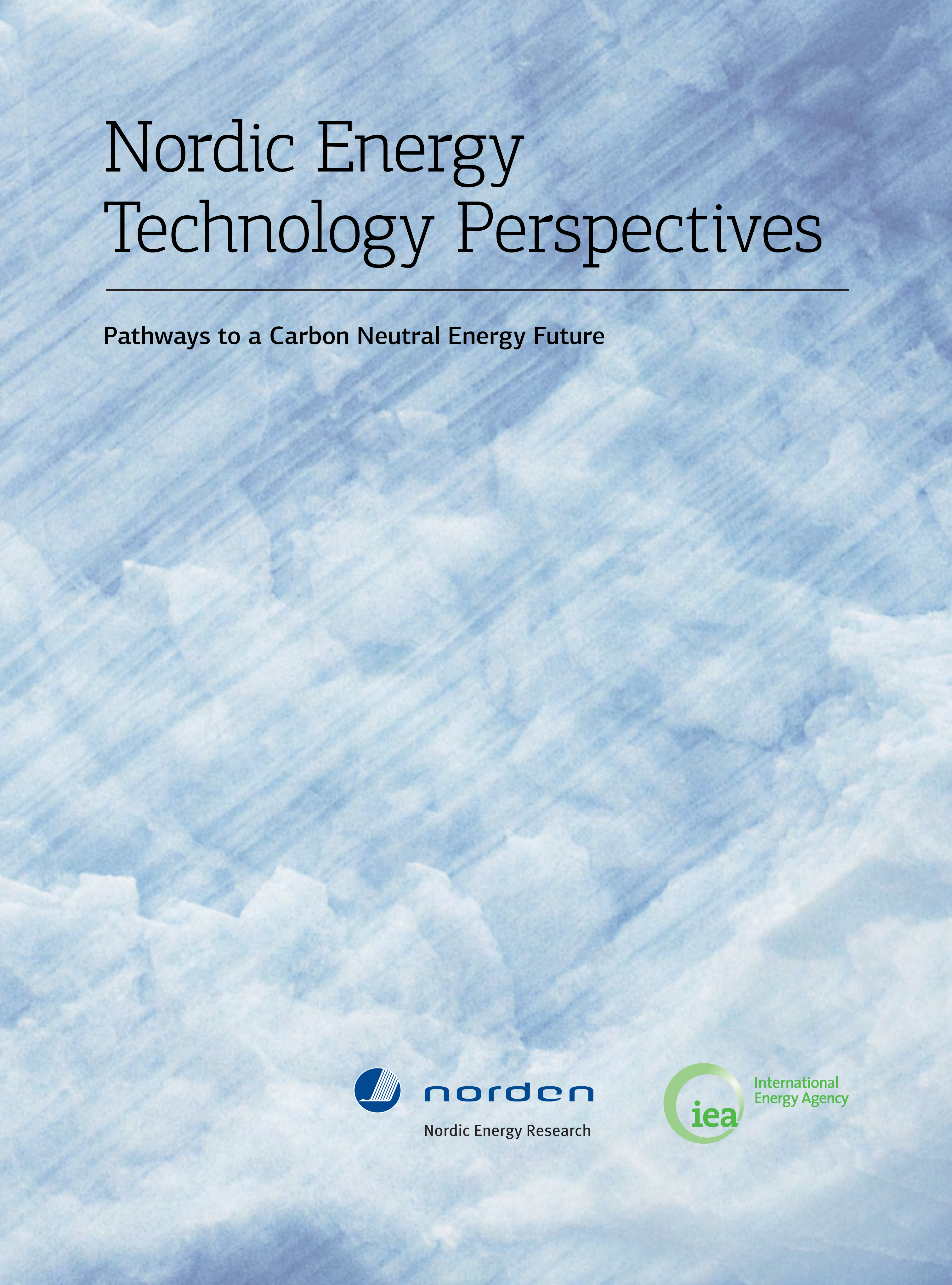

Nordic Energy Technology Perspectives

Pathways to a Carbon Neutral Energy Future

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Nordic Energy Technology Perspectives at a glance

The five Nordic countries of Denmark, Finland, Iceland, Norway and Sweden have announced ambitious goals towards decarbonising their energy systems by 2050. Based on the scenarios and analysis of *Energy Technology Perspectives 2012,* the International Energy Agency (IEA) and leading Nordic research institutions jointly assess how the Nordic region can achieve a carbon-neutral energy system by 2050.

Without doubt, the Nordic countries are front-runners in taking decisive action toward clear, long-term energy targets. In examining their approach, this project aims to provide objective analysis that will increase the Nordic region's chances of success. A secondary – but ultimately more important – aim is to prompt other countries and regions to follow their lead.

The report identifies five central challenges that the Nordic countries face in achieving a carbon-neutral energy system. Other countries seeking to radically transform their energy systems should take note.

- **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.

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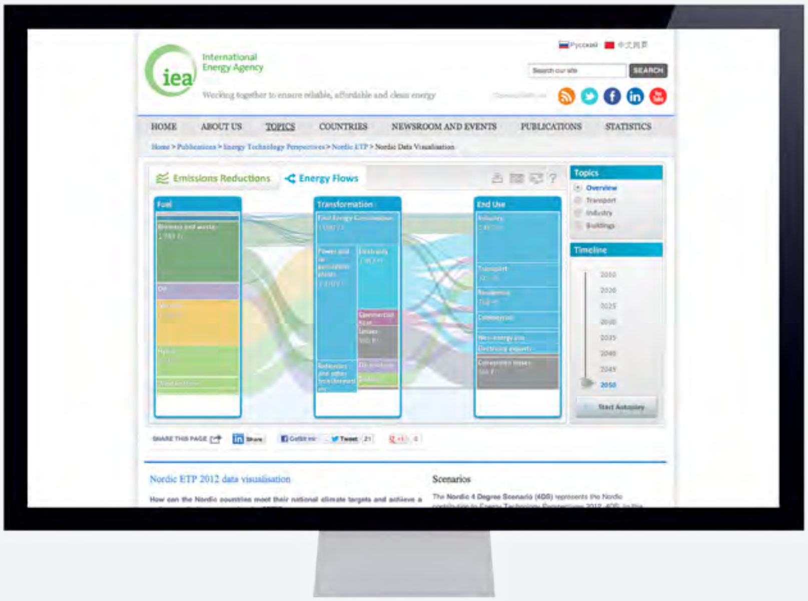
This Nordic ETP technology paper is the result of a collaborative effort between the International Energy Agency (IEA), Nordic Energy Research (NER), Risø DTU, Ea Energianalyse A/S, (EAEA), VTT Technical Research Centre of Finland (VTT), University of Iceland (UI), National Energy Authority of Iceland (NEA), Icelandic Meteorological Institute (IMI), Landsvirkjun, Institute For Energy Technology (IFE), SINTEF Energy Research (SINTEF), Profu Ab (Profu), IVL Swedish Environmental Research Institute (IVL), Chalmers University of Technology (Chalmers), KTH Royal Institute of Technology (KTH) and Luleå University of Technology (LTU). This Nordic ETP technology paper reflects the views of the IEA Secretariat, NER, Risø DTU, EAEA, VTT, UI, NEA, IMI, Landsvirkjun, IFE, SINTEF, Profu, IVL, Chalmers, KTH and LTU, but does not necessarily reflect those of their respective individual Member countries or funders. The Nordic ETP technology paper does not constitute professional advice on any specific issue or situation. NER, the IEA, Risø DTU, EAEA, VTT, UI, NEA, IMI, Landsvirkjun, IFE, SINTEF, Profu, IVL, Chalmers, KTH and LTU make no representation or warranty, express or implied, in respect of the contents of the Nordic ETP technology paper (including its completeness or accuracy) and shall not be responsible for any use of, or reliance on, the roadmap. For further information, please contact: rights@iea.org.

Nordic Energy Technology Perspectives

Pathways to a Carbon Neutral Energy Future



Nordic ETP 2012 data visualisation

How can the Nordic countries meet their national climate targets and achieve a

Scenarios

The Nordic 4 Degree Scenario (4DS) represents the Nordic

Explore the data behind *NETP* www.iea.org/etp/nordic

The IEA is making available the data used to create the Nordic Energy Technology Perspectives publication. Interactive data visualisations and extensive additional data are available on the IEA website for free.

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INTERNATIONAL ENERGY AGENCY

The International Energy Agency (IEA), an autonomous agency, was established in November 1974. Its primary mandate was – and is – two-fold: to promote energy security amongst its member countries through collective response to physical disruptions in oil supply, and provide authoritative research and analysis on ways to ensure reliable, affordable and clean energy for its 28 member countries and beyond. The IEA carries out a comprehensive programme of energy co-operation among its member countries, each of which is obliged to hold oil stocks equivalent to 90 days of its net imports. The Agency's aims include the following objectives:

- Secure member countries' access to reliable and ample supplies of all forms of energy; in particular, through maintaining effective emergency response capabilities in case of oil supply disruptions.
- Promote sustainable energy policies that spur economic growth and environmental protection in a global context – particularly in terms of reducing greenhouse-gas emissions that contribute to climate change.
- Improve transparency of international markets through collection and analysis of energy data.
- Support global collaboration on energy technology to secure future energy supplies and mitigate their environmental impact, including through improved energy efficiency and development and deployment of low-carbon technologies.
- Find solutions to global energy challenges through engagement and dialogue with non-member countries, industry, international organisations and other stakeholders.

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Foreword

If we are to realise a clean energy future globally, we cannot sit idle waiting for the lowest common denominator. Some regions must lead the transition towards a cleaner future, realising both the costs and benefits of being first. The Nordic countries have set ambitious political targets towards 2050 and have the unique possibility of assuming this leadership role.

Achieving these political targets will not be easy. The Nordic energy system must undergo dramatic changes under the 2°C Scenario (2DS), as outlined in the IEA *Energy Technology Perspectives 2012*; however, further regional action is needed. *Nordic Energy Technology Perspectives* introduces a new, more ambitious Carbon-Neutral Scenario (CNS) to assess how Nordic policy action can lead the way to a cleaner energy system and serve as an example for other countries and regions.

This study marks the first regional edition of the *Energy Technology Perspectives* series since its inception in 2006. For the first time, Nordic governments can compare their national climate goals with the contribution required of them in the 2°C world described in *Energy Technology Perspectives 2012*. The analysis evaluates the region from an external perspective and points to the important role of the Nordic energy system in facilitating the decarbonisation of Europe.

By applying the IEA's globally-recognised scenarios and analysis to the specific context of the Nordic countries, this publication offers a unique tool to policy makers and regional energy sector players. The analysis is tailored to the Nordic policy landscape and offers a level of detail not feasible in a global study. It provides an assessment of the stated climate and energy targets of the Nordic governments while maintaining direct compatibility with the global scenarios underpinning international discussion of energy policy.

Co-operation is a key aspect of *Nordic Energy Technology Perspectives*. The project was conducted in close collaboration between the IEA, 14 leading Nordic research institutions, and the Nordic Council of Ministers through its energy research funding institution, Nordic Energy Research. A reference group of ministries, energy agencies and industry guided the analysis to ensure a high degree of relevance for Nordic policy-makers. We are very pleased to see the synergies that have resulted from the tight integration of IEA and Nordic perspectives and analysis.

A key benefit of these joint efforts is that decision makers in the Nordic region now have a common point of reference to bridge current energy technologies and policies with the political targets of tomorrow. Of equal importance, decision makers outside the Nordic countries are provided with a leading example of the type of energy system transition required if we are to ensure a sustainable energy future globally.

Maria van der Hoeven
Executive Director

Halldór Ásgrímsson
Secretary General of the Nordic Council of Ministers

Executive Summary

The five Nordic countries of Denmark, Finland, Iceland, Norway and Sweden have announced ambitious goals towards decarbonising their energy systems by 2050. These aspirations are even more ambitious than the global 2°C Scenario (2DS) outlined in ***Energy Technology Perspectives 2012*** (***ETP 2012***), the strategy put forth by the ***International Energy Agency*** (***IEA***) to limit average global temperature increase to 2°C.

Using the modelling and analysis approaches of *ETP 2012*, *Nordic Energy Technology Perspectives* (*NETP*), a joint project of the International Energy Agency (IEA) and leading Nordic research institutions, probes the question: *Can they do it?*

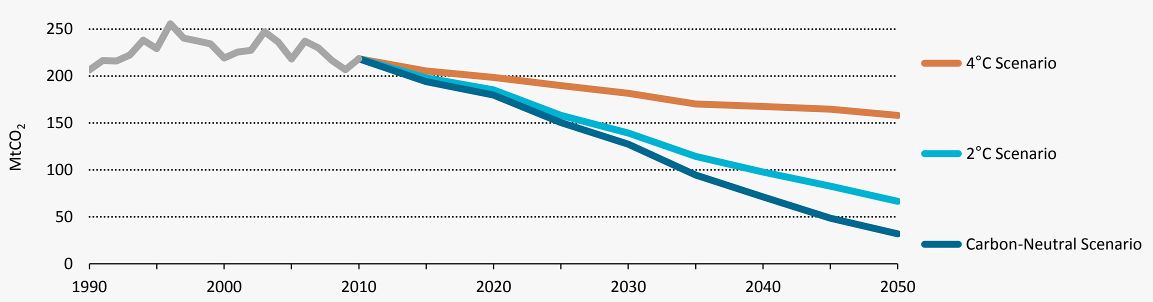
With rich renewable energy resources, the Nordic countries are in a strong position to make the transition from fossil fuels to low- or zero-carbon energy sources. Moreover, they are front runners in decisive policy action towards clear, long-term energy targets – including the establishment of interconnected grids and a common liberalised power market.

