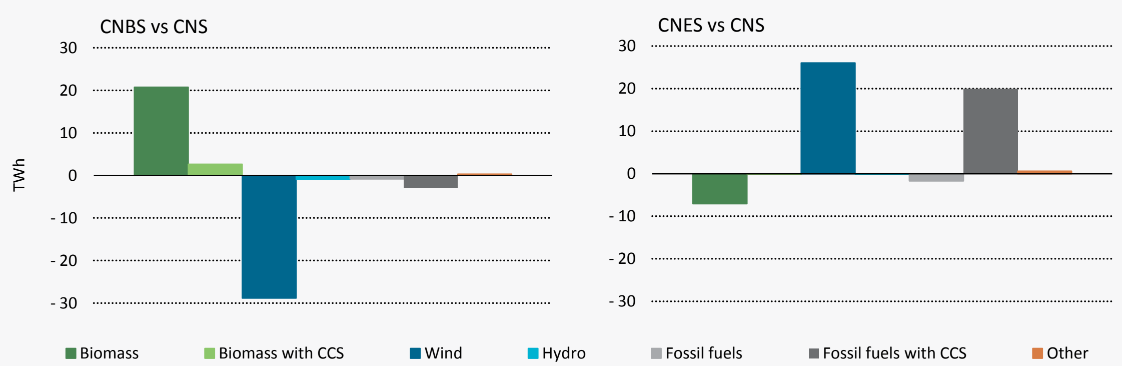
Figure 3.11 Nordic net electricity capacity by scenario



Key point *Growth in overall installed capacity is largely driven by wind capacity and reaches around 50 GW by 2050 in all three scenarios.*

In the CNBS, the level of overall electricity generation is on a similar level as in the CNS. In the variant, a shift from wind to biomass in the electricity generation mix exists (Figure 3.12). This shift is caused by increased biofuel imports from outside the Nordic region due to lower import prices in this variant (a sensitivity analysis of import prices on biofuels is presented in Annex C). Instead of being used for biofuel production, more domestic biomass is available for the power sector. Due to this shift, the biomass use in the power sector in 2050 increases by 160 PJ or almost 30% in the CNBS compared with the CNS.

Figure 3.12 Change in electricity generation in the CNBS and CNES relative to the CNS in 2050

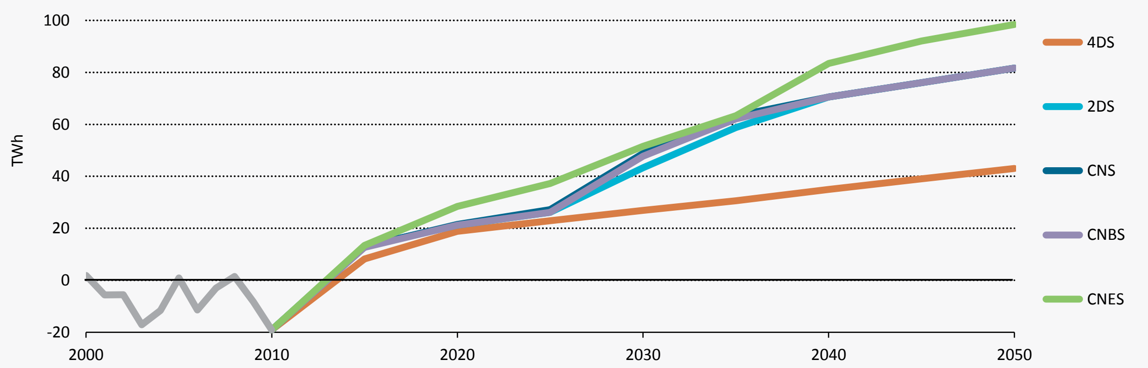


Key point *More available biomass in the CNBS leads to a switch from wind to biomass-fired generation, whereas increased transmission capacities for exports in the CNES drive the increased electricity generation by wind.*

In the CNES, overall electricity generation increases by 7% in 2050 compared with the CNS. The increased generation is mainly covered by wind and to a lesser extent by natural gas plants with CCS (Figure 3.12).

In all scenarios, growth in electricity generation outpaces electricity demand, which implies net exports from the Nordic region will rise to a level of roughly 80 TWh by 2050 in the CNS (Figure 3.13). Exports to Continental Europe represent a considerable amount of this rise. Historically, however, the Nordic region has often been a net importer of electricity, particularly from Russia. If imports from Russia are excluded in the trade balance, the remaining net exports of the region to Continental Europe have generally been less than 10 TWh. The trend seen in the scenarios is driven by two factors: the comparative cost advantage of the Nordic region in providing low-carbon electricity to Continental Europe; and the increased transmission capacity, which takes into account lines currently under construction as well as proposed future transmissions projects (Figure 3.13). Wholesale electricity prices are, therefore, generally lower in the Nordic market than in Continental Europe (see Annex C for information on electricity prices).

Figure 3.13 Net electricity exports of the Nordic region (including imports from Russia)



Key point *Net electricity exports have a large growth potential.*

The increase in export flows between the 4DS and 2DS are due to a 10% increase in export prices in the 2DS as well as the assumption that there will be an increase of 2 GW in transmission line capacity for exports.

In the CNES, overall net exports of the Nordic regions in 2050 at roughly 100 TWh are one-quarter higher than in the CNS (Figure 3.13). Net exports vary significantly among the countries in 2050, from 5 TWh in Denmark to 50 TWh in Sweden. Additional export transmission line capacity to Continental Europe, assumed in this scenario variant, drives the increased exports (Table C.4 in Annex C) and stresses the cost advantage of the Nordic region in producing low-carbon electricity. The exports are the main factor behind the increased electricity generation in the CNES compared with the CNS (Figure 3.12), whereas the potential for the electrification of the industry and buildings sectors have already largely been exploited in the CNS.

A further discussion on Nordic electricity exports is found in a sensitivity analysis for the CNES reported in Annex C. It illustrates that the perspectives for exporting electricity from the Nordic region also depend on the cross-border transmission capacity and on the broader electricity market conditions. In other words, exports depend on the electricity price in Continental Europe as well as the potential for generating low-carbon electricity in the Nordic region. Lower electricity prices in Continental Europe result in a decrease in electricity exports, *e.g.* for a price level of USD 100/MWh[2] instead of USD 150/MWh in 2050, exports fall from 100 TWh to 60 TWh in 2050. Reducing the deployment potential of low-carbon electricity, for example limiting the nuclear deployment to 3.2 GW instead of 16 GW in 2050, results in a further reduction of exports to 20 TWh at an export price level of USD 100/MWh.

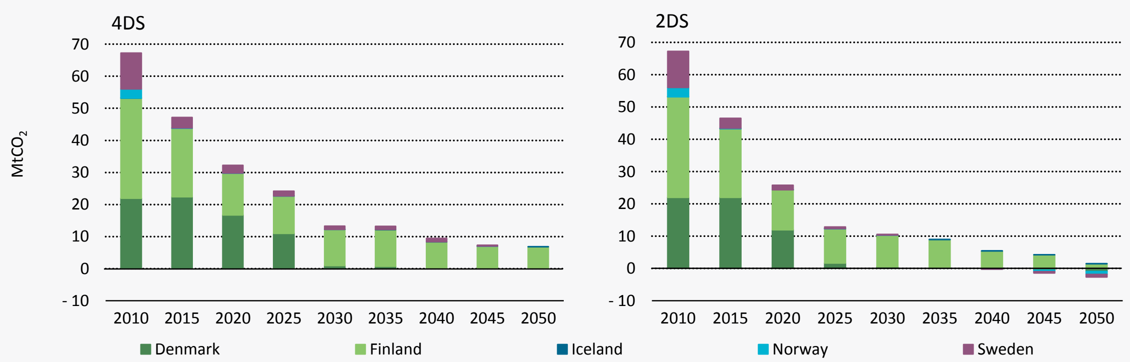
2 Unless otherwise stated, all costs and prices are in real 2010 USD, i.e. excluding inflation. Other currencies have been converted into USD using purchasing power parity (PPP) exchange rates.

CO_2 emissions from electricity generation

The current Nordic electricity generation is characterised by its relatively low CO_2 emissions of approximately 100 grams of CO_2 per kilowatt hour (gCO_2/kWh) of electricity.[3] This is considerably lower than the global average of around 550 g/kWh and the EU average of approximately 430 g/kWh. Large annual variations exist, however, due to certain variations in hydropower. The majority of the 67 million tonnes of CO_2 ($MtCO_2$) emissions from the Nordic power sector in 2010 were generated by Denmark (33%) and Finland (46%). In both of these countries coal, peat and natural gas still feature heavily in the power sector (Figure 3.14). The other countries contribute fewer emissions in absolute terms due to the presence of renewables and nuclear power.

In the 4DS and 2DS, CO_2 emissions from electricity generation decrease significantly. In the 4DS, emissions are reduced by 80% by 2030 compared with 2010. The decline continues further, and by 2050 emissions from Nordic electricity generation reach 7 Mt or 10% of the 2010 level. The CO_2 emissions reduction in the 4DS is mainly due to a reduced reliance on fossil fuels and an increasing share of renewables in the Nordic electricity mix from around 60% in 2010 to almost 80% by 2050.

Figure 3.14 CO_2 emissions from electricity generation by scenario



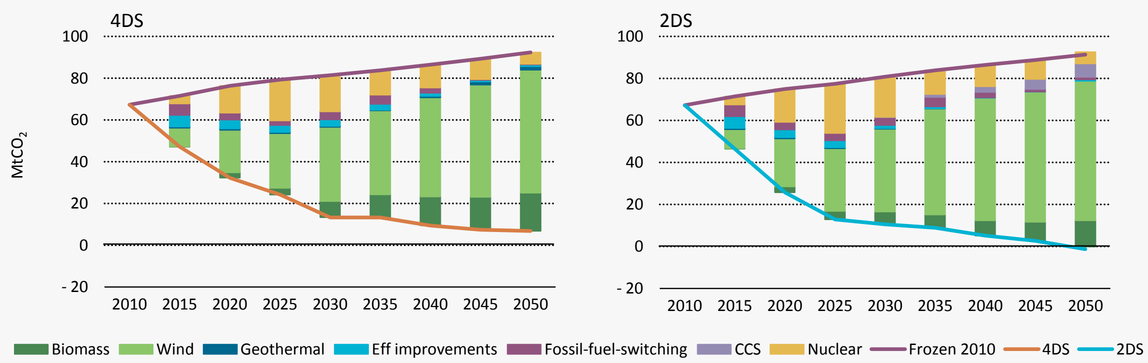
Key point *Denmark and Finland are the main emitters of CO_2 in the Nordic electricity sector today, but emissions are substantially reduced in the 4DS and 2DS by 2050.*

The emissions reductions are even greater in the 2DS. Carbon dioxide emissions from Nordic electricity generation even fall slightly below zero by 2050 due to the CO_2 being captured at biomass-fired power plants, which results in a net removal of CO_2 from the atmosphere. To illustrate the CO_2 savings in the 2DS, one can compare emissions in the 2DS with those in a scenario with the same electricity generation as in the 2DS but with the electricity mix and fossil efficiencies frozen at 2010 levels (Figure 3.15). Compared to such a frozen development (referred to as "frozen 2010"), wind power is the main option to reduce emissions in the 2DS relative to the frozen 2010 mix. Furthermore, biomass, nuclear, fossil-fuel switching and CCS contribute to this reduction. As with any decomposition analysis, the resulting

3 The indicator is defined as CO_2 emissions from electricity generation divided by electricity generation. For co-generation plants, CO_2 emissions from electricity have been calculated by assuming that the heat would have been generated in a heat boiler with an efficiency of 90%. CO_2 emissions allocated to electricity are the total CO_2 emissions of the co-generation plant minus the thus derived emissions linked to the heat output (IEA, 2012).

decomposition depends on the developments in the reference scenario, in this case on the mix in 2010. As the share of hydropower declines in the 4DS and 2DS relative to the mix in 2010 (Figure 3.10), the technology does not feature in Figure 3.15. Hydropower, however, is still an important option to meet a low-carbon electricity system that requires additional capacity and investment, as discussed in the section on investment requirements.

Figure 3.15 CO_2 reductions in the power sector in the 4DS and the 2DS relative to the 2010 fuel mix, by technology area



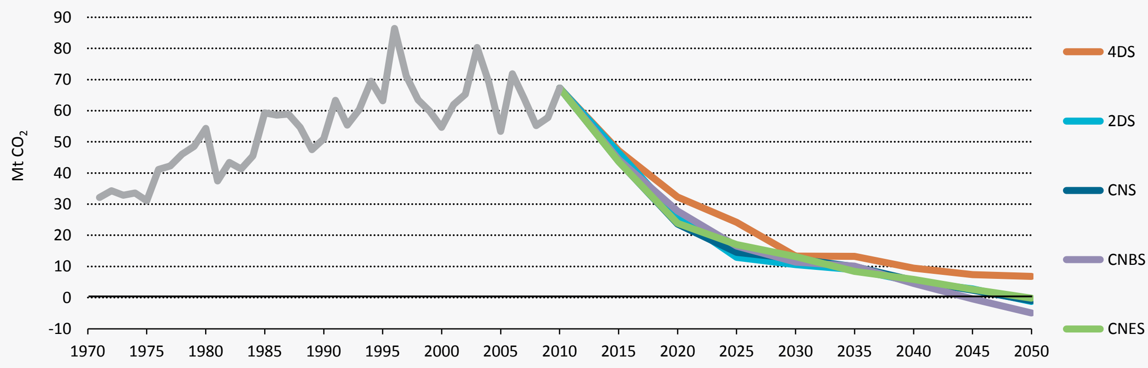
Note: Eff improvements = efficiency improvements.

Key point *Wind, CCS and switching from coal to gas are the main contributors in reducing CO_2 reductions in the 2DS relative to a frozen 2010 fuel mix.*

In the CNS, about 8 Mt CO_2 are captured annually in the power sector, which contains around 1 GW of coal capacity with CO_2 capture in Finland and around 200 MW from biomass-fired plants with CCS in both Denmark and Sweden. Taking into account CCS in fuel transformation and industry, altogether around 20 Mt of CO_2 are captured annually in the Nordic region by 2050. Denmark, Finland and Sweden (the latter two via transport to Norway for storage) are the main countries deploying CO_2 capture in the scenarios. Denmark and Norway have available offshore storage capacity in the North Sea, which means that a transportation system to storage locations could be constructed with some benefits from economies of scale. In comparison with large-scale CCS infrastructure (capture as well as transportation and storage) probable in Continental Europe, the Nordic dependency on CCS in the power sector is low.

As in the CNS, CO_2 emissions from electricity generation in the CNBS and CNES approach zero by 2050 (Figure 3.16). The lowest CO_2 emissions are obtained with negative emissions of -5 $MtCO_2$ in 2050 in the CNBS compared with around 0 Mt in the CNS and CNES. This additional reduction in the CNBS is due to an increased use of bioenergy with CCS (BECCS) in the power sector, which results in negative net CO_2 emissions. In the CNBS, 7 Mt of CO_2 are captured at BECCS plants in the power sector compared with 3 Mt in the CNS. When considering the entire energy sector and the ambition to meet the overall 85% reduction target in the Nordic countries, the electricity system plays a significant role by completely decarbonising electricity generation. This reflects the assumptions on the cost of technology in the different sectors, with industry requiring the most expensive options to cut emissions significantly.

Figure 3.16 CO_2 emissions from the power sector (including heating plants)



Key point *The power sector becomes completely decarbonised in all scenarios, except the 4DS.*

District heating

As mentioned above, district heating has enjoyed a steady increase for decades in the majority of the Nordic countries and has now reached a high market share in the heating of buildings. This means that the possibilities for further growth are limited, a fact that is also confirmed by the results from the IEA scenario calculations. Final use of district heat in residential and commercial buildings has been analysed in both the 4DS and 2DS (Figure 3.17).

Figure 3.17 Development of district heating use in the Nordic region (left) and its breakdown by sector (right)

Note: These diagrams also include the end-use sector "Agriculture, fishing, non-specified other", but here the use of district heating is comparatively small..

Key point *District heating use increases only slightly in the 4DS but stagnates and even falls slightly in the 2DS and CNS.*

The 4DS with moderate climate ambitions shows a very slow increase in the use of district heating in the Nordic countries. The significant drop in district heating use between 2010 and 2015 is an effect of the very cold 2010, whereas the future model years are calculated with average climate data.