In examining their approaches to date and plans for the future, *NETP* aims to provide objective analysis that will increase the Nordic region's chances of success. A secondary – but ultimately more important – aim is to prompt other countries and regions to follow their lead.

In the global 2DS set out by *ETP 2012*, energy-related carbon dioxide (CO_2) emissions in the Nordic region must be reduced by almost 70% by 2050 compared to 1990. But the Nordic countries have set their ambitions on a Carbon-Neutral Scenario (CNS) in which such emissions are reduced by 85% and international carbon credits are used to offset the remaining 15%. Within this strategy, some Nordic countries achieve a carbon-neutral energy system by 2050.

Scenarios

Nordic energy-related CO_2 emissions



Note: $MtCO_2$ = million tonnes of carbon dioxide. Emissions include process CO_2 emissions from industry. The 4°C Scenario (4DS) represents a future in which strategic action limits global average temperature increase to 4°C. The 2°C Scenario reflects more aggressive approaches to limit the rise to 2°C. The Carbon-Neutral Scenario depicts even greater emissions reductions within the Nordic region, with the rest of the world pursuing the 2°C Scenario.

A near complete decarbonisation of the Nordic energy system is possible – but very challenging.

Decarbonisation is vital in the areas of electricity generation and energy use in industry, transport and buildings; it also requires deployment of carbon capture and storage (CCS) for cost-effective reduction of greenhouse-gas (GHG) emissions. Four factors will play critical roles in achieving the CNS; falling short in any one area will seriously undermine the overall aim.

Nordic electricity generation needs to be fully decarbonised by 2050. Wind generation, today some 3% of Nordic electricity generation, needs to grow particularly quickly and alone accounts for some 25% of electricity generation in 2050. This will increase the need for flexible generation capacity, grid interconnections, demand response and electricity storage. Total investments required in the power sector are equal to some 0.7% of cumulative GDP over the period.

To achieve the necessary 60% reduction in direct industry emissions (from 2010 levels), all sectors must contribute by taking up energy efficiency measures and CCS technologies. At present, Nordic industry is characterised by a high share of energy-intensive industries – all countries except Denmark use more energy per unit of GDP than the OECD average. Collectively, industry will need to cut the share of fossil fuel in its energy use in half, to below 20%. Even combined with very aggressive action to increase energy efficiency, this is not enough to reduce emissons to the extent necessary. Consequently, 50% of cement plants, and at least 30% of iron and steel and chemical industries, need to be equipped with CCS in 2050. To make this scenario possible, current uncertainty over national positions on CCS must be resolved.

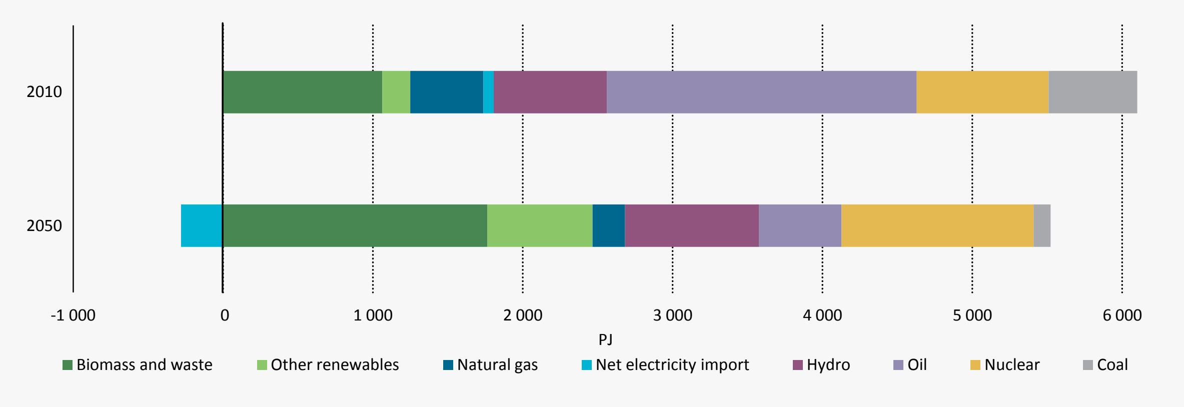
Transport requires the most dramatic emissions slash, from 80 million tonnes of carbon dioxide (MtCO_2) in 2010 to just 10 MtCO_2 in 2050. This will require limiting growth in transport demand, substantial reductions in technology costs, securing a sustainable biofuel supply and intelligent modal shifts. Improved fuel economy provides the majority of transport emissions reduction through 2030, with biofuels and electric vehicles becoming more important in the longer term. By 2050, average fuel consumption of new cars must decrease to about 3 litres per 100 kilometres (L/100km), down from 7 L/100km in 2010. Electric vehicles including plug-in hybrid, battery and fuel-cell 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 demand for biofuels.

Direct CO_2 emissions in the building sector are relatively low, but emissions associated with the energy used in buildings must be reduced from 50 MtCO_2 in 2010 to approximately 5 MtCO_2 in 2050. In addition to decarbonising electricity supply, several reduction options exist in the buildings sector itself. Widespread retrofits of older building stock will be needed to achieve the necessary energy efficiency improvements. In the short term, policies should focus on improving existing building shell performance and on requiring best available technologies (BATs) for space heating. In the longer term, more advanced building technologies, urban planning, and intelligent systems that empower consumers and encourage behaviour change become the higher priority.

A systems approach will make transforming the energy system easier and less costly. Nordic countries have already taken important steps in this direction.

Changes in energy demand and supply must be considered simultaneously across multiple sectors. Complete decarbonisation of electricity is the most central, system-wide change and has large spill-over effects for end-users. A high share of variable electricity generation requires extensive system integration. More broadly, synergies exist among systems for district heating, power generation, electric transport, municipal waste management and industrial energy use. These synergies must be tapped further.

Projections Nordic total primary energy supply in the Carbon-Neutral Scenario



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 countries a major net exporter of electricity. With the right infrastructure and pricing in place, the Nordic region could achieve annual exports of 50 terawatt hours (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 to facilitate this.

Supplying the region's growing demand for biomass will rely on a well-functioning international market. In the CNS, bioenergy use increases by two-thirds to become the largest energy carrier at some 1 700 petajoules (PJ) annually. This highlights a need for research in sustainable biofuels to increase domestic production.

Five central policy challenges facing the Nordic countries.

NETP identifies five central challenges that the Nordic countries face in achieving a carbon-neutral energy system. Other countries seeking to radically transform their energy systems should take note.

- ***Energy efficiency improvement offers the greatest potential for energy saving and emissions reduction in the short term.*** *Policies to ensure rapid and sustained energy efficiency improvements in end-use sectors will be necessary in all scenarios.*
- ***Infrastructure development will set the stage for success – or be a stumbling block for decades to come.*** *The significant need for new infrastructure in transport systems, electricity grids and power generation (particularly wind) will pose technological and financing challenges, and also require social acceptance.*
- ***Carbon capture and storage (CCS) accounts for more than 25% of industry emissions reduction and is also applied in electricity generation.*** *Progress in this technology has been slow and uncoordinated among 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 CNS projects a net import of bioenergy to the Nordic region, making sustainability criteria all the more important.*
- ***Continued Nordic co-operation is vital to reducing the cost of achieving these scenarios.*** *Regional co-operation in infrastructure development, in research, development and demonstration (RD&D), and in strategies for transport and CCS would offer critical benefits.*

The IEA will continue to track progress of the Nordic region towards its aim of achieving a carbon-neutral energy system, with the goal of providing objective analysis and promoting information sharing and lessons learnt with the rest of the world. The Nordic countries are well positioned to “export” both low-carbon energy and energy system know-how, along with other products and services vital to a green growth strategy.

Acknowledgements

Nordic Energy Technology Perspectives is a collaborative project between the International Energy Agency (IEA), leading Nordic research institutions and Nordic Energy Research – an intergovernmental organisation under the Nordic Council of Ministers.

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The individuals and organisations that contributed to this study are not responsible for any opinions or judgements contained in this study. Any errors and omissions are solely the responsibility of the IEA.

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Chapter 1

Choosing the Future Nordic Energy System

The Nordic countries have demonstrated themselves as leaders in the development and implementation of clean energy policy. They are well positioned to meet ambitious national climate targets and to play an important role in the European energy system, but still face a number of challenges.

Advantages

- ***The Nordic countries are all listed among the top 20 economies of the world.***[1] *The economy of the region has remained relatively strong despite recent economic difficulties in Europe.*
- ***All Nordic countries have strong ambitions for carbon dioxide (CO_2) emissions reduction.*** *Energy-related CO_2 emissions have remained relatively stable for several decades, while GDP has continued to grow.*
- ***In a global scenario that aims to limit average temperature rise to 2°C, energy-related CO_2 emissions in the region will need to fall by 70% by 2050, compared with 2010.*** *The Nordic countries have chosen to set their targets even higher, showing a strong political commitment to energy efficiency and climate change mitigation.*
- ***Several pathways can lead to a low-carbon Nordic energy system.*** *How other regions develop and implications for energy prices will influence which pathway would be most attractive for the Nordic region.*
- ***The Nordic region already has a high share of renewable energy production.*** *Current renewable energy production in the region is equal to almost 30% of that produced in the EU-27 countries.*
- ***The region has a common electricity market and is well positioned to provide flexible electricity*** *to Central and Eastern Europe. Ambitious non-hydro renewable energy plans in Central European countries may make the Nordic region – with its vast hydropower resources – an increasingly important provider of flexible electricity.*

Challenges

- ***Energy-intensive industry in the region is a major contributor to the economy, but also a large source of emissions.*** *With the exception of Denmark, all Nordic countries have large energy-intensive industry, which at least in part explains the high levels of energy consumption per capita.*
- ***The region is sparsely populated and has a cold climate.*** *This drives up transport volumes and creates high demand for heating services.*
- ***Oil and gas production remains significant.*** *Driven by Norway's production, Nordic oil and gas corresponds to more than one-third of total production in the EU-27.*

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[1] Measured as gross domestic product (GDP) per capita. Together, the Nordic region had a combined real GDP of USD 1 trillion in 2011 (equivalent to roughly 7% of the EU-27 GDP) and 25 million inhabitants. Annex B contains more detailed data.

Nordic ETP: regional choices in a global context

Individually and collectively, the five Nordic countries have among the most ambitious energy and climate policy agendas in the world, having set challenging targets and milestones along a road to creating a truly sustainable energy system. This project analyses these targets to assess the level of ambition required to achieve a carbon-neutral energy system by 2050.

Perhaps as a result of the strong link between its natural resources and economic progress, the Nordic region has developed an impressive track record in environmental preservation. Social awareness is high in terms of the importance of sustainable resource management.

At the same time, the Nordic economy relies heavily on energy, with more energy being used per unit of GDP than in most other OECD member countries. To some extent, this reflects the resource endowment that provides a favourable business environment for energy-intensive industries. As a consequence, the structure of the economy has, for a long time, been built upon access to relatively low-cost energy. Any transformation of the energy system needs to take this into account.

A combination of respect for natural resource endowments, aggressive policy targets, the implementation of innovative policy mechanisms, and strong economic development have resulted in the region becoming an international forerunner in the deployment of clean energy. Individually, the Nordic governments have stated clear visions towards decarbonising their energy systems. This report interprets these visions as a carbon-neutral Nordic energy system by 2050 and shows how it can be realised.

Nordic Energy Technology Perspectives (*NETP*) is, in many respects, an extension of the analysis conducted in *Energy Technology Perspectives 2012* (*ETP 2012*)[2], a biennial publication of the International Energy Agency (IEA) (IEA, 2012). At the core of the analysis is a study of various scenarios of possible future energy systems. As the Nordic region is a relatively small and very open economy, analysis of the regional energy system must be made in a global context, while recognising that even global change is based on domestic and regional action. Denmark, Sweden and Finland are members of the European Union, and Iceland has applied for membership. While Norway is not an EU member, it maintains a very high level of economic integration and political co-operation with the European Union and its member states. Consequently, the analysis in *NETP* is tightly integrated with the European and global perspective presented in *ETP 2012*.

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[2] See: www.iea.org/etp

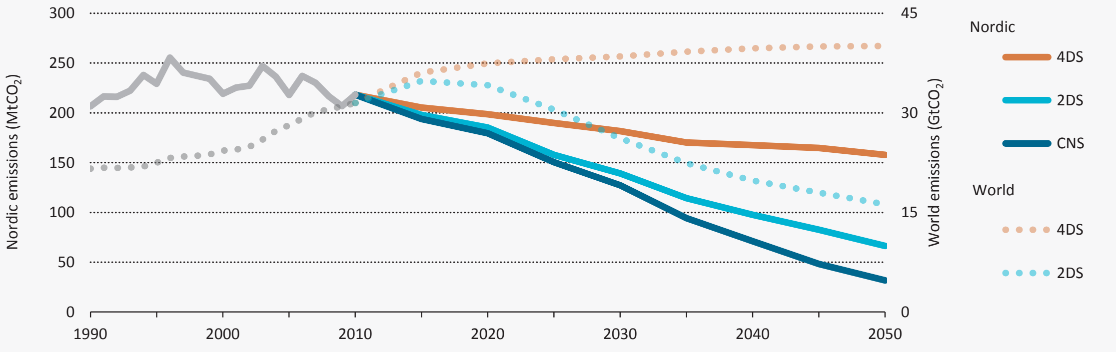
Box 1.1 *Nordic ETP scenarios*

While being future-oriented, this report is not a prediction. Rather, it is an exercise to use advanced modelling techniques as a means of comparing a variety of possible futures or scenarios, taking into account proven technologies and current and/or planned policies. With 2050 as the "target date" in mind, the modelling helps to identify the least-cost path toward achieving the stated goals.