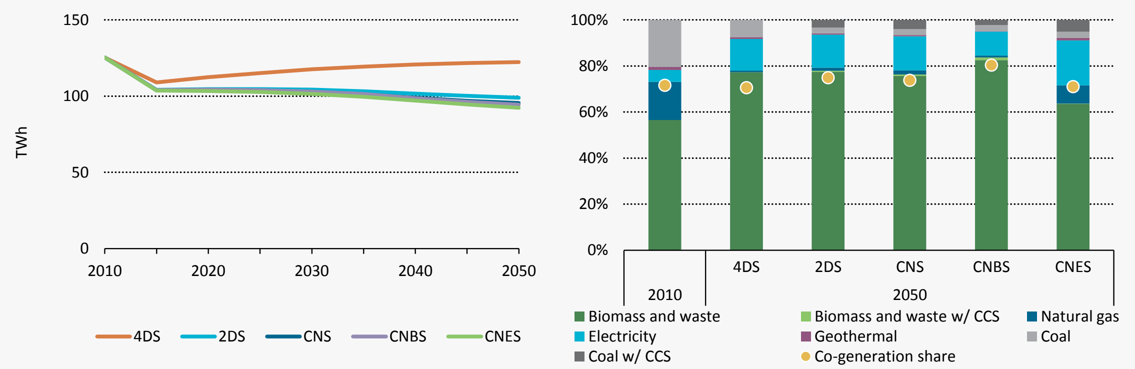
In the more climate-ambitious 2DS and CNS, the use of district heating decreases slightly between 2015 and 2050. This does not indicate that district heating loses large market share. Instead the total heating market decreases due to increased energy efficiency efforts for space and water heating in buildings. The share of district heating in the final energy use for space and water heating maintains its level in the residential and service sector, with around 40% (space) and between 50% and 60% (water).

District-heating production shows the same general trend as electricity generation, with decreasing use of fossil fuels and increasing use of renewable energy. Especially in the 2DS and CNS, carbon capture and storage at coal- and biomass-fired co-generation plants are used to reduce emissions even further. In addition, electricity is increasingly used in boilers or heat pumps for district heat generation. Combined with heat storage, this can be an option to store surplus electricity from wind generation during times of low electricity demand.

In the CNBS and CNES, the use of district heat in the buildings sector develops along similar lines to the 2DS (Figure 3.18). The structure of its supply changes, however. Biomass plays a more important role in the scenarios in 2050. It reaches its highest share in the CNBS in 2050 with almost 85% (defined as the share of district heating from biomass-fired co-generation and heat plants in the total district heat generation), whereas the share of electricity increases in the CNES compared with the CNS. Co-generation in district-heating supply increases in all scenarios compared with the current level. The largest share is again reached in the CNBS compared with over 80% in 2050.

The development of co-generation in the generation of electricity differs. Electricity from co-generation, for example, initially declines over time in the CNBS until 2030 and increases thereafter by 2050 to a level similar in absolute terms to today. Its share in total electricity generation, however, continuously declines from the current level of 19% to 15%, as generation from other sources, notably wind, increases at a much faster rate. In addition to changes in the relative cost of technology (wind becoming cheaper as a result of global learning), changes in the final demand structure also affect the development of co-generation.

Figure 3.18 Development of final use of district heating in the buildings sector (left) and its supply mix in 2050, by fuel (right)

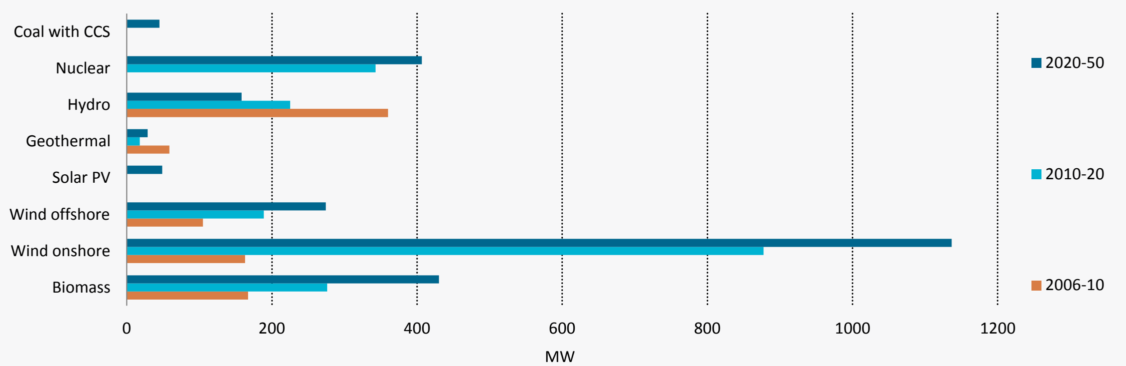


Key point *Demand for district heating does not alter in the CNS and its variants, but the fuel mix of its supply changes.*

Investment needs and fuel cost savings

Despite the current low-carbon intensity of the Nordic electricity system, further decarbonisation of the power sector in the 2DS and CNS requires a significant acceleration in the use of low-carbon technologies. Wind power, for example, in the 2DS requires the annual construction rate to increase from the 0.3 GW/yr over the past five years to 1.0 GW/yr in the next decade and then still further to 1.4 GW/yr between 2020 and 2050 (Figure 3.19).

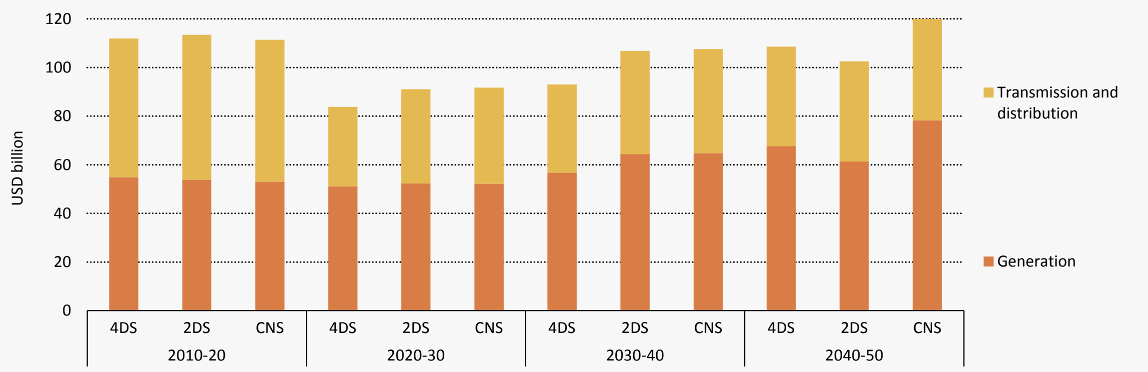
Figure 3.19 Annual new capacity additions of low-carbon power technologies in the Nordic region in the 2DS



Key point *Deployment of low-carbon technologies has to be accelerated in the 2DS compared with current rates, notably for wind, biomass, nuclear and CCS.*

Cumulative investment requirements in the power sector over the next four decades in the 4DS, 2DS and CNS are in the range of USD 400 billion (4DS) to USD 450 billion (CNS) (Figure 3.20). Absolute investment may appear huge, and mobilising it can be challenging. The absolute cumulative investment required in the power sector, however, represents no more than 0.5% in the 4DS and 0.7% in the CNS of the cumulative gross domestic product (GDP) created in the Nordic region over the next 40 years. Around 60% of the investments are needed for power generation, whereas the remaining 40% are linked to the electricity transmission and distribution network.

Figure 3.20 Investment requirement in the power sector by scenario



Note: This figure includes power generation and transmission.

Key point *Investments of around USD 400-450 billion are required over the next four decades for the power sector in the Nordic region.*

Compared with the 4DS, the 2DS requires additional cumulative investments of some 15 billion (4%), and of some 40 billion (10%) in the CNS. The additional investment in the 2DS and CNS can be offset by savings in fuel costs. In the 2DS, cumulative savings in fuel costs between 2010 and 2050 amount to more than USD 70 billion (including revenues from increased electricity net imports). In sum, overall net savings in the 2DS could amount to USD 55 billion. For the CNS, the cumulative savings in fuel costs are around USD 90 billion (or higher) due to increased net exports of electricity. Net savings are therefore around USD 50 billion.

Technology spotlights

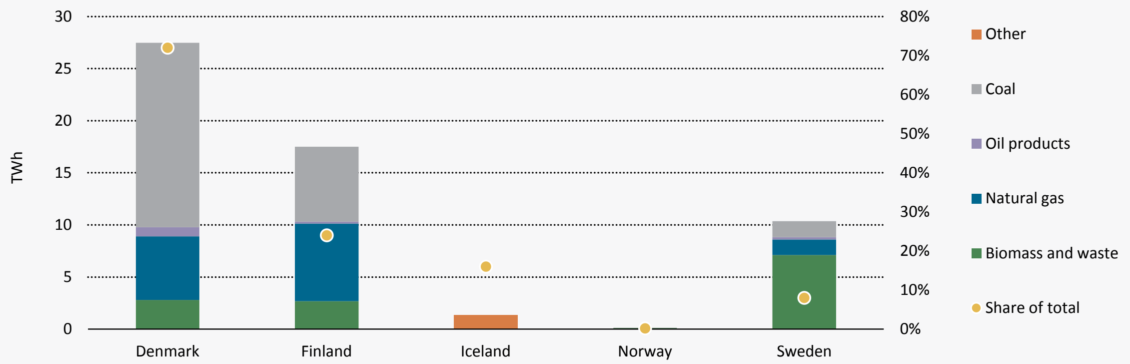
Co-generation – an efficient technology linking several energy markets

In the *Nordic Energy Technology Perspectives* (*NETP*) scenarios, power generation from non-nuclear thermal electricity is characterised by a switch in fuel use from fossil fuels to renewable and waste fuels, and by an increase in overall efficiency. This means that co-generation, which is widely used in the Nordic countries, is likely to continue to play a key role in the future development towards ambitious climate targets.

The prime benefit of co-generation is that it combines the production of electricity and heat into one single and efficient process. Since the heat rejected in the production of electricity is used for district heating or process heat, the overall efficiency is significantly higher than in conventional condensing power-plant units. Thus, co-generation plants tend to combine and integrate several energy markets. Besides electricity, district heating and industrial steam, also waste management through waste incineration and, possibly in the future, transportation fuels (poly-generation) may be linked in co-generation schemes.

Co-generation in district-heating systems accounts for about 70% of total electricity generation in Denmark and 25% in Finland (Figure 3.21).[4] Iceland, Norway and Sweden have smaller shares of co-generation, primarily due to their abundant resources of hydropower, which historically has implied fewer incentives for co-generation.

Figure 3.21 **Gross electricity production from co-generation in district-heating systems by fuel and in relation to total electricity generation, 2009**



Source: EUROSTAT, 2012. We assume that the EUROSTAT "Main activity CHP plant" definition refers to co-generation in primarily district heating. This has also been verified by Nordic statistics.

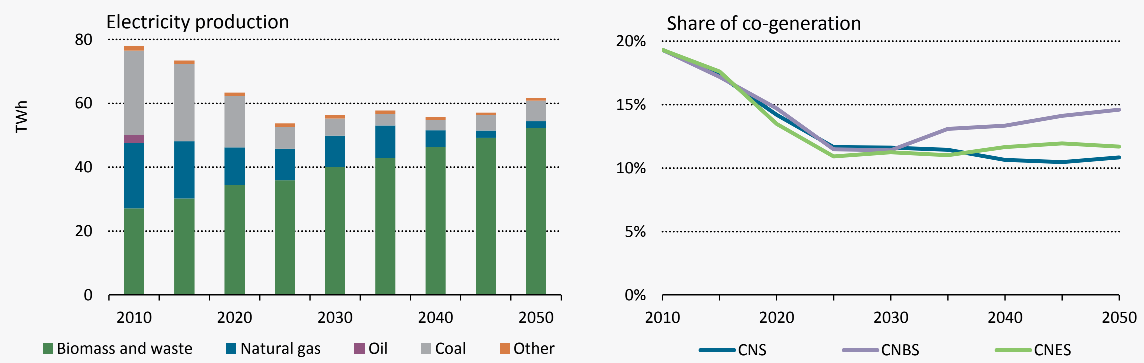
Key point *Significant shares of co-generation in district-heating systems already exist, especially in Denmark and Finland.*

4 The definition of co-generation includes, however, a rather large variety of power and heat plant configurations. In Denmark, for instance, large centralised co-generation schemes, which are primarily used for electricity production and often operated in condensing mode, account for a large share of the electricity and district-heating supply. Such units generally have a relatively low overall efficiency, but are still higher than in a condensing power plant.

In the *NETP* model runs (85% reduction cases), the share of co-generation (of total electricity production) is reduced somewhat over time (Figure 3.22). This is a consequence of both stagnating demand for district heating and switching from fossil fuels to waste fuels (which is a result of bans on landfills) and biomass (which is a result of renewable support schemes). Such plants are, generally, characterised by lower power-to-heat ratios than fossil-fuelled schemes, especially natural gas (biomass integrated gasification combined cycles could potentially reach a similar power-to-heat ratio as natural gas-combined cycles). These circumstances reduce the potential for producing electricity linked to the district-heating market. Furthermore, other means of new electricity supply in the Nordic market are also efficient from a climate-policy perspective and may compete with co-generation investments. These include hydropower, wind power and nuclear power. If co-generation relies on policy instruments favouring low CO_2-technologies and/or renewables, there is, thus, competition from other sources of renewable electricity production. The CBNS assumes a decrease in biomass prices, which therefore increases the competitive advantage of biomass-based co-generation (Figure 3.22 [right panel]). In such a case, competing sources of renewable electricity generation, such as wind power, will generate a somewhat smaller contribution.

Co-generation becomes almost entirely decarbonised in the CNS by 2050 (Figure 3.22).

Figure 3.22 **Electricity production from co-generation in district heating and industry in the Nordic countries**



Note: Represented in nominal figures (left, from the CNS) and in relation to total electricity production (right).

Key point *Biomass rapidly becomes the most important fuel in co-generation.*

Synergies between district heating and the electricity system

Balancing variable electricity production is set to be a key issue in the future energy system. Improved demand response to price signals is an important measure to achieve this. Synergies between district heating and the electricity system can also be an important measure to efficiently help the balancing issue. Even though heat consumption, the same as electricity consumption, fluctuates from one hour to the next, storing heat is an option that could decouple consumption time and production time. Decoupling would therefore make it possible to use electricity for heat production when electricity prices are low. When there is less wind power in the system, electricity prices are generally higher and co-generation plants generate more heat. The different heat generation technologies are activated on the basis of their marginal generation costs. Such costs are linked to the electricity price, which is determined on the basis of the marginal generation costs in the system. When there is a great deal of wind power in the system, especially in the CNES, a downward pressure is exerted on electricity prices. Price signals in the electricity market function as a control parameter for cost-effective operation in both the district-heating and the electricity systems. Large-scale heat pumps in district-heating systems could reduce generation when the electricity price increases, while co-generation plants and heat storage could increase their generation during such times. Low electricity prices would lead to the opposite response. For optimal results, it is important that co-generation systems are operated in relation to the price signals of the electricity market. In that way, district-heating systems will be used efficiently to balance fluctuating electricity generation. In this case, district-heating systems and thermal storage can be used for the efficient integration of variable power generation.

The role of nuclear power in the Nordic countries – other modelling experiences

The analysed *NETP* scenarios all share the same rather optimistic view that nuclear power will expand in the Nordic countries. The expansion amounts to roughly 40 TWh by 2050, which is significant given that around 80 TWh has been produced in recent years. This also means that the existing share of nuclear power in the Nordic generation of around 20% will remain until 2050. A fifth nuclear reactor in Finland (Olkiluoto 3) is currently under construction, adding 1.6 GW of capacity. Two additional reactors proposed by utilities Teollisuuden Voima Oy (TVO) and Fennovoima[5] are also under consideration, but no investment decisions have been taken as yet. In Sweden, parliament removed the ban on new nuclear power plants in 2010, opening the way for new investment. In recent years, repowering investments (capacity increases) have been made and are expected to continue. In the *NETP* model runs, it is assumed that the maximum additional capacity in Finland will be less than 4 GW by 2050. The assumptions for Sweden are that the existing capacity is maintained.

Even though such a considerable expansion of nuclear power may be feasible and in line with current climate policy, the future of nuclear power is controversial. A development with a less optimistic view on the future of nuclear power is likely to affect several of the findings presented in *NETP*.