The first two scenarios represent the Nordic contribution to the global scenarios set out in *ETP 2012*, which chart the technologies and policies needed to reach specific energy and emissions targets by 2050. With the aim of achieving an 80% chance of limiting the global temperature rise to 2°C, the 2°C Scenario (2DS) is ambitious but possible. It requires cutting global energy-related CO_2 emissions by more than half in 2050 (compared with 2009) and ensuring that they continue to fall thereafter. The 4°C Scenario (4DS) has more moderate aims but also acknowledges that a temperature rise of 4°C will bring serious consequences. It is important to note that strategic policy action is needed to achieve either of these goals. With no action, current trajectories suggest a minimum global temperature increase of 6°C.

A third scenario – the Carbon-Neutral Scenario (CNS) – reflects the stated aims of the Nordic countries to have in place, by 2050, an energy system that produces no net greenhouse-gas (GHG) emissions. In stretching beyond the *ETP 2012* aims, this scenario raises challenging questions that form the core of the ***Nordic ETP*** project: *Is reaching a carbon-neutral energy system in less than 40 years possible? What role can technology play in achieving it? And what are the policies required to realise the transformation?*

Figure 1.1 Reduction pathways for energy-related CO_2 by scenario



Note: : Figures and data that appear in this report can be downloaded from www.iea.org/etp/nordic

Key point *All scenarios lead to significant reductions in CO_2 emissions by 2050.*

The Nordic **4DS** reflects concerted efforts to move away from current trends and technologies, with the goal of reducing both energy demand and emissions. Serving as a reference scenario for the analysis, the 4DS is less ambitious than the other *NETP* scenarios, but still requires strategic policy action by governments to combat climate change and improve energy security. Total primary energy supply (TPES) increases by less than 5% compared to 2010 (Figure 1.2), and energy-related CO_2 emissions decrease by 29% compared to 1990 levels. More than 75% of electricity is based on renewables, the industry and buildings sectors become more efficient, and dependence on fossil fuels in the transport sector falls significantly.

The Nordic **2DS** acknowledges that transforming the energy sector is vital, but not the sole solution: the goal can be achieved only if GHG emissions in non-energy sectors are also reduced.

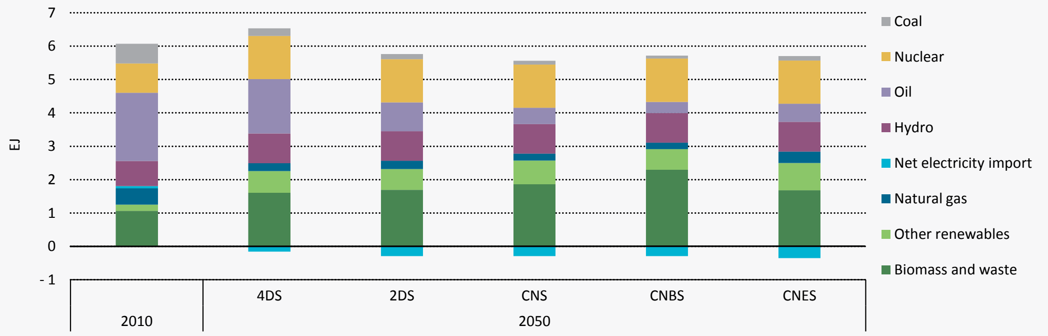
Nordic total primary energy supply falls by 10% compared to 2010, a noteworthy contrast against global projections in which TPES increases in all scenarios (including the 2DS). Also, the composition of the energy supply sources changes, resulting in a 68% decrease in CO_2 emissions compared with 1990 levels. Electricity decarbonisation is very similar to that in the 4DS.

The Nordic **CNS** reflects the national climate targets in the Nordic countries for 2050; of note is the diversity and ambition of approaches set out (see Chapter 2 for a discussion of national targets). Consequently, the CNS sees Nordic CO_2 emissions fall by 85% by 2050 compared to 1990 levels, with the remaining 15% offset by international carbon credits. The 85% reduction is consistent with the decarbonisation scenarios of the EU 2050 Energy Roadmap. TPES decreases by close to 15% compared to 2010. This requires, among other efforts, rapid transformation of the transport system away from fossil fuels, accelerated energy efficiency improvements coupled with increased deployment of carbon capture and storage (CCS) in industry, and increased refurbishments to boost efficiency in the buildings sector.

Within the CNS, two variant scenarios were also developed to examine alternative pathways:

- The Nordic **Carbon-Neutral high Bioenergy Scenario (CNBS)** pushes for higher use of bioenergy, with optimistic assumptions on the availability and import costs of biofuels. The use of oil in the transport sector is completely phased out by 2050, and the use of biomass and waste in the buildings sector is substantially higher than in CNS.
- The Nordic **Carbon-Neutral high Electricity Scenario (CNES)** reflects increased electrification and grid integration throughout the Nordic region, and between the Nordic and Central European grids. It assumes an increase in net electricity generation of 45% compared to 2010 levels, and electricity capacity at just over 50% higher than 2010 levels. To facilitate grid interconnections with Central Europe and Russia, as well as among Nordic countries, an additional 11 transmission projects are assumed to be built (double the number of transmission lines currently available).

Figure 1.2 Primary energy supply by scenario



Note: EJ = Exajoules.

Key point *Nordic primary energy supply decreases in all scenarios except the 4DS. Net electricity exports increase in all scenarios.*

The Nordic energy system at a glance

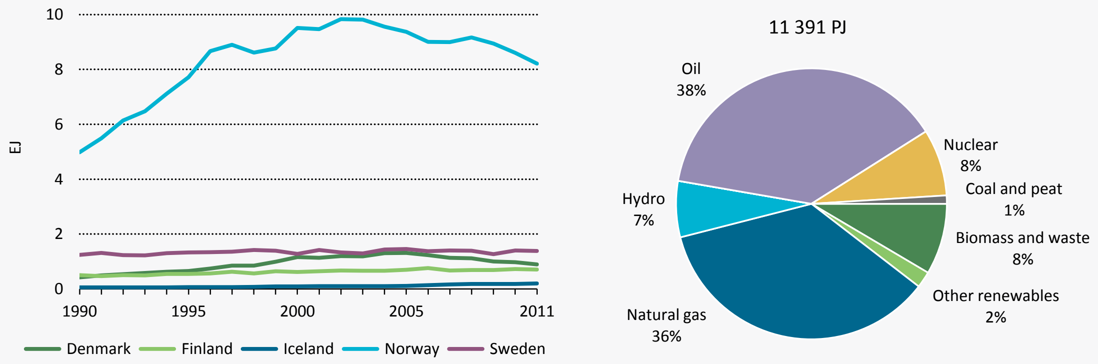
Primary energy supply

The Nordic region is well endowed with energy resources, including petroleum, hydropower, wind, biomass and geothermal. While each country has different dominant energy resources, the region as a whole is in a favourable position from an energy security perspective.

Norway's substantial oil and gas reserves dominate the region's primary energy supply, representing about 68% in 2010 (Figure 1.3). In 2010, Norway's total oil and gas exports were third-largest in the world, after Russia and Saudi Arabia. Its gas exports, at 99 billion cubic metres (bcm) per year, were the third-highest (after Russia and Qatar) and its net oil exports, at 1.6 million barrels per day (mb/d), the ninth-largest (IEA data).

Mainly owing to Norway's decrease in petroleum production since its peak in 2003, overall Nordic energy production has declined by about 16% since its overall peak in 2002. Despite this recent dip, primary energy production in the region has grown by 58% since 1990, and is the equivalent of one-third of total EU production.

Figure 1.3 **Primary energy production in Nordic countries; share of production by fuel, 2011**



Note: : For definitions and accounting principles, see Annex D.

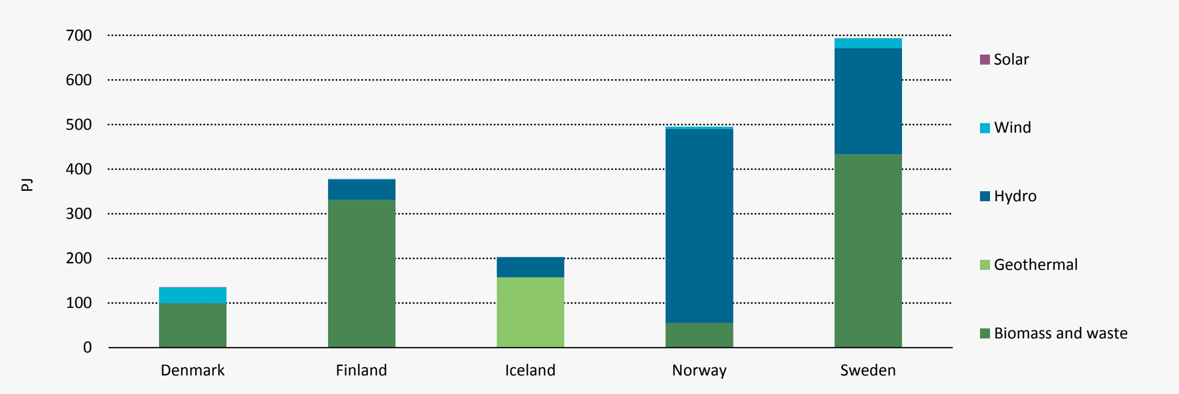
Key point *Primary energy production in the Nordic region corresponds to more than one-third of the EU-27 total, mainly owing to Norway's role as a major oil and gas producer.*

Renewable energy (including hydropower) is another particularly important primary energy resource for the region (Figure 1.3). At 1 905 petajoules (PJ) in 2011, Nordic renewable energy supply was equal to almost 30% of total supply in EU-27. Sweden is the leading producer of renewable energy among the Nordic countries, dominated by biomass and hydropower (693 PJ in 2011); Norway is the largest producer of hydro power (432 PJ in 2011).

Bioenergy is the main source of renewable energy supply in Sweden, Finland and Denmark, with sources ranging from biofuels, woodchips, pellets, firewood, straw and biogas. It is primarily used in heating, for the combined supply of heat and electricity, and as a fuel in the transport sector. Biomass in Sweden and Finland is mainly produced in the pulp and paper industry, and used for industrial heat production. It is also used for district heating and co-generation.[3] Biomass in Denmark differs from the rest of the Nordic countries, as straw is used in large heat plants.

Over the last decades, Denmark has undertaken a significant build-out of wind power; in 2011, 21% of Danish electricity production was from wind. Iceland is the only Nordic country having geothermal as its main energy source, with a supply of 157 PJ in 2011. Together, hydropower and geothermal account for 82% of total primary energy supply in Iceland. The solar resource is relatively limited in the Nordic region compared to other renewable sources.

Figure 1.4 Primary renewable energy production in the Nordic countries, 2011



Key point *The renewable production in the Nordic countries is dominated by biomass (heat) and hydropower (electricity).*

Energy intensity

The energy intensity of the Nordic economies (measured in terms of energy consumption per unit of GDP) has remained above the OECD average since the mid-1980s (Figure 1.5). This is largely owing to overall increases in industrial activity and to the high concentration of energy-intensive industries (*e.g.* metals and pulp and paper) and the substantial petroleum industry. Nevertheless, the Nordic countries have fared well in terms of stabilising CO_2 emissions over the last 40 years.

Nordic energy intensity per capita (measured in energy consumption per person) is for the most part above the OECD average, owing to the cold climate and industrial activity (Figure 1.6). Electricity consumption is particularly high, with some Nordic countries (led by Iceland and Norway) ranking among the top per capita consumers in the world. This is linked to high rates of electricity use for space heating and in industry.

Major opportunities remain to reduce energy intensity, particularly in the transport sector and through energy efficiency improvements.

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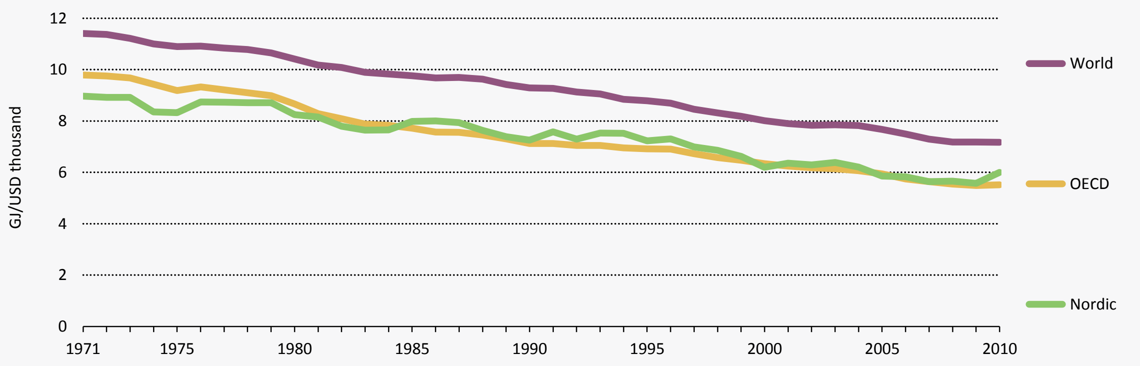
[3] Co-generation refers to the combined production of heat and power (CHP).