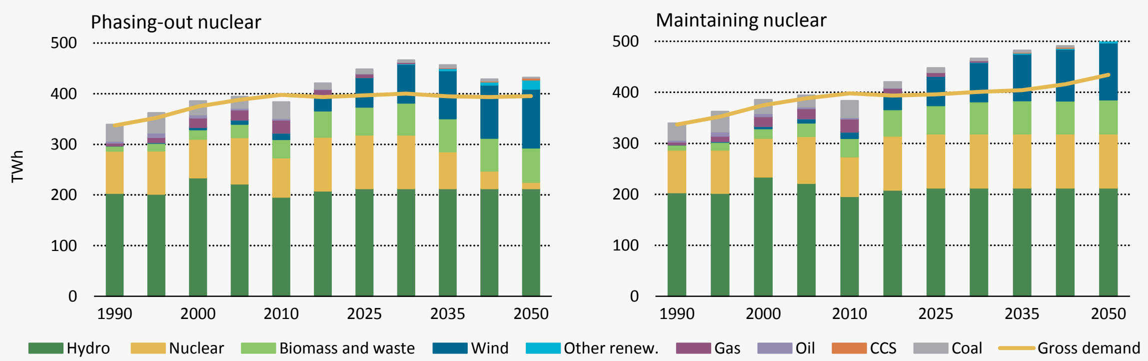
Whether new nuclear power plants will be built or not is, of course, a matter of cost versus income gained in the wholesale electricity market (further considerations such as public acceptance and risk assessment are, of course, also important if economical feasibility exits). Model calculations in an interdisciplinary research project titled “North European Power Perspectives” (*NEPP*, 2012) report a significant interval in the future development of whole sale electricity prices in the Nordic market in different climate-policy-orientated scenarios.

5 Fennovoima is a joint venture among several energy and industry companies.

In several cases, these price projections end up below the assumed costs of new nuclear power plants. This is especially true for scenarios assuming a high degree of end-use efficiency measures and significant support for renewable electricity supplementing carbon trading in order to reach ambitious climate-policy goals. These scenarios differ from the reported *NETP* scenarios in that they assume a more offensive end-use efficiency strategy. On the other hand, they share the ambitious climate targets for the Nordic countries. Wholesale electricity prices are generally lower in the *NEPP* study than in the *NETP* scenarios in which demand is higher. Cost estimates for new nuclear power plants differ widely among the various sources. The *NEPP* project assumes that investment costs will be around USD 4 400 per kilowatt (kW). This is in line with the assumptions of the *ETP 2012*, which assumes roughly USD 4 000 per kW.

The impact of a nuclear phase-out in Finland and Sweden has been investigated in more detail in the *NEPP* project. The report is somewhat in contrast with *NETP* in which the prospect for investment in new nuclear plants is the same across the scenarios. In the *NEPP* project, a specific scenario, which assumed the Nordic region's existing nuclear capacity (including the fifth reactor in Finland) would be maintained until 2050, was compared with another scenario in which the lifespan for nuclear energy was limited to 60 years.

Figure 3.23 Nordic electricity generation in a climate-policy-orientated scenario



Source: *NEPP*, 2012.

Key point *A phase-out of nuclear power in the Nordic countries is likely to be handled by reduced electricity demand induced by higher electricity prices, less electricity export to Continental Europe, and more investments in renewable and fossil electricity generation.*

The two modelling cases with and without existing nuclear capacity post-2030 produced a handful of important findings regarding the long-term development of the Nordic energy markets. As a consequence of the nuclear phase-out, total Nordic electricity generation would be significantly lower post-2030 than if nuclear power had not have been phased out (Figure 3.23). On the other hand, the production of renewable electricity is higher if nuclear power is phased out. However, in both cases power generation from renewables increases considerably due to substantial investment support, climate policies and higher fossil-fuel prices. Investment in the Nordic region's renewable electricity generates excess capacity that could be exported to Continental Europe. This is also a clear result of the reported *NETP* scenarios. In both investigated *NEPP* scenarios, the net export is of significant size post-2020. In the case in which nuclear power is phased out, net export declines significantly post-2030 when the phasing out is initiated.

In Finland and Sweden, where nuclear power is currently used, the impact of the analysed nuclear phase-out on the electricity balance is of a significant magnitude. This is due to the relative importance that nuclear power has today in these two countries.

In the *NEPP* study it is also shown that Nordic electricity demand is lower when nuclear power is phased out because electricity prices are higher as a consequence of the phase-out. Maintaining the existing production capacity throughout the modelling period by extending the lifespan of nuclear plants will keep wholesale electricity prices lower than would otherwise be the case. This is due to the fact that costs for extending the lifespan are assumed to be low in relation to the calculated electricity prices. Electricity demand in the Nordic market is, therefore, higher when nuclear power capacity remains constant, according to the scenario definition. A larger overall Nordic production is accompanied by a larger domestic demand. Since production exceeds demand, electricity is net exported, which is also the case when nuclear power is phased out but at a lower level.

Finally, CO_2 emissions are also affected but only to a minor extent. If nuclear power is phased out, emissions from the Nordic stationary energy system (*i.e.* excluding transportation) are around 5% higher (still far lower than today) than if nuclear power is maintained at the same level throughout the modelling period. The impact on emissions from phasing out nuclear power is comparatively low because nuclear power is largely replaced by greater investment in renewable electricity and a slight reduction in demand. However, in a less climate-conscious context with lower carbon prices and less support for renewables, the emissions impact of phasing out nuclear is likely to be more significant.

To conclude, sensitivity analyses of the prospects of nuclear power in the Nordic electricity market, as reported here, are important in order to further complete the picture. The findings discussed here may, therefore, be used as additional reflections on the reported *NETP* model runs where such a sensitivity analysis has been excluded from the scope. The status of nuclear power in Nordic countries in 2050 will significantly affect the entire electricity market, including electricity generation, demand, prices and cross-border electricity trade.

Can the electricity system handle an electrified transport system? – the Icelandic case

In the CNS, CNBS and CNES, which all assume an 85% emissions-reduction target for the Nordic region, the use of electricity in transportation in all five Nordic countries increases significantly from the current total of 4 TWh (mainly railroads) to typically around 40 TWh in 2050. A large share of this amount is assigned to electric vehicles (EVs). Such a development will, of course, present new challenges to the electricity-supply system.

In many respects, a shift towards electric-powered transportation is especially desirable and technically feasible in Iceland. Abundant clean energy, low electricity prices, and particularly reliable nationwide transmission and distribution systems make Iceland a promising place for EVs (World Economic Forum, 2011).

An analysis of the effect of EV usage on Reykjavik's power and heat company, Reykjavik Energy (RE), shows that 50 000 EVs could be charged within RE's distribution area by 2030 (Kristmundsson and Einarsdóttir, 2010). That amounts to more than 15% of the forecast nationwide car fleet at that time and may seem unrealistic. It is, however, a scenario, not a forecast, that is set to demonstrate how the power system could cope with a major shift to EVs. The authors deem RE's distribution system, for the most part, able to cope with such a shift. It would need some reinforcements, they conclude, but in some areas it could meet the additional distribution needs of a 100% EV car stock.

The power capacity required to service the fleet of 50 000 would be around 70 MW, assuming a 2.9 kW average charging power per car and at most 35% of the fleet being charged simultaneously, according to the authors. The scenario comes down to 112 gigawatt hours per year (GWh/yr), some 9.8% of RE's production in 2010, and a mere 0.56% of the forecast total Icelandic production for 2030 (National Energy Authority, 2011).

If the cars were charged cyclically, 60 MW of additional power capacity would be needed within RE's system. However, if the charging took place in off-peak hours, no further power plants would be needed. Whether such excess capacity is already contained in the existing system is not disclosed. In 2010, the installed capacity in the Icelandic electricity system was around 2 580 MW, and the 60 MW increase is a relatively insignificant addition to the generating capacity.

In the most extreme scenario, a 2030 aggregate car stock comprising EVs only yields an annual demand of approximately 750 GWh, which is almost 4% of production forecast for 2030. Unharnessed resources currently deemed fit for use according to government plans for hydropower and geothermal energy resources amount to 8 289 GWh. According to the national transmission system operator Landsnet, a car stock fully comprising EVs would not require any changes on their part. Electrification of the car fleet is, therefore, technically possible.

The conditions in Iceland to increase sharply the share of EVs are good and little additional investment is needed. Even a car fleet consisting solely of EVs is technically feasible and, consequently, free of CO_2 emissions. The assumptions behind all the scenarios in this report rely on the introduction of EVs to a varying degree. The situation in Iceland shows that these assumptions are quite realistic and no significant changes are required, either for infrastructure or generating capacity. This creates the possibility to electrify the transport sector relatively quickly, which is in accordance with the scenarios in this report.