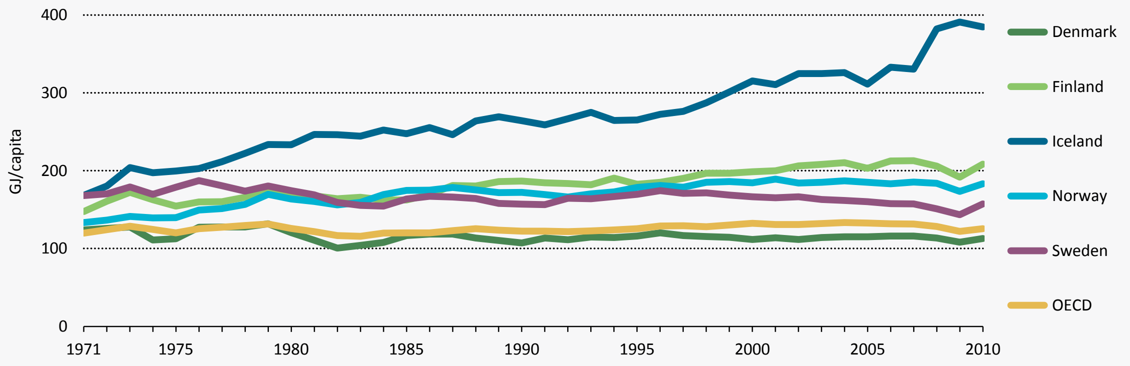
Figure 1.5 Energy intensity in the Nordic region, and globally



Notes: GJ = Gigajoules. Energy intensity is estimated as TPES/GDP.
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.

Key point *Energy intensity of the Nordic region has declined at rates similar to the OECD average since the mid-1980s.*

Figure 1.6 Final energy consumption per capita, Nordic countries and OECD average

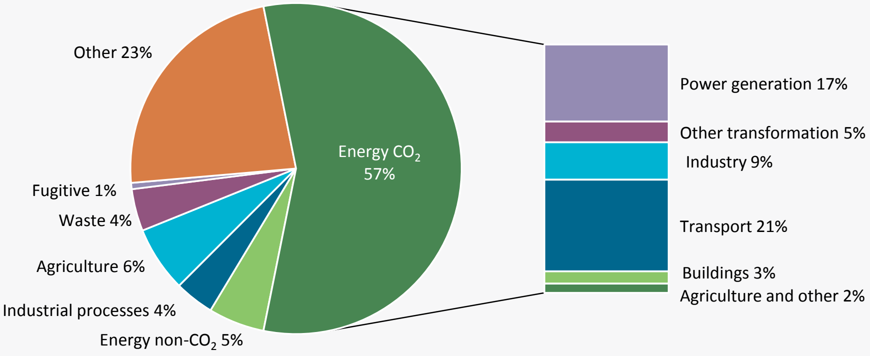


Key point *With the exception of Denmark, energy consumption per capita in the Nordic region is above OECD average but relatively stable. Iceland's trajectory reflects a dramatic rise in industrial activity.*

Energy-related CO_2 emissions

At present, the energy sector accounts for almost two-thirds of GHG emissions in the Nordic region (Figure 1.7). Individually and collectively, Nordic governments have set ambitious policies to support the decarbonisation of their energy systems (Chapter 2 gives details on these policies and targets). While each Nordic country has a slightly different approach to emissions management, their targets as a whole surpass those of most countries around the world. In most cases, they are more ambitious than requirements set out by the Kyoto Protocol and the EU Emissions Trading Scheme (EU ETS).

Figure 1.7 Nordic GHG emissions in 2010



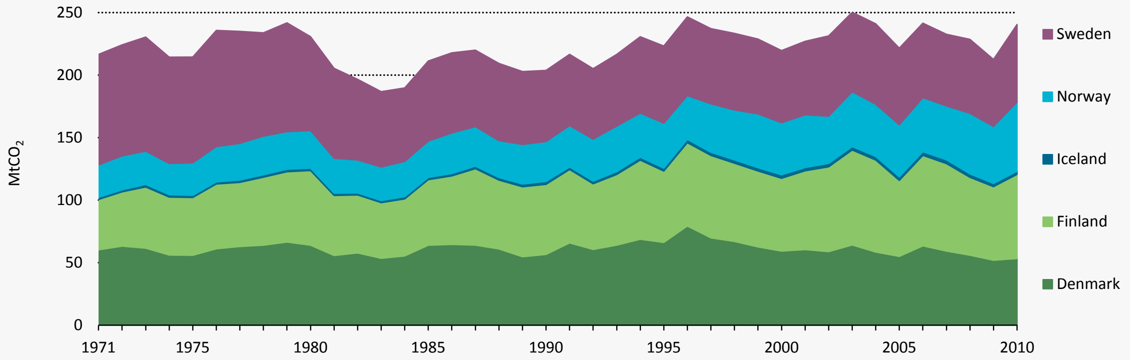
Notes: GHG emissions are calculated based on IEA sectoral approach for CO_2 emissions from fuel combustion; the EDGAR 4 database is used for other emissions. In general, estimates for emissions other than CO_2 (CH_4, N_2O, HFCs, PFCs, SF_6) from fuel combustion are subject to significantly larger uncertainties.

Key point *In 2010, the energy sector accounted for 62% of GHG emissions in the Nordic region.*

Total energy-related CO_2 emissions from the Nordic countries have varied between 200 million tonnes (Mt) and 250 Mt over the last decades. Both Sweden and Denmark show about a 5 Mt reduction in CO_2 emissions since 1990. In Sweden, emissions reduction is linked to the replacement of fossil fuels with renewable energy in district heating, and the introduction of biofuels in the transport sector. Denmark's decline can be attributed to a shift in energy consumption by source, with an increase in renewable energy and natural gas against a decrease in the use of oil and coal.

Norway's emissions have increased by about 9 Mt since 1990 (Figure 1.9). Road transport and offshore gas turbines (for electricity generation and pumping of natural gas in pipelines) were the biggest emitters and also show the largest increase since this time.

Figure 1.8 Development of energy-related CO_2 emissions in the Nordic region



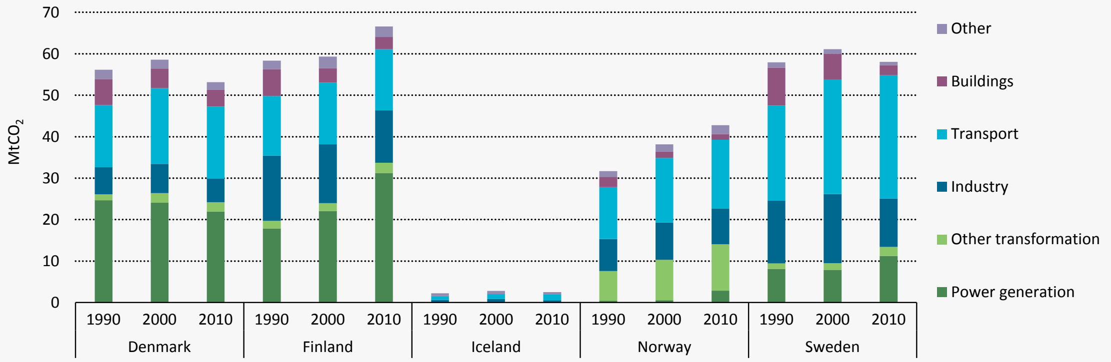
Notes: Energy-related CO_2 emissions, including direct emissions from fuel combustion, industrial process emissions (starting from 1990), and international marine and aviation bunkers. International marine bunkers emissions for Iceland are not available from 1971 to 1982.

Key point *Energy-related CO_2 emissions in the Nordic region have fluctuated around 200 Mt since the 1970s.*

Transport is the sector showing the largest increase in emissions in the Nordic region in the past 20 years. As the increase in transport demand is expected to continue, more efficient transport technologies and new transport fuels will be necessary to curtail increasing emissions.

In Iceland, the share of emissions from industrial processes has increased substantially, due to a new aluminium production plant and increased capacity in others. In relative terms, this increase remains small: Iceland still accounts for only about 1% of total CO_2 emissions in the Nordic region.

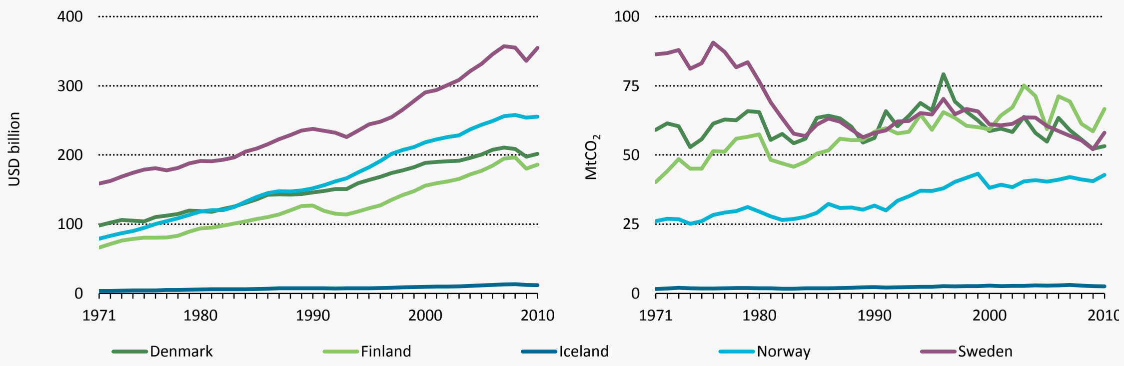
Figure 1.9 Nordic CO_2 emissions by sector and country



Key point *The share of emissions from transport and power generation increased from 1990 to 2010.*

The Nordic region benefits from large renewable energy resources, including hydropower and geothermal energy. Together with nuclear power, this puts the Nordic countries in a favourableposition with a largely decarbonised electricity system. Beyond electricity, GHG emissions have been reduced in other sectors (including district heating), owing to strong policies to shift away from the use of fossil fuels. Since 1990, energy-related CO_2 emissions in the region have remained stable, even while GDP increased by almost 50% (Figure 1.10).

Figure 1.10 Nordic GDP (left) and energy-related CO_2 emissions (right)



Notes: Energy-related CO_2 emissions, including direct emissions from fuel combustion, industrial process emissions (starting in 1990), and international marine and aviation bunkers. Emissions for international marine bunkers for Iceland are not available from 1971 to 1982.

Key point *The Nordic region shows a decoupling of economic growth and energy-related CO_2 emissions.*

Electricity generation and prices

Electricity generation is an important component of the Nordic energy system: in fact, it has shaped the region's economy through trade, and by attracting electricity-intensive industry. Electricity production in the Nordic countries exceeded 400 terawatt hours (TWh) in 2010, equal to approximately 12% of the electricity production in the EU-27 (Figure 1.11). Hydropower represented about half of the Nordic electricity generation that year, with more than 50% coming from Norway (118 TWh), followed by Sweden (66 TWh).

The share of non-hydropower renewables in the electricity mix has started to rise. In Denmark, thermal power plants, mainly fired with fossil sources, continue to dominate electricity production; however, there is a steady replacement of coal-fired power plants with biomass, gas and wind. The share of electricity generation from wind, for example, rose from 12% in 2000 to 21% in 2011, bringing total net wind generation close to 10 TWh.

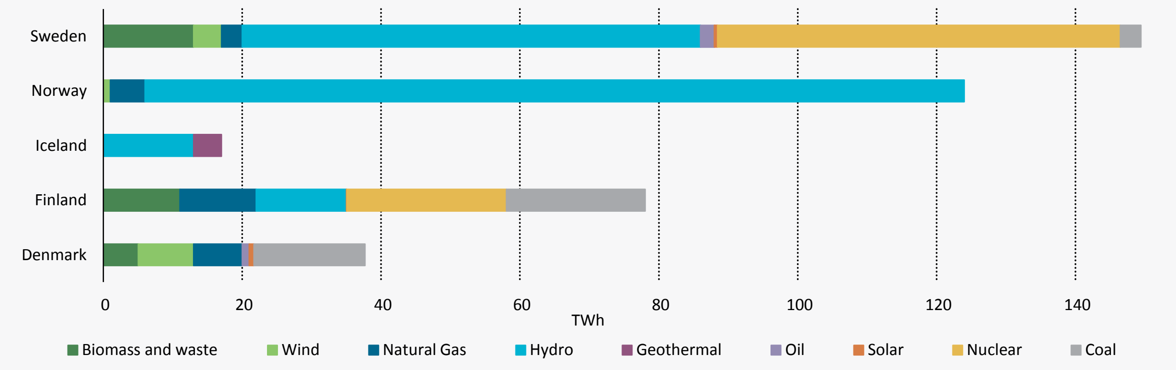
Electricity generation in Finland is dominated by coal-fired power plants and nuclear, each providing some 20 TWh out of the total of almost 80 TWh. Natural gas, biomass and waste, and hydro each account for annual generation of 10 TWh to 15 TWh.

Close to 100% of Iceland's electricity in 2010 was produced from renewable energy, with hydropower accounting for 74% and geothermal for 26%.

Accounting for almost 95% of supply, hydropower continued to dominate Norway's electricity generation in 2010. Norway has one natural gas combined cycle (NGCC) plant that can produce natural gas power under the right market conditions (dependent on price of natural gas, CO_2 and the price of electric power in Europe). Norway also has a small share of wind power generation.

Sweden has the largest electricity generation in the Nordic countries (143 TWh in 2011), withproduction from nuclear, hydropower and biomass-fired power plants. Over the last decade, wind power has become an increasingly important source; generation reached 6 TWh in 2011, representing a sixfold increase since 2006, and 75% increase over 2010.

Figure 1.11 Electricity generation in the Nordic countries, 2010

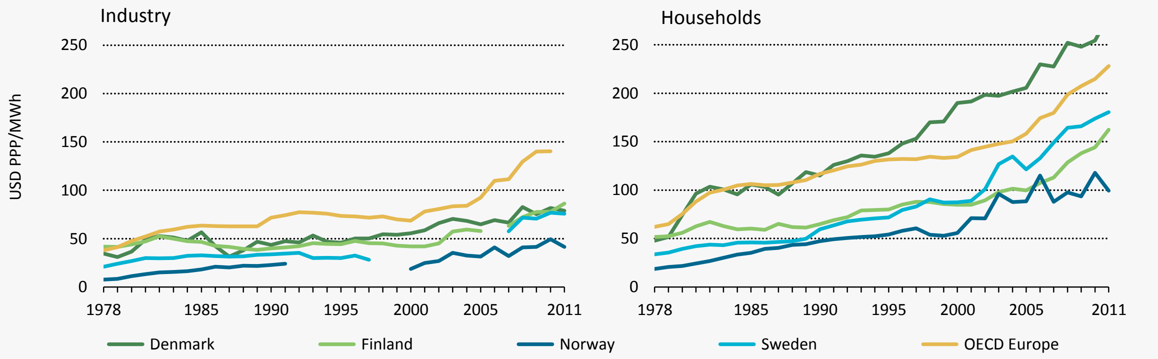


Key point *At present, 83% of the electricity production in the Nordic countries is carbon neutral, of which 63% is renewable.*

Electricity prices vary significantly among the Nordic countries; with the exception of Denmark, they are well below OECD average for both industry and household consumers (Figure 1.12). As the oldest international electricity market in Europe, and the largest in the world, the Nordic wholesale power market (Nord Pool Spot) is dominated by a few large companies but is generally considered both liquid and efficient. This, in combination with the region's vast electricity generation resources, has resulted in relatively low electricity prices.

Industry electricity prices in OECD Europe have increased in recent years, from an average of about USD 38 per megawatt hour (MWh) in 1978 to USD 140/MWh in 2010. By contrast, Nordic industry electricity prices currently range from USD 50/MWh to USD 82/MWh. These low industrial prices have played a major role in attracting electricity-intensive industry to the region – particularly to Norway and Iceland.

Figure 1.12 Comparison of average electricity prices in Nordic countries



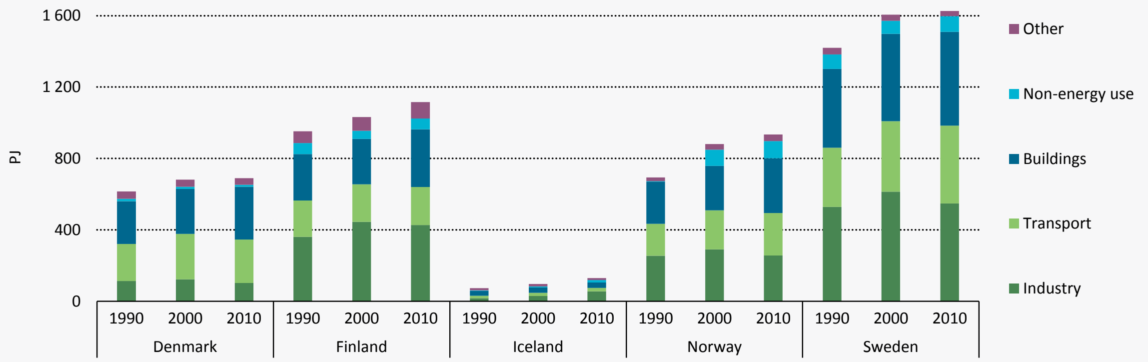
Notes: Electricity prices include ex-tax price, excise tax and value-added tax (VAT). VAT is not included in industry prices as it is refunded to the customer. Industries often have long-term contracts with suppliers that are not public, so official price statistics should be interpreted with care. See Annex C and D for more information on electricity prices.

Key point *Electricity prices in Finland, Norway and Sweden are lower than the OECD average.*

Final energy consumption

Energy consumption in the Nordic region has increased by 17% since 1990, and was just over 4 200 PJ in 2010, equal to about 8% of energy consumption in EU-27. The industry, transport and buildings (including residential and commercial) sectors each accounted for close to one-third of total energy consumption in the region (Figure 1.13). The largest increases in final energy consumption were seen in the transport and commercial buildings sectors, each with a 30% increase in energy consumption over the past 20 years.

Figure 1.13 Final energy consumption by sector in the Nordic countries



Key point *The transport, industry and buildings sectors each represent close to one-third of final energy consumption in the Nordic region.*

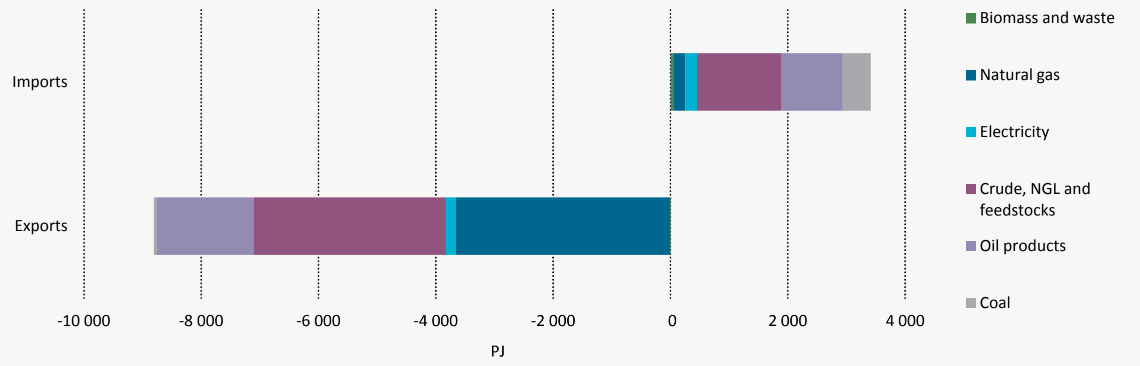
Industry accounts for some 40% of electricity use in the Nordic countries on average. Access to electricity, coupled with a rich endowment of raw materials such as wood and minerals, has played an important role in the development of energy-intensive industry. The forest-based industry is especially important in Finland and Sweden (in Sweden it represents about 10% of industry value added). Metal manufacturing is of particular importance in Iceland – where the aluminium industry alone contributed more than 6% of GDP in 2010 – and Norway. Due to the high volume of electricity consumption by the aluminium industry, Iceland and Norway have the world's highest electricity consumption per capita. In Iceland, which has a population of only 360 000, demand from industry represented more than 84% of the total electricity demand in 2010.

The cold climate, combined with a history of low-cost and easy access to electricity, has resulted in high rates of electricity consumption for heating, particularly in Norway, Sweden and Finland. During the 1980s, many oil boilers in Sweden and Norway were replaced with electric boilers, resulting in an increase in electricity consumption for heating. In Sweden, decarbonisation of the district heating system has greatly contributed to emissions reduction (see Chapter 3).

Energy trade

The Nordic region is a net exporter of energy. In 2011, primary energy production was close to double the Nordic final energy demand. Norway's role as an oil and gas producer must not be overlooked: in 2011, its exports accounted for 82% of total Nordic exports.[4] Yet oil and gas also accounted for the largest share of imports to Nordic countries (led by Sweden, Finland and Denmark), primarily to meet demand in the transport sector (Figure 1.14).

Figure 1.14 Nordic primary energy production: imports and exports, 2011



Note: NGL = Natural gas liquids

Key point *The Nordic region is a net exporter of primary energy, led by Norway's oil and gas exports.*

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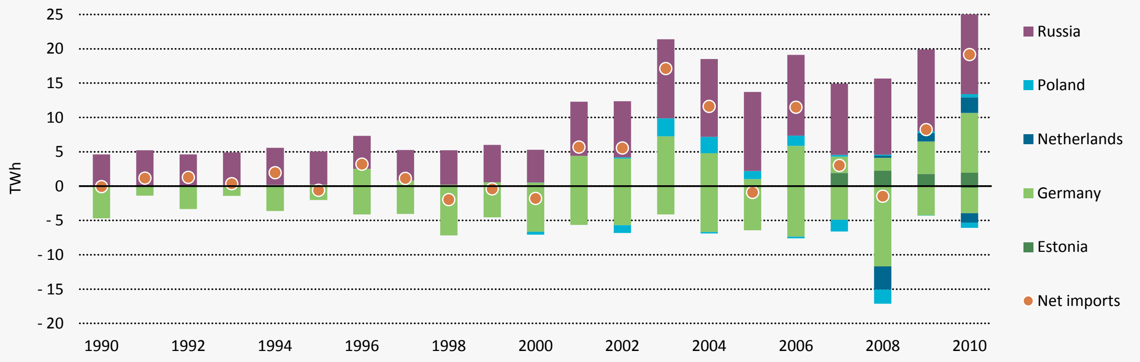
[4] Based on estimated energy supply balance in 2011 (IEA, 2012).

In addition to electricity trade among its participating countries, Nord Pool Spot trades with Central and Eastern Europe, and with Germany, Russia and the Netherlands (Figures 1.15, 1.16). The volume of trade has grown steadily since 2000.

Figure 1.15 Electricity trade outside the Nordic region



Note: Positive numbers represent imports, negative represent exports.

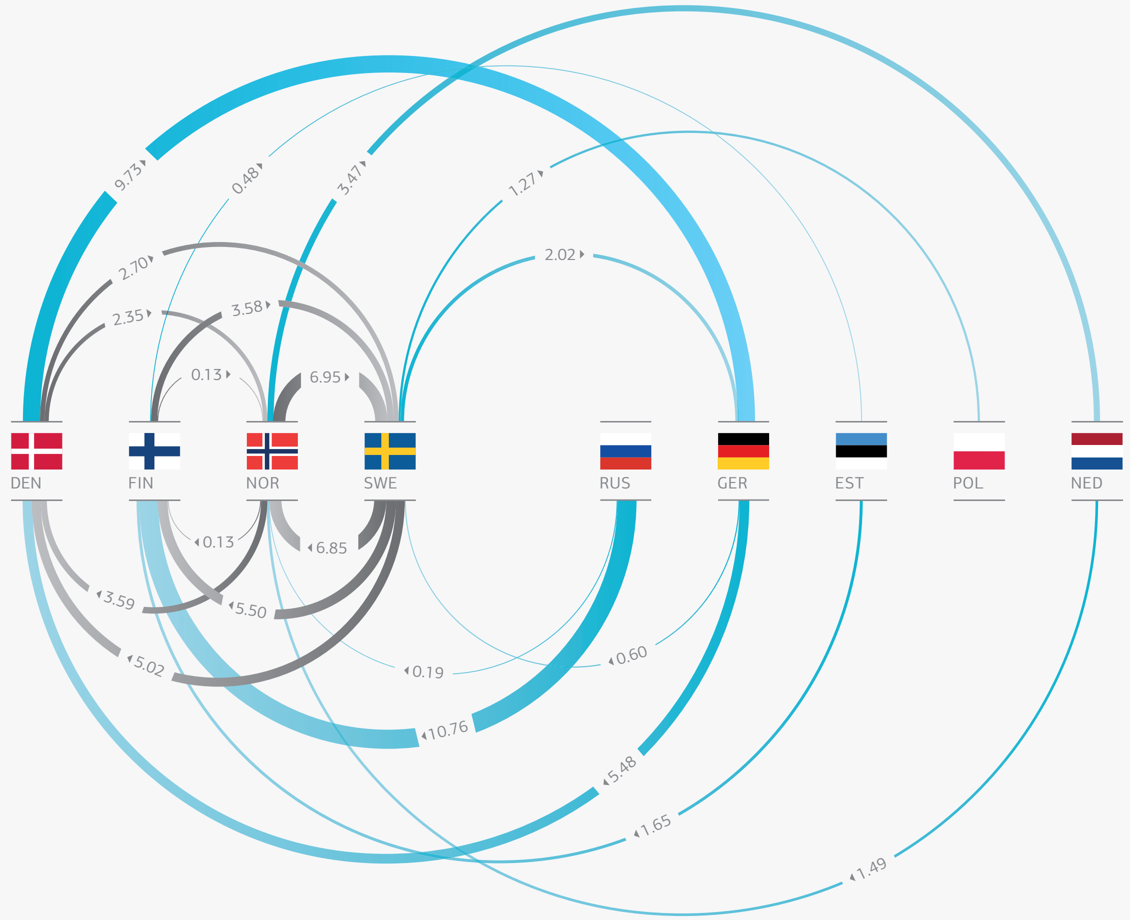
Key point *Germany and Russia are the two most important trading partners for Nordic electricity.*

Within Nord Pool Spot, Norway, Finland, Denmark and Sweden are the largest electricity trading partners. In 2010, a particularly dry year for hydropower, three Nord Pool Spot countries were net importers of electricity: Denmark from Germany; Finland from Estonia and Russia; and Norway from Russia. Sweden was a net exporter to Poland but required imports from Germany (Figure 1.15). Increasingly, a number of European countries are using the flexible generation from the Nordic region to complement the deployment of variable renewable electricity capacity.

The region holds strong potential to become a provider of flexible and low-carbon electricity as Central Europe seeks to further decarbonise its electricity system, but this potential needs to be managed carefully. As grids and interconnections expand, the Nordic region must ensure that domestic electricity demand is met while also putting in place sufficient supply and infrastructure to meet the planned exports to other markets.