(Far) offshore wind power

The contribution from wind power is increasing rapidly in all *Nordic ETP* scenarios. In the CNES, the scenario with the largest volume of wind power, the total generation in Nordic countries amounts to around 150 TWh by 2050. Almost 40% of that amount is generated in offshore installations. Wind conditions are typically better offshore than onshore, partly compensating for the added costs associated with offshore installations. In many countries, financial support mechanisms exist to encourage offshore wind development. These factors coupled with reduced visual and environmental impact make offshore wind power attractive, and current projections indicate a rapid increase in installed offshore wind capacity over the next decade, at least in Northern Europe.

Based on the *Nordic ETP* model runs it is, however, clear that a significant increase in offshore investment is required to support the ambitious climate policies. While onshore wind investments amount to almost 80 TWh by 2050 in the 4DS, which is the least climate-policy-ambitious scenario, offshore investments correspond to merely around 25 TWh. This contribution more than doubles in the CNES.

According to statistics from the European Wind Energy Association, the Nordic region had 486 offshore wind turbines with a total installed capacity of 1 052 MW at the end of 2011. Of this capacity, 860 MW was in Denmark, 164 MW in Sweden, 26 MW in Finland and 2.3 MW in Norway. The turbine in Norway is a floating prototype, while all the others are wind turbines mounted on a bottom-fixed substructure. The current offshore wind power plant is typically deployed in fixed (to the seabed) configurations at water depths of less than 30 metres. The offshore wind industry in Europe is set to experience a general move towards larger installations in deeper waters and farther from shore, as available shallow-water near-shore sites are becoming scarce. This brings technical and financial challenges that have to be overcome.

The largest offshore wind farm in the Nordic region is Horns Rev 2 in Denmark, which has a capacity of 209 MW. The Nordic IEA model runs indicate that prospects for offshore wind farms are more favourable in Denmark than in the other Nordic countries. Offshore wind power is not an option considered in Iceland. In the CNES, around 13 GW is installed in Denmark by 2050, while the corresponding investments in Norway, Sweden and Finland do not exceed 3 GW.

Compared to onshore wind power, the installation and maintenance costs of offshore wind farms are significantly higher. Emphasis is therefore placed on investing in technology that simplifies installation while increasing reliability. A clear manifestation of this is the trend towards permanent magnet generators in either gearless or simplified gearbox turbines.

Floating turbines, which will enable offshore wind installations to be set in deeper waters, are currently being researched and developed but are not yet commercially competitive.

The typical grid connection of offshore wind farms currently consists of turbines connected along a number of radial feeders that are brought together at an offshore substation, followed by offshore and onshore voltage transformation. For large and far offshore wind farms, this solution is no longer suitable due to excessive power loss and need for expensive reactive power compensating equipment. It is generally agreed that beyond certain power and distance, high-voltage direct current technology is the preferred choice. The offshore wind industry is developing at a rapid pace and no standard design has yet emerged that provides the best solution for grid connection. In addition to transmission capacity from the offshore wind farm to land, there is also a need for sufficient grid capacity onshore to transport the power to demand centres.

Critical challenges

Developing the power and district-heating markets is central to the Nordic policy of decarbonisation. By replacing fossil fuels in power generation and district-heating production with energy sources without CO_2 emissions, power and district heating can also be used for the decarbonisation of other sectors. Nordic power can, in addition, be exported and contribute to decarbonisation in other European countries.

Although the Nordic power and district-heating systems already have low CO_2 emissions, our scenarios show that the development towards a CO_2-free situation leads to a number of challenges:

- Wind power is expanded considerably in all scenarios. It is challenging to implement this with local acceptance of all the wind turbines, both land- and sea-based, needed for this expansion. The variable and partly intermittent generation from wind leads to challenges for the power system and power market related to maintaining generation capacity.
- Nuclear capacity increases in the scenarios. Nuclear power decisions (mainly in Sweden, but also in Finland) are always challenging, both politically and from a public acceptance perspective. The reason for this is the well-known nature of nuclear power (*e.g.* safety in operation, and handling and storage of nuclear waste). Furthermore, utilities may refrain from such investment due to significant uncertainties concerning final construction costs.
- An expansion of the electricity-transmission grid is required in order to facilitate an effective use of the power system. Expansion is required both within the Nordic region and for export from the region. This expansion also leads to a number of challenges:
  - Building cables to the continent and to the United Kingdom (technical, financial and acceptance challenges).
  - Strengthening the transmission grid within and among the Nordic countries, as well as within countries that exchange power with the Nordic region (technical, financial and acceptance challenges).
  - Increased export from the Nordic region is beneficial in a European context but also leads to increased electricity prices in regions with traditionally low prices (typically the Nordic region). This may lead to negative reactions among Nordic consumers.
- Even though the model runs indicate that the future contribution from CCS is small in the Nordic countries, the development of CCS is a key factor in a European context according to the presented scenarios. This is a major technical challenge, but may also be challenging from a public acceptance point of view.
- It is important to maintain and strengthen the competitiveness of district heating on the heating market in order to take advantage of important synergies. Synergies among the district-heating system, power generation, the municipal waste management system and industrial energy systems are important for meeting the decarbonisation policy.
- When goals and strategies for improving energy efficiency are established, it is important that they are based on a goal of minimising the use of primary energy, while taking advantage of district heating.
- The high market share of district heating in most Nordic countries makes it difficult to expand further. Although challenging, new markets for district heating will be increasingly important to identify and develop. Examples of such use could include absorption cooling, household appliances (*e.g.* washing machines and dishwashers), greenhouse heating, and heat for industrial processes.
- In addition to the challenges discussed above, implementing policies that create driving forces and incentives large enough to achieve the necessary decarbonisation will be a great political challenge.

Chapter 7

Conclusions

The *Nordic Energy Technology Perspectives* (*NETP*) describes three possible scenarios for the Nordic energy system in 2050, each of which is greatly decarbonised, more efficient and has a high share of renewable sources. All three scenarios describe a region that is a significant electricity exporter and carbon capture and storage (CCS) practitioner, and has a completely revolutionised transport sector.

Key Findings

- ***The NETP scenarios provide a valuable context to assess the potential of current national targets.*** *The Carbon-Neutral Scenario (CNS) offers a cost-effective pathway to an energy system with no net emissions; the 2°C Scenario (2DS) and 4°C Scenario (4DS) describe how the Nordic countries contribute in least-cost global scenarios that limit global average temperature rise to 2°C or 4°C. The results are not bound by specific national targets, such as a completely renewable energy supply or a transport system independent of fossil fuels. Rather, the scenarios aim to give in sight into the range and possible mix of additional efforts needed to reach such targets.*
- ***Challenge 1: Energy efficiency is the first-order priority for policy makers.*** *In the short term, energy efficiency must deliver most of the emissions reduction. Governments must act to unlock the potential and ensure long-term duration of energy efficiency improvement, especially in buildings and industry.*
- ***Challenge 2: Infrastructure that enables technology change and integration will be critical to a "system" approach.*** *The pace of infrastructure construction needs to be stepped up in many areas. In transport, new systems to supply and distribute fuels are needed, as is higher rail capacity. In electricity, new wind capacity and a stronger and smarter grid are key priorities that need investment in infrastructure.*
- ***Challenge 3: Carbon capture and storage is a key technology by which to achieve deep cuts in greenhouse-gas (GHG) emissions, particularly in industry.*** *Since progress in this technology has been slow, governments must scale up policy action to support its further development and deployment.*
- ***Challenge 4: Biomass use will increase, primarily to support greater production of biofuels; development of advanced biofuels is a priority.*** *Bioenergy will be the single largest energy source in 2050, particularly important in transport. Public support for research, development and demonstration (RD&D) is needed to meet the challenge of reaching the supply volumes required sustainably and to efficiently use the resources.*
- ***Challenge 5: Strong co-operation among Nordic countries can reduce the cost of reaching the scenarios.*** *Co-ordination of policies, RD&D and infrastructure development could accelerate technology development and penetration towards a low-carbon energy system.*
- ***Challenge 6: A set of "no-regret" options can deliver co-benefits.*** *Policy makers should prioritise action in the areas of energy savings and measures that deliver co-benefits in relation to other environmental, economic and social objectives.*

Policy challenges

The *NETP* describes three different visions for the Nordic energy system in 2050. An ambitious CNS that achieves national emissions reduction targets; a scenario in which the Nordic countries play their part in a global 2DS; and a less-ambitious scenario describing pathways to limit temperature rise to 4°C (4DS). None of these scenarios are "business as usual": all imply significant changes in the production, distribution and use of energy in the region.