Electricity trade among the Nordic countries varies. Finland has been, for all years, a net importer, purchasing electricity from Russia. Norway, Sweden and Denmark fluctuate, being net importers in one year and net exporters in the next. The export/import question depends highly on the climate (*e.g.* average temperature) and hydro inflow in Norway and Sweden. Since 2000, the average export from Denmark was 1.75 TWh and from Norway 3.85 TWh. Over the same period, Finland imported 10.89 TWh and Sweden imported 1.66 TWh.

Figure 1.16 Electricity trade in the Nordic region, 2011



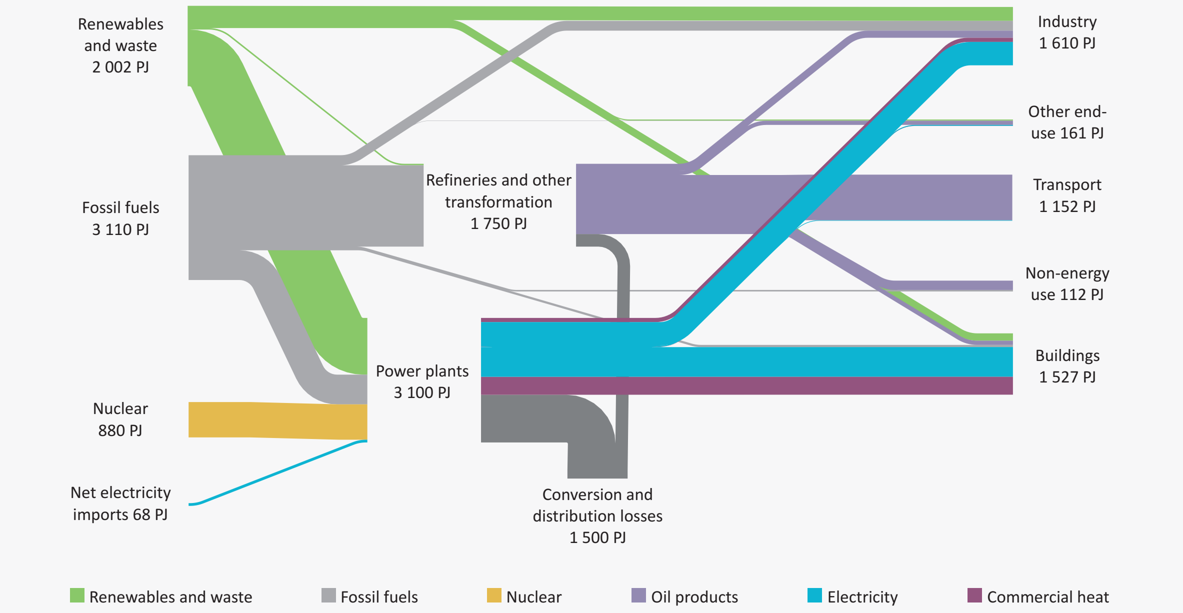
Notes: Flows are expressed in TWh. Flows below 0.1 TWh are not shown.
Source: Nord Pool Spot.

Key point *The Nordic electricity system has become more integrated with adjacent neighbouring markets*

Looking ahead: changes in Nordic energy flows

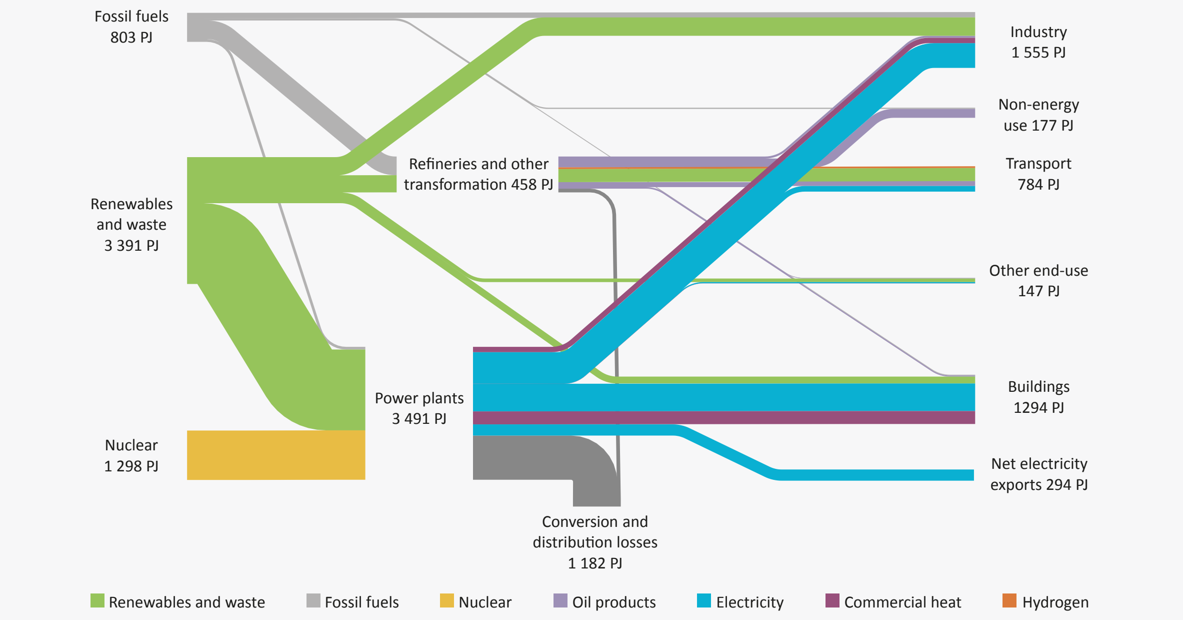
It is clear that the Nordic energy system will need to undergo profound changes over the coming 40 years in order to realise the vision of the Carbon-Neutral Scenario. The following chapters will explore in detail how the different sectors need to develop. At a high level, however, it may be useful to look at the overall energy flows in the Nordic system, and compare the situation in 2010 with the one envisioned in the CNS in 2050 (Figures 1.17, 1.18). Energy supply is shown to the left, energy use to the right. Arguably, the two most striking differences between the two figures are the virtual elimination of oil use in transport, and the disappearing fossil component in power generation.

Figure 1.17 Nordic energy flows in 2010



Key point *In 2010, fossil fuel plays an important role in all sectors, and is the dominant energy carrier in transport.*

Figure 1.18 Nordic energy flows in 2050



Key point *In 2050, fossil fuel use has decreased by 90% compared with 2010. Most of what remains is used in industry.*

Nordic Policies and Targets

By setting ambitious, long-term goals for reducing greenhouse-gas (GHG) emissions and increasing the share of renewable energy, the Nordic countries have demonstrated international leadership within the energy sector. Valuable lessons can be drawn from their approach in the areas of regional co-operation, market-based mechanisms, and emphasis on research, development and demonstration (RD&D).

Key findings

- ***The Nordic governments have set ambitious, long-term domestic climate and energy policy targets.*** *In many cases, these targets and visions (e.g. renewable energy targets) exceed the EU average. Policies at national and regional levels will be needed for these strategies to be implemented successfully.*
- ***Relatively stringent policies and regulations underpin long-term strategies for technology development and deployment. Nordic*** *countries have often been frontrunners in applying strict policies and regulations (e.g. regarding implementation of a carbon dioxide [*CO_2*] tax*[1]*). This secure policy framework has helped to accelerate clean energy investment that supports these ambitious plans while sustaining economic development.*
- ***Each Nordic country has its own unique approach to energy policy design and implementation,*** *but several common features and examples of close co-operation exist. Common elements include a market-driven approach, a strong focus on RD&D, and carbon and energy taxation. Close co-operation is most evident in the common electricity market operating among Sweden, Norway, Denmark and Finland.*
- ***A strong focus on energy technology research, development and demonstration*** *(RD&D) exists through domestic programmes and international collaboration. The Nordic countries have been co-operating formally on RD&D more than 25 years.*
- ***Carbon and energy taxation have been one of the most important policies behind the decreased use of fossil fuels,*** *especially in the Nordic energy sector. Taxes on energy and* CO_2 *emissions are applied in all Nordic countries.*
- ***A market-driven approach is common across the Nordic electricity market,*** *and is effectively complemented by targeted energy technology policy. The competitive Nordic electricity market, Nord Pool Spot, was the world's first international market for trading power and is currently the largest market of its kind. It may serve as an example for other countries and regions globally.*

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[1] Hereafter referred to as the carbon tax.

Long-term targets in the Nordic countries

The EU Energy Roadmap 2050, a strategic plan adopted by the European Commission in 2011, presents an overall target for 2050 to reduce total domestic GHG emissions by at least 80% compared to 1990, with intermediate targets of a 25% reduction by 2020 and 40% by 2030. Within this all-encompassing target (which includes transport), energy-related emissions are to be reduced by 85%. All Nordic countries have presented long-term strategies for CO_2 emissions reduction to be achieved by 2050 (Table 2.1). Policies at the national and regional level will be needed to implement successfully these strategies.

Sweden's long-term vision is to release no net GHG emissions into the atmosphere. It is not yet finally decided if this vision will include sinks and international trade of carbon credits. In a commission to the government, the Swedish Environmental Protection Agency (EPA) has analysed roadmaps both with and without sinks and trade. Norway's target, which includes international trade of credits, is to be carbon neutral in 2050. If an ambitious international climate agreement is achieved in which other developed countries also take on extensive obligations, Norway will undertake to achieve carbon neutrality by 2030[2]. Denmark's 2050 target is to have the entire energy supply covered by renewable energy. Calculations from the Danish Commission on Climate Change Policy show that when domestic energy and transport systems no longer use fossil fuels, GHG emissions will be reduced by approximately 85%. Finland aims to cut domestic GHG emissions by 80% by 2050 from the 1990 level. Iceland's long-term vision includes reductions of net GHG emissions by 50% to 75% by 2050, with 1990 as reference year. All Nordic countries have targets for emissions reduction to be achieved by 2020.

Each country has set related, but more specific, targets. The current Swedish government has an ambition to make the vehicle fleet independent of fossil fuel by 2030. Finland has applied the 20% by 2020 target to renewable energy supply for road transport.[3] Finland's Ministry of Trade and Industry recently launched a CleanTech programme, which sets very ambitious targets for decreasing the use of oil, coal and natural gas by 2025 (*e.g.* phasing out of condensing coal-fired power). Denmark's long-term goal is supported by several milestones: 50% of electricity supply from wind power in 2020; phasing out coal consumption at power plants by 2030; phasing out oil burners by 2030; and covering all electricity and heat supply with renewables by 2035.

The European Union has set a number of climate and energy targets to be met by 2020, known as the 20/20/20 targets. These targets include: reduction of EU GHG emissions of at least 20% below 1990 levels; at least 20% of EU energy consumption from renewable resources; and a 20% reduction in primary energy use compared to projected levels, to be achieved by improving energy efficiency. On this basis, a national burden-sharing agreement regarding renewable energy has been decided for each member state. Sweden has a target of 49% renewable energy shares of total energy use (which it raised to 50%), while Finland's target is 38% and Denmark's is 30%. In Norway, the target is to have a renewable energy share of 67.5% by 2020. Similarly, the EU target of 20% increase in (primary) energy efficiency is translated into national targets for all EU member states. Compared to projections, the targets to decrease energy consumption are 4.0 gigajoules (GJ) for Sweden, 11.8 GJ for Denmark and 1.3 GJ for Finland. Iceland, which is currently applying to join the European Union, has a target of 64% renewable energy share of total energy use by 2020.

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[2] In fact, the European Union, Norway and Iceland have all explicitly stated that their ambition levels depend on the commitment showed by other countries and regions.

[3] Calculated according to the RES-directive's (RES = Renewable Energy Sources) method for transport (*i.e.* double-counting of second-generation biofuel, which means that there will actually be less than 20% renewable).

Table 2.1 Climate- and energy-related targets for Nordic countries and the European Union, 2012-50

	GHG emission reduction targets (CO_2 equivalents) (reference: 1990)				Renewable energy targets, gross final energy consumption		Climate- and energy-related constraints or targets, examples
	2012 (Kyoto)	2020	2030	2050[2]	Reference 2005	2020 (EU)	
Denmark	-21%	-20% (non-ETS) -40% (ETS and non-ETS)		100% renewable energy supply[3]	17.0%	30% (35% national decision)	• 100% renewable energy system (all sectors) in 2050 • All use of coal phased out by 2030 • 100% renewable electricity and heating in 2035 • Phase out of oil for heating in buildings by 2030 • Wind power covers 50% of power production in 2020
Finland	0.0%	-16% (non ETS)		-80% (domestic)	28.5%	38% (20% renewables in road transport)	• Regulations on the use of water resources (*e.g.* hydro power) by the Water Act • Decisions on licences for new nuclear to be adopted by the Parliament
Iceland	+10%[1]	-15% (-30% if climate agreement)		-50-70% (net)	55.0%	64%	
Norway	+1%	-30% (net, - 40% if climate agreement)	-100 % (net, if climate agreement)	-100% (net)	58.2%	67.5%	• Protection Plan for Water-courses, protection of water resources from hydro power • 2/3 of emission reductions in 2030 will be domestic (rest through flexible mechanisms)
Sweden	+4%	-40% (non ETS)	Fossil fuel independent transport fleet	-100% (net)	39.8%	49% (50% national decision)	• Law to protect some rivers from hydro power • Limitation on new nuclear: *e.g.* maximum 10 reactors, no effect limit
European Union	-8%	-20% (-30% if climate agreement)			8.5%	20% (10% renewables in transport)	
EU roadmap		-25%	-40%	-80%			

Notes: ETS= Emissions trading sheme. 1) Iceland is also subject to provision 14CP7, allowing an increase in emissions of 1 600 tonnes CO_2 per year (tCO_2/yr) from energy-intensive industry. Combined with the 10% allowed increase in emissions over 1990 levels, 14CP7 translates to allow 57% increase in GHG emissions over 1990 emission levels. 2) Emission reduction targets for Norway (all), Sweden (2050) and Iceland (2050) may include offsets. Finland's 2050 target includes domestic reductions only. 3) Denmark does not have a 2050 target for GHG emissions only, but a target of 100% renewable energy in 2050. The Climate Change Policy Commissions calculations showed that this target would lead to a reduction of approximately 85% of GHG.

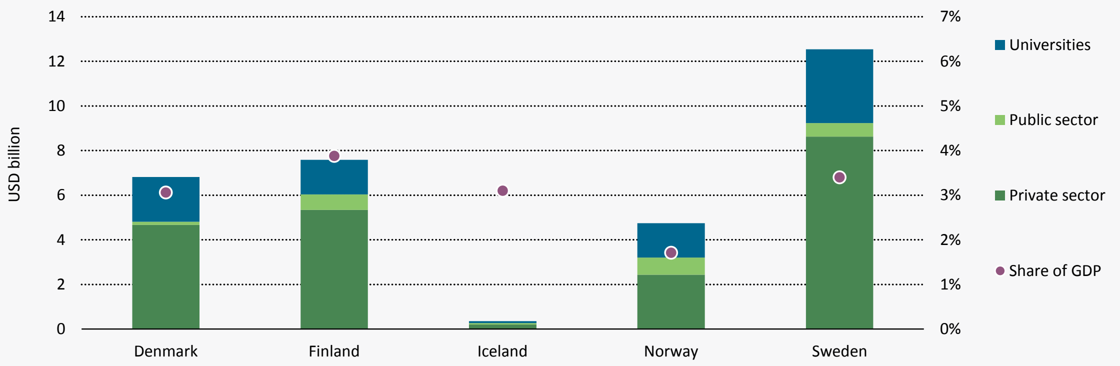
Sources: General/EU: European Commission, 2009. Denmark, Finland, Sweden: EEA, 2012. Norway, Iceland: European Commission, 2011. Denmark: Ministry of Climate, Energy and Building, 2012. Finland: Finnish Government, 2008. Iceland: Ministry for the Environment and Natural Resources, 2007. Norway: Norwegian Government, 2008; Norges Offentlige Utredninger, 2012; Norwegian Parliament, 2012. Sweden: Swedish Government, 2009; Swedish Environmental Code, 1998.

Key point *All Nordic countries have long-term climate- and energy-related targets and visions that are ambitious and often surpass EU strategies. Climate- and energy-related constraints differ among the Nordic countries.*

RD&D in focus in the Nordic countries

The Nordic region has traditionally placed a strong emphasis on research and development (R&D) in a broad range of areas. Among IEA member countries, the Nordic members are leaders in terms of R&D funding support per unit of GDP. Total funding of research has been increasing since 1990, and the Nordic countries have increased funding for R&D as a percentage of GDP to reach levels of 1.7% to 3.9% of GDP in 2010 (Figure 2.1). Norway is the exception, where funding has remained relatively stable (1.7%). In the Nordic countries, a large share (66%) of the research is ultimately carried out in the private sector (Figure 2.2). Nordic RD&D funding for clean energy technology has increased in recent years, owing to the development of RD&D strategies and programmes that focus on achieving carbon-neutral objectives. Between 2007 and 2010, for example, energy-related RD&D funding rose dramatically in Sweden (70%) and Denmark (65%). In 2010, about 36% of the energy-related public RD&D funding was used for research in energy efficiency, with the largest shares in Sweden (33%) and Finland (60%). Renewable energy followed closely, receiving about 31% of the total RD&D funding (Figure 2.4). Almost two-thirds of Norwegian energy research funding in 2007 was directed towards fossil energy and carbon capture and storage (CCS). In 2010, funding for fossil energy had reduced while support for CCS had seen strong growth. The climate agreement in Norway from 2007 (Norwegian Government, 2008) led to a substantial increase in energy-related RD&D (total energy-related RD&D budget was USD 145 million in 2010 compared to USD 102 million in 2007). Wind energy has been an important research area in Denmark; however, in 2006 funding for wind research was 17% while funding for hydrogen and fuel cells was more than 30%.

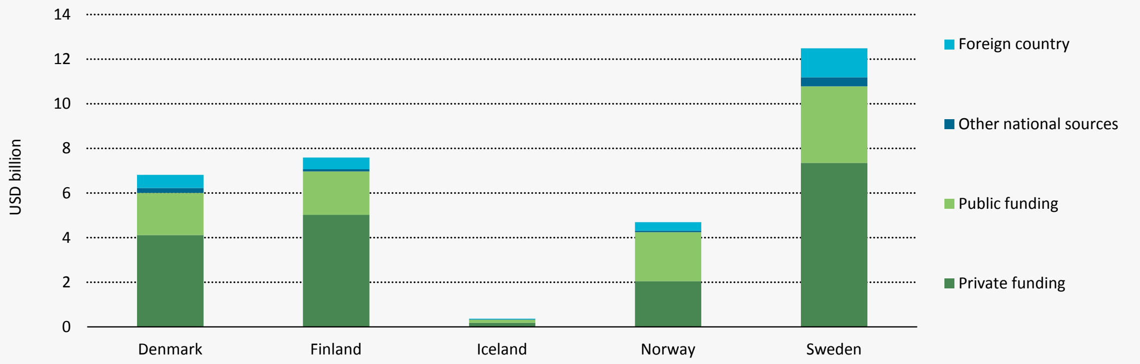
Figure 2.1 Sectors where R&D has been carried out and R&D as share of GDP



Note: 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. R&D investments in sectors in which research has been carried out: public sector, private sector and universities. Figures and data that appear in this report can be downloaded from www.iea.org/etp/nordic
Source: NIFU-STEP, 2012.

Key point *The Nordic countries have high funding support per unit of GDP and a large share of R&D is carried out in the private sector.*

Figure 2.2 R&D sources of finance



Source: NIFU-STEP, 2012.
Note: Denmark and Finland data from 2010.

Key point *A large share of research and development is made possible through private funding.*

Box 2.1 Innovation theory and policy design

Innovation theory describes technological development as a process in which innovation evolves through several phases: research, technology development, demonstration, deployment and diffusion. The process from innovation to diffusion may roll out over a long time period, and may be held back by several market failures (*e.g.* information failures and principal-agent problems) and behavioural barriers (*e.g.* credibility of information sources, inertia, culture and values). Public acceptance can be another barrier, as is currently the case for development of carbon capture and storage (CCS), for example. Hence, efforts and policies to accelerate the innovation process are crucial. Moreover, not all technologies will be successful, implying the need for – and wisdom of – supporting a broad range of portfolios.

Technological innovation is usually described through two models: the **market-pull model** and the **technology push model**[4]. The market-pull model creates disincentives for emissions (*e.g.* carbon pricing or market share requirement for renewable sources) while the technology-push model uses incentives (*e.g.* RD&D investments) to push new technologies into the market.

The Nordic region provides an interesting example of countries with strong policies for both push and pull. All Nordic countries have a market-based approach that uses the disincentives of energy and carbon taxes to phase out the use of fossil fuel in the energy sector, counterbalanced by R&D programmes to stimulate actions to develop alternative sources of energy.

Many experts argue that carbon pricing provides the most efficient incentives for technology development and emissions reduction because it quickly stimulates least-cost abatement while engaging actors across all parts of the value chain to innovate. By contrast, "command-and-control" approaches concentrate on one specific technology and risk freezing the development of others.

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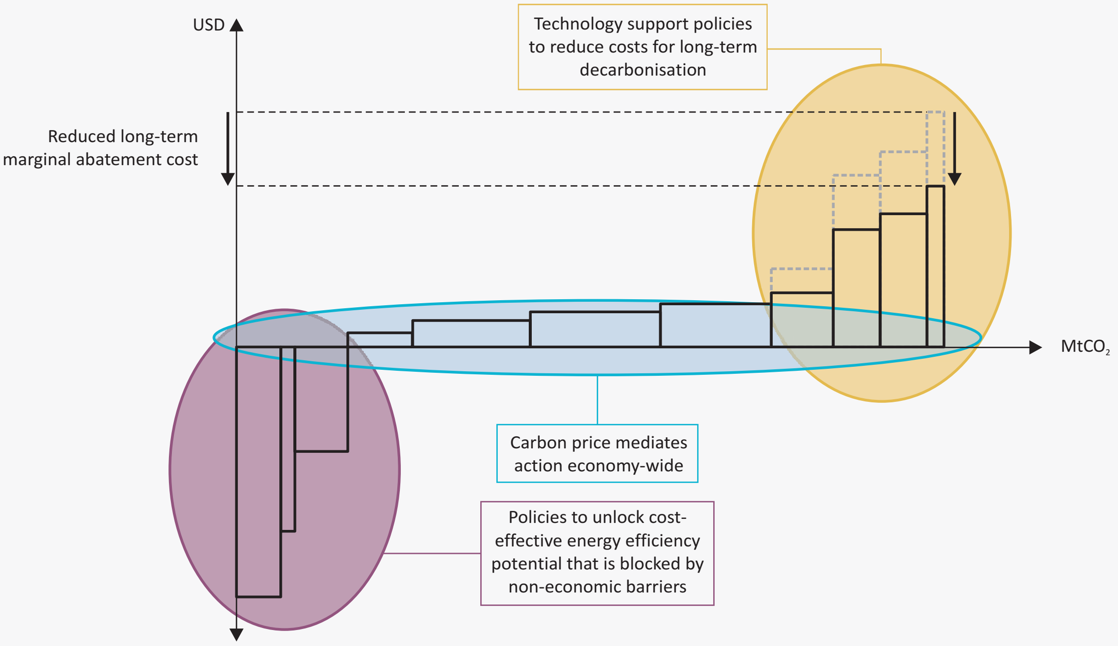
[4] See, for example, Fischer, 2009.

Carbon pricing should be balanced with policies to unlock cost-effective energy efficiency improvements and technology support policies to reduce costs for long-term decarbonisation investments. The latter may involve public and private RD&D, green certificates and/or feed-in tariffs.

Innovations in new energy technologies are often very capital-intensive, requiring substantial funds to support the necessary RD&D. Policies to support early actions are crucial, as are investments when technologies are ready to advance to commercial markets. Iceland's early experiments with geothermal heating and the Danish subsidy system for deployment of wind turbines are two examples of successful early actions to promote technology innovation. From a cost-effectiveness perspective, combining policies for energy efficiency improvement with RD&D of new technologies and carbon pricing provides the least-cost policy mix for transition over the long term (Hood, 2011) (Figure 2.3).

Figure 2.3 Policy mix with energy efficiency policies, carbon price and technology policies

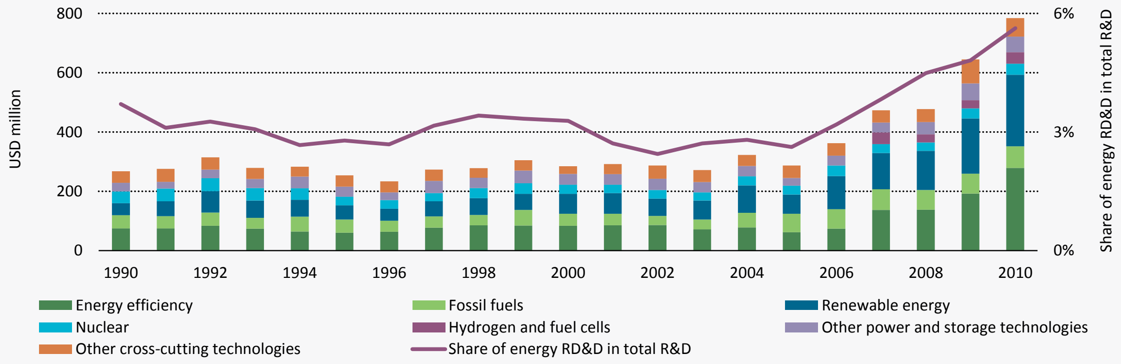


Note: $CO_2e = CO_2$ equivalent
Source: Hood, 2011.

Key point *An effective energy policy scheme involves a balanced mix of policies for carbon pricing, technology support and energy efficiency improvement.*

Despite recent increases, the share of energy-related RD&D funding in overall RD&D budgets in Nordic countries is lower than in the 1980s: in 1981, the average energy-related R&D share for Denmark, Finland, Norway and Sweden was 7.5%. After a decline to 2.6% in 2005, funding has been on the rise and currently stands just below 6% (Figure 2.5). This is well above the IEA country average, but remains relatively low given the emphasis on achieving a low-carbon society in the region. Finland has the highest energy share of total RD&D: almost 11% (Figure 2.5). While strong public RD&D funding is important, several other critical elements are also required to ensure the achievement of RD&D goals: coherent energy RD&D strategy and priorities; adequate government and policy support; co-ordinated energy RD&D governance including a strong collaborative approach that engages industry through public-private partnerships; effective RD&D monitoring and evaluation; and strategic international collaboration (IEA, 2011a).

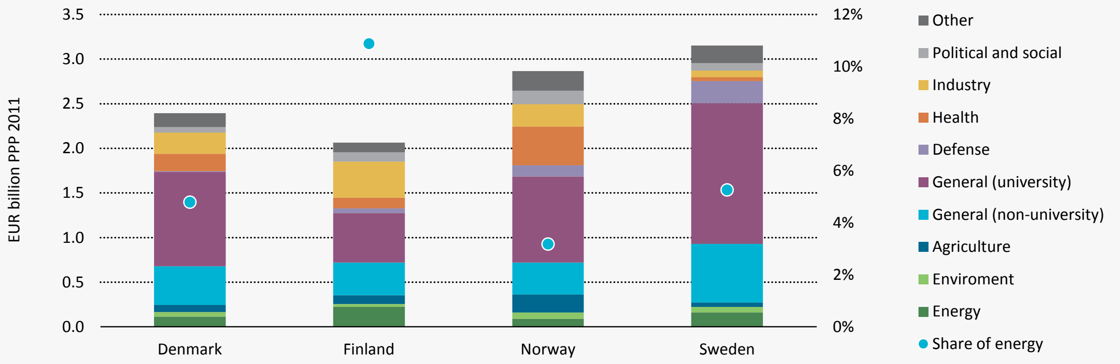
Figure 2.4 **Distribution of public R&D spending by energy resource in Nordic countries**



Key point *In 2007, energy efficiency received the largest share of public RD&D funding in the energy sector in the Nordic countries.*

Strong collaboration is an important element of the Nordic RD&D approach. The Nordic countries have a long tradition of co-operation in the areas of technology development and policies to reduce environmental impacts. The process has been characterised by openness and close co-operation among countries, and between government and industry (a "co-operative state"), with both parties having incentive to co-operate and to be open. Industry recognises that in the absence of transparency regarding environmental improvement potentials, the state would apply costly charges. The government, in turn, understands that by contributing research funding it can accelerate development (Bergquist and Söderholm, 2011). One example of co-ordinated co-operation in the region is RD&D financed through Nordic Energy Research (Box 2.2).

Figure 2.5 Total public energy RD&D and share of energy in total RD&D, 2011



Source: IEA, 2012; Eurostat, 2012; OECD, 2012.

Key point *To achieve its goals, public RD&D funding must be aligned with a coherent energy strategy and supported by effective policy and governance, collaboration with stakeholders, and monitoring and evaluation.*

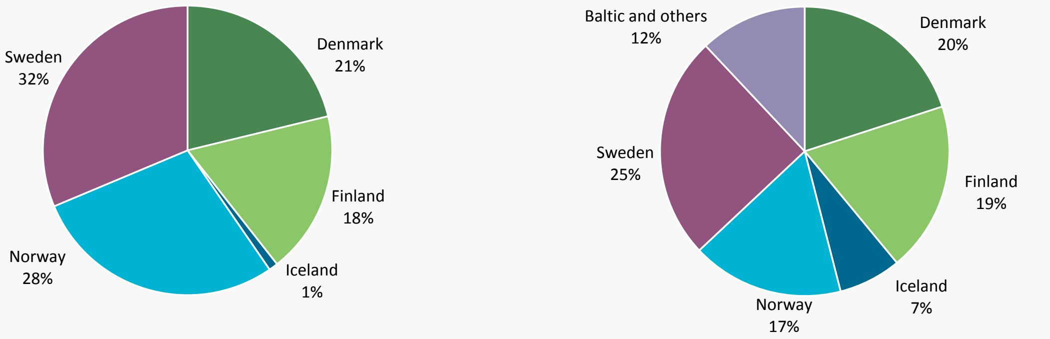
International and bilateral technology co-operation are also important features of the common Nordic RD&D approach, including participation in: the IEA Implementing Agreements (the Nordic countries collectively participate in 33 Implementing Agreements); the EU 7th Framework Programmes for research, technological development and demonstration activities for 2007-13; and important bilateral technology co-operation in strategic energy technology areas (such as CCS).

Box 2.2 Nordic co-operation in R&D

In addition to bilateral and European co-operation, the Nordic countries have had a policy of regional co-operation within energy R&D since 1985. The five national funding agencies contribute to a common “pot” of funding administered by Nordic Energy Research, an institution with a mission to “fund and promote Nordic co-operation within energy research and make a significant contribution to energy policy making”. Funding for this common Nordic pot is sourced based on the GDP of the member country and distributed based on project merit (Figure 2.6). It supports projects involving research partners from three or more countries in the region.

Co-operation at the Nordic level is facilitated by the shared energy research priorities of the member countries, and by the linguistic and cultural similarities.

Figure 2.6 Nordic common R&D funding by contributing country, 2011; Nordic PhDs by research country of origin 1985-2011



Source: Nordic Energy Research, 2012..

Key point *The common "pot" for Nordic-level R&D funding distributed EUR 8.9 million in 2011 and has financed 415 Nordic PhDs since 1985.*

In 2010, the Nordic-level fund equalled 4% of total national public funding for low-carbon energy technologies in the Nordic countries. Although relatively small, this budget aims to connect the national research communities, and to develop a long-term regional research and innovation network. Consortia formed at the Nordic level have gone on to receive support from national and European programmes.

Current Nordic funding programmes support research on sustainable energy systems, specifically within the areas of renewable energy, electricity grids and low-carbon transport. All of these areas are of common interest to the participating countries and support their work towards the ambitious emission reduction targets for 2050 set by Nordic governments.

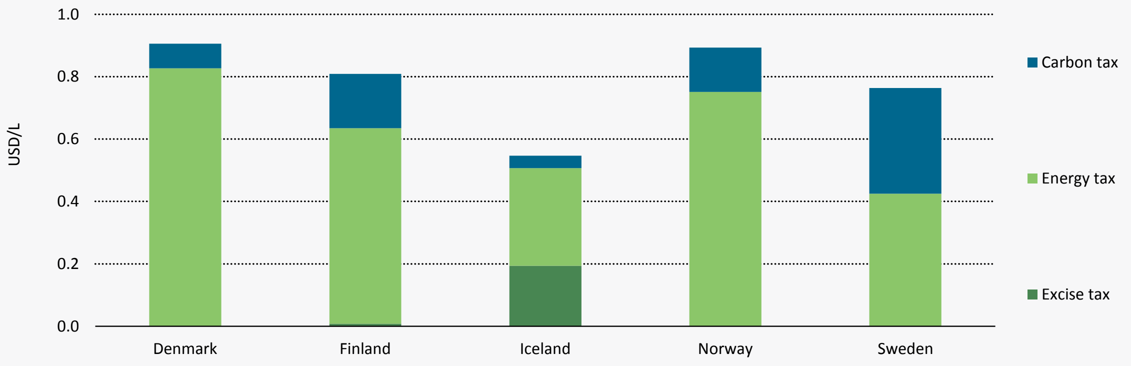
Experience in the use of energy and carbon taxation

Taxes on energy and CO_2 emissions are used in all Nordic countries and, in some cases, have contributed to the increased share of renewable energy (see *e.g.* Swedish EPA, 2006; Swedish Government, 2009; Box 2.3). Together with the EU ETS, carbon and energy taxation are important elements of the current Nordic energy policy framework. They have, for instance, contributed to reducing fossil fuel use in the Swedish district heating system (Box 2.3). In all of the Nordic countries, carbon tax levels are substantially higher than the price of an EU ETS allowance. Some exceptions in the carbon tax levels for industry exist; these are designed to protect specific sectors against international competition and are a result of the introduction of EU ETS.

Comparing tax levels among the Nordic countries is complicated since the coverage, definition and tax exceptions differ. All the Nordic countries have an energy tax in addition to the carbon tax (Table 2.2); these energy taxes are typically excise taxes, often not defined as environmental taxes but fiscal taxes. There is, however, a fine line between these two types of taxes since the energy tax has both fiscal and environmental purposes for different fuels without exceptions. An overview of tax levels on motor gasoline in the Nordic countries provides just one example of striking differences (Figure 2.7).

In Sweden, industries covered by the EU ETS are exempted completely from the carbon tax. At present, Swedish industries outside the EU ETS are exempted a large share, but an increase is planned such that, by 2015, the tax share they pay will range from 21% to 60% of the overall level. A first step has already been taken with an increase to 30% in 2011. In Denmark, sectors not covered by EU ETS are subject to carbon taxes. A high level of energy tax is applied on fossil fuels for heating purposes and on electricity consumption in the household and services sectors; these measures provide a significant incentive to save energy and to convert to renewable energy.

Figure 2.7 Tax levels on motor gasoline in the Nordic countries



Source: Denmark: Danish Energy Agency, 2011. Finland: Finnish Government, 2008. Iceland: Parliament of Iceland, 2004; 2009; 2011. Norway: IEA, 2011b; Norsk Lovdata, 2011. Sweden: SPBI, 2012; Swedish Tax Agency, 2012.

Key point *Energy and carbon taxes for motor gasoline vary in the Nordic countries. The price paid by customers at the pump is influenced by fuel price and VAT, which also vary from country to country.*

Fuel consumption within industry and fuel for electricity generation are, to a large extent, exempted from Sweden's energy taxes, because these sectors are subject to international competition. In Iceland, policy instruments such as carbon taxes have only recently been implemented. An energy tax is levied on all end-users and on industry for use of electricity and hot water. Initially, this was a temporary measure to be applied 2009-12, but a recent proposal now aims to make it a permanent law. Iceland is now a part of the EU ETS, and the country's energy-intensive industry will enter in 2013. In Norway and Finland, energy and carbon taxes have been long-term policies to reduce energy demand and emissions in the energy and industry sectors. Norway had a national trading scheme in 2005-07, under which Norwegian installations had the possibility to use allowances from the EU ETS. From 2008, Norway has participated in the EU ETS.

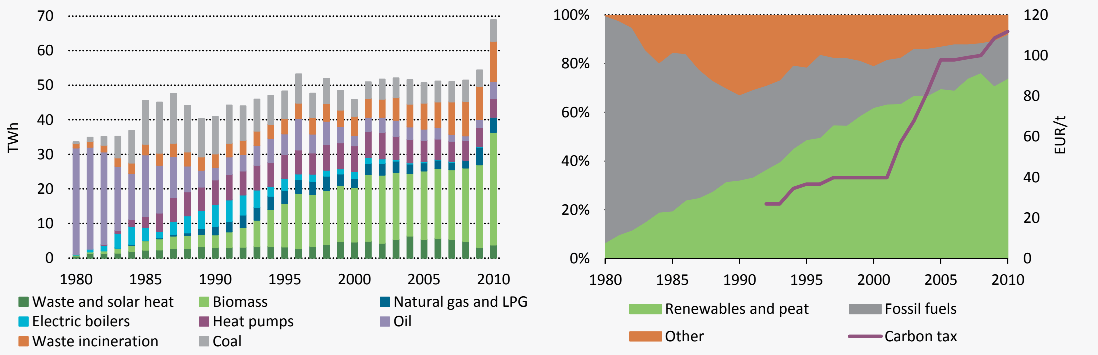
Box 2.3 Production of district heat as an arena for effective policy intervention: the Swedish case

The production mix of district heat in Sweden has undergone a dramatic change since the 1980s, when oil was virtually the only fuel in use (Figure 2.8). The oil crises of 1973 and 1979 spurred Swedish energy policy to aim at reducing oil dependence, which meant a certain revival of coal along with the introduction of peat, biomass and electricity in electric boilers and heat pumps in district heating. Massive expansion of nuclear power in the 1980s – again in order to reduce dependency – along with a general electrification of heating, led to the use of electricity as a means for producing district heat. During the 1990s, energy and climate taxation became the prime means of intervention in the production of district heat.

The use of energy in Sweden has been subject to taxation since the 1950s (Swedish EPA, 2004). At that time, the purpose of energy taxation was primarily fiscal. In 1991, Sweden introduced a carbon tax with a clear environmental objective. In 2001, the government agreed to a green tax reform that raised the carbon tax. Today, the carbon tax corresponds to around USD 160/tCO_2 – significantly above the USD 10/tCO_2 of the current allowance prices in the EUETS (12 September 2012, European Energy Exchange).

Since the taxation was introduced, CO_2 emissions from production of district heat have declined by around 70% when compared to the beginning of the 1980s. Significant variations exist among different local district-heating systems, due to local conditions.

Figure 2.8 Fuel mix in the Swedish district-heating production



Note: TWH = terawatt hours. 2010 was an extremely cold year, leading to very high use of district heating.
Source: Swedish Energy Agency, 2012.

Key point *Swedish carbon and energy taxation has promoted substantial fuel switching – away from fossil fuels – in the production of district heat.*

Design of the carbon tax has led to different impacts depending on the type of heat supply. Since 2004, the carbon tax level has gradually been reduced, especially for co-generation[5]. In 2011, it amounted to 7% of the nominal level (only fuel use for heat production is subject to taxation), which is around USD 160/tCO_2. This reflects an aim to avoid overlapping policies: since many co-generation plants are also covered by the EU ETS, they were exempt from the carbon tax. In September 2012, the Swedish government proposed eliminating the carbon tax for co-generation.

Heat-only stations also included in the EU ETS have been subject to relief of carbon taxation, but not to the same extent as many of these plants are too small to be covered by the EU ETS. In 2003, Sweden introduced the "electricity certificate scheme" with the aim of significantly increasing production of renewable electricity. Since biomass for electricity generation is used exclusively in co-generation stations (Sweden has no biomass-fired condensing plants), this has also affected the production of district heat. Taxation has gradually driven up costs of fossil fuels, despite some cost reductions in co-generation schemes. The use of biomass in electricity production has been supported by the electricity certificate system and previously by other schemes.

Table 2.2 Taxation in Nordic countries, different fuels

	Denmark	Finland	Iceland	Norway	Sweden
Motor gasoline, excise tax, USD/L	-	0.008	0.194	-	-
Motor gasoline, energy tax, USD/L	0.820	0.627	0.313	0.751	0.425
Motor