The Nordic countries have demonstrated international leadership by taking targeted actions to reduce GHG emissions. Their targets for reductions towards 2050 are among the most ambitious in the world. While *ETP 2012* assesses the possibility of a carbon-neutral world in 2075, the Nordic region presents an opportunity to achieve the same objective 25 years earlier. The obstacles identified along the way are not entirely specific to the Nordic countries, and may serve as examples of those that will confront other countries. Governments outside the region are encouraged to use the experience of the Nordic region as a reference in their own transitions to low-carbon energy systems.

Decarbonised electricity is at the core of a transformed energy system, with spillover effects into end-use sectors. As with other regions with an old building stock, average efficiency is low and curbing overall energy demand will be a substantial challenge. While the cold climate exacerbates these difficulties, access to fossil-free electricity and renewable district heating provide possibilities. Since the Nordic countries are sparsely populated, decarbonising road transport is a major future challenge. The Nordic countries will, like all countries, face challenges from increased emissions in the aviation and shipping sectors. A very low carbon industry sector will be particularly difficult to achieve in the Nordic countries, due to the predominance of heavy industries with significant process emissions.

Overall, the absolute additional investments needed to realise the CNS compared to the 4DS seem manageable; they are estimated to some USD 180 billion[1] between 2010 and 2050, roughly equal to 0.3 % of cumulative Nordic GDP over the period. More than half of this is required in the buildings sector. However, there are technical challenges, distributional effects and issues related to public acceptance that will be equally – if not more – important than the absolute cost of realising the scenarios. The following section lays out some key characteristics of a future low-carbon Nordic energy system leading to six critical policy challenges.

Challenge 1. Energy efficiency in demand sectors

The future system is more energy efficient. All scenarios except the 4DS show reductions in total primary energy supply, driven by extensive energy efficiency improvements, especially in the end-use sectors.

Unlocking potential energy efficiency requires action across all sectors. Improvements in the industry and buildings sectors have been implemented, but large potential for improvements remain. Existing and new EU directives, *e.g.* European Commission (2009) and European Commission (2012), are important policy steppingstones, but complementary national and regional policies are needed to cover all demand sectors.

Integrated minimum energy performance codes and standards for new and existing buildings are central to increasing energy efficiency. The implementation of the EU Energy Performance of Buildings Directive includes a requirement that by 2020 all new buildings must be "near zero" in energy consumption. Additional policies are needed to facilitate the renovation of old buildings. One general barrier for energy efficiency improvement is the lack of

1 Unless otherwise stated, all costs and prices are in real 2010 USD, i.e. excluding inflation. Other currencies have been converted into USD using purchasing power parity (PPP) exchange rates.

understanding of potential and long-term effectiveness from energy efficiency improvements in buildings. Stronger financial incentives and de-risking of investment are needed. Today, few investors or financing agencies adequately take into account that energy efficient buildings yield lower operation costs.

Policies to support energy efficiency improvement in industry must also maintain global competitiveness. Adoption of new technologies can unlock energy and economic savings. Energy-saving potential in industry can further be addressed by energy management policies; minimum energy performance standards for industrial equipment, electric motors and systems; energy efficiency services for small- and medium-size enterprises; and economic and financial policy packages that support investments in energy efficiency. Many of these measures are already present in the Nordic countries, but have the potential to be further increased.

Key policy priorities to improve fuel economy in the transport sector should focus on implementing stringent fuel economy standards and encouraging consumers to choose more efficient vehicles. The IEA has developed 25 energy efficiency recommendations across sectors with high energy use to help governments achieve the full potential of energy efficiency improvements (IEA, 2011).

To stimulate a resource-efficient energy system, policies for energy efficiency improvement should be based on minimal primary energy use (not final energy consumption). Considering only final energy consumption may be misleading since it does not take into account losses during energy conversion in other parts of the energy value chain, such as electricity or fuel production.

Challenge 2. Infrastructure in electricity and transport

The scenarios presented in this report will require upgrades and investments in new energy infrastructure, particularly in electricity and transport.

A decarbonised electricity and heat sector is central to the transition. Access to low-carbon electricity substantially reduces emissions in other sectors (*e.g.* transport and buildings). The Nordic electricity system is already 84% decarbonised, but *NETP* analysis confirms the need to bring emissions from the power generation sector to near zero in all scenarios. Current national and European policies and pledges towards 2020 are expected to provide an early start to the further decarbonisation of the electricity sector. The share of renewable sources in electricity develops very similarly in all scenarios (including the 4DS), increasing from 63% to some 75% between 2010 and 2050.

In the 2DS and CNS, carbon dioxide (CO_2) emissions from electricity are even slightly negative by 2050: capture of CO_2 at biomass-fired power plants results in a net removal of CO_2 from the atmosphere. Wind (both onshore and offshore) will increase, making up around 15% of total electricity generation in 2030 and up to 25% in 2050 in the 2DS and CNS. This implies building up to 10 000 new turbines onshore, and another 2 500 offshore. Managing the variability inherent in wind generation would be greatly facilitated by investment in more intelligent grid and demand-side control systems. Electricity generation derived from biomass and hydro will increase in both scenarios, while electricity generation from nuclear will be steady around 20%. The use of coal and gas for electricity generation will be reduced dramatically in all scenarios. In the 2DS and CNS, the only coal-fired electricity generation remaining after 2030 will be equipped with CCS.

The Nordic energy system is a net exporter of renewable electricity in 2050. A low-carbon and flexible Nordic electricity system is essential for reaching a resource-efficient energy system in the Nordic region. It could also benefit other European regions by providing balancing capacity across a broader context. The region’s significant natural resources and efficient regional grid provide a basis for a large expansion in renewable electricity generation at lower cost than in surrounding regions. Consequently, the region will be a net exporter of electricity to Continental Europe in all scenarios, with exports accounting for over 15% of total production in the high electricity variant of the CNS. The level of export possible depends largely on how much new transmission capacity is built among the Nordic countries and Continental Europe and the United Kingdom. Price developments in the rest of Europe will determine the economic case for trade. The *NETP* analysis indicates that export could range from 20 terawatt hours (TWh) to up to 100 TWh per year depending on the framework assumptions. Realising these volumes will not be easy or smooth: some actions will face public acceptance issues. The export potential represents significant economic value and will drive a significant proportion of the investments in the power sector, but it can only be realised if several new large interconnectors are built between the Nordic countries and Continental Europe. Experience shows that this will not be easy.

Transport in the Nordic region must undergo dramatic changes. In the short term, better fuel economy in conventional vehicles provides the highest impact. In the mid- to long term, transport needs to shift from fossil fuels to biofuels or electric vehicles, and be combined with modal shifts. Electric- and hydrogen-driven vehicles are two important technology areas. Electric vehicles save both primary energy use and emissions since they are much more energy efficient than conventional vehicles. Energy use from electric cars will make up some 10% of the vehicle stock energy use in the 2DS in 2050 and more than 20% in the CNS. In the most extreme scenario, the Carbon-Neutral high Electricity Scenario (CNES), transport uses some 7% of total Nordic electricity generation in 2050. Biofuels are expected to contribute the greatest share of emissions reduction, but the large volumes used raise supply and sustainability issues.

Half of the emissions from international shipping and aviation activities associated with the Nordic countries are attributed to the Nordic CO_2 balance in this analysis. Meeting emissions-reduction targets in this sector is more challenging than for domestic transport. Technically, there are fewer options; politically, the issue is more complex since collaboration with other countries and regions will be necessary, for example to build infrastructure for refuelling.

The *NETP* scenarios rely on near complete transition from fossil fuels to biofuels and electricity in road transport, which will require a well-developed infrastructure for different fuels. The large increase of railway transport – practically all growth in freight transport must be done on rail – will also require upgrading existing rail systems and investments in new rail infrastructure.

Challenge 3. Carbon capture and storage

CCS is a central technology to meet the emissions reduction envisioned in the 2DS and the CNS, particularly in industry. Under the assumptions for future industry production, CCS is expected to deliver between 20% and 30% of the emissions reduction. This implies that, in 2050 in the CNS, 50% of all cement and ammonia plants are equipped with CCS, and CCS is used in 30% of all ethylene and iron and steel plants. Moreover, in the 2DS and CNS, CO_2 capture technology reduces emissions at coal- and biomass-fired co-generation[2] plants, resulting in negative CO_2 emissions from this sector.

Depending on the scenario, the Nordic countries capture between 7 million tonnes of CO_2 ($MtCO_2$) (4DS) and 40 $MtCO_2$ (CNS) by 2050.[3] Deploying CCS at this level requires broad policies to address technological development, infrastructure, public acceptance and risk governance. Few commercial CCS projects currently exist.

2 Co-generation refers to the combined production of heat and power (CHP).
3 This may be compared *e.g.* to 1990 year's Nordic CO_2 emissions of 206 Mt.

The actual implementation of the whole CCS value chain from capture to storage, including transport and other infrastructure, is complicated and time consuming, especially when considering the associated legal and contractual issues, and the need for continuous monitoring and surveillance.

In the *NETP* scenarios CCS is introduced from 2025, a development that requires decisive and immediate policy action. Although two large-scale CO_2 storage projects are already under way in Norway (the Sleipner and Snøhvit projects), public funding for demonstration projects needs to increase.

Policies need to cover the whole technology value chain, providing incentives from capture through transport and storage. Policies are needed to encourage and identify storage sites, to develop the infrastructure around the technology, and for the continuous monitoring and responsibilities during the storage.

Challenge 4. Bioenergy supply

Bioenergy will be the single most important energy source in the Nordic region. In the 2DS and CNS, the share of biomass and waste in total primary energy supply doubles to 2050, reaching about 1 700 petajoules (PJ) (or one-third). Overall oil, coal and gas use fall from over 50% of total energy demand in 2010 to 23% by 2050 in the 2DS. In the CNS, this figure decreases to 16% due to new technologies being available earlier. Biomass usage for transport must be doubled already by 2015 and multiplied twelvefold by 2050 in the CNS. Over the same period, oil use for transport will decrease by 90% in 2050. The scenarios also assume a shift to carbon-neutral sources of energy for different industry processes where possible.

The Nordic region becomes a net importer of bioenergy, importing 9% of its supply in the 2DS and 13% in the CNS. These numbers assume increasing international trade in bioenergy and price forecasts for imported biomass. This is consistent with the analysis of global availability of biomass for energy purposes conducted in *ETP 2012*, which indicates that by 2050 bioenergy is the world's largest energy carrier, accounting for some 30% of the total global supply. The *NETP* analysis is cost-optimised and allows for import to the Nordic region, when economically efficient. Ensuring that this bioenergy is produced in a sustainable way will be a central challenge for policy makers across the world. International co-operation and standards are therefore very important, *e.g.* the sustainability criteria laid out in the EU Renewable Energy Directive (European Commission, 2009) as well as the ISO standardisation work on sustainability of biofuels (Guerriero, C. and Kerckow, B., 2011).

Policies to support development of advanced biofuels – solid, liquid and gaseous – will be important to provide different sectors with biofuels. Continued policy support is needed to bring down costs to competitive levels and while several new bioenergy technologies are approaching market competitiveness, their development must be accelerated through public RD&D. Governments should act to reduce risks associated with large investments when technologies are immature.

Economic instruments, such as the common Norwegian-Swedish electricity certificate system, feed-in tariffs and premiums for biofuels, can also address the currently high production costs of new biofuels for electricity production. These instruments are important for development of other renewable electricity production as well, such as wind power. Blending obligations for retail suppliers of road transport fuel have also proven effective.

Challenge 5. Leveraging Nordic collaboration

Nordic countries have demonstrated initiative and willingness to go beyond international agreements. Ambitious, long-term targets clearly show that the Nordic countries are motivated to go even further in the future. The *NETP* CNS shows pathways towards a Nordic energy system with very low CO_2 emissions. For these scenarios to be realised, powerful and predictable policies are required. Co-ordinating such policies would offer substantial benefits and cost reductions.

Energy prices that reflect the true cost of energy must be at the heart of Nordic energy policy. Without efficient price signals to consumers, policy targets will be more expensive to reach. The Nordic countries all have pricing mechanisms in place and are also all part of the EU Emissions Trading Scheme (ETS). However, the price levels for carbon emissions will need to increase substantially in order to realise the 2DS and CNS. Harmonising the carbon price across all Nordic countries and expanding the scope of the carbon price to cover more sectors is likely to lower total mitigation costs to reach common climate objectives. Policy harmonisation may be difficult in practice; it typically implies conceding some degree of control of national priorities. It may also shift costs significantly between countries and sectors. However, a balanced level of policy convergence may render benefits with limited distributional effects.

The *NETP* scenarios involve technologies that are currently immature, such as advanced biofuels, offshore wind and CCS. Significant RD&D efforts in the near term are required to advance these technologies. Nordic governments should consider where comparative advantages in the region exist and focus their efforts accordingly. Some technology areas may be better to leave to other regions to pursue, so prioritisation will be important.

Cost-effective infrastructure development will also require close Nordic policy co-ordination. At present, national strategies for sustainable transport put focus on different technology priorities. Choosing very different strategies for transport infrastructure solutions may come at very high costs in a sector that is already expensive to decarbonise.

Charting a common approach to CCS may also deliver substantial benefits. Sweden and Finland have the highest need for CO_2 capture but lack significant storage potential, meaning co-operation in CO_2 transport and storage infrastructure is central to technology implementation.

Challenge 6. Deploying no-regrets options

A number of no-regrets options are available, with the largest potential in the transport, building and industry sectors. In addition to climate change mitigation, no-regret options can deliver economic, environmental or social co-benefits, while also lowering costs; reducing local air pollution, traffic congestion and waste; and increasing energy security. The most obvious category is energy efficiency improvements. These options include improved fuel economy and increased transport efficiency through modal shifts to bus and rail within passenger transport, and from road to rail within freight transport. Improved logistics, shortened routes and optimised aviation traffic control will reduce transport volumes. In the buildings sector, improved insulation and optimised energy operation is likely to increase energy efficiency substantially. In industry, energy efficiency can be increased through for instance process optimisation and more efficient burners. Increased recycling of materials, notably metals and plastics, will also reduce overall energy use.

Uncertainties in technology deployment rates may require that several different technology pathways are supported in parallel. Different modal alternatives in the transport sector will hedge against the uncertainty of when and how alternative technologies (such as electric and hydrogen fuel vehicles) will have a break through.

Do the *NETP* results see countries reaching their specific national energy targets?

The 2DS and CNS by definition meet the goals set up in the modelling exercises: the cost-optimised Nordic contribution to the world envisioned in the global *ETP 2012* 2DS and a carbon-neutral Nordic energy system. But do these scenarios also deliver the Nordic national visions and targets summarised in Table 2.1? All Nordic countries have targets of reduced emissions of GHGs, without allocation among different gases by 2050; in addition, Denmark has a target of 100% renewable energy supply. Since the *NETP* results show CO_2 emissions, exact comparisons among the national targets and the *NETP* results are not possible. By definition the analysis of the CNS shows aggregate energy related Nordic CO_2 emissions falling by 85%. But it is not possible to conclude if these results hold for all GHG emissions. Moreover, Denmark's target of 100% renewables will not be reached in either scenario. In the 2DS, only Iceland will reach its emissions-reduction target (*i.e.* to decrease emissions 50% to 70%) by 2050. It is important to note that the *NETP* findings do not consider emissions reduction from carbon offsets; thus, there is a chance that national GHG emission targets can still be met through the purchase of international emissions-reduction credits.

Intermediate targets or more narrow national targets exist within many Nordic countries. For example, Sweden plans to have a fossil-fuel-independent transport fleet by 2030. The definition of fossil-fuel-independent is not yet clarified. If "independent" means "no use", this ambition is far from being reached in the *NETP* scenarios. In 2030, oil remains the most important fuel in the transport sector within all scenarios and makes up more than one-half of the energy use in Sweden. Denmark's target of phasing out coal use by 2030 is within reach in all of the *NETP* scenarios through early conversion to renewable energy sources. However, some coal still remains in the industry sector in Denmark.

The scenarios do not align perfectly with the political targets in each Nordic country, but instead provide least-cost pathways for the Nordic region as a whole. The *NETP* findings therefore provide a valuable context for comparison of national targets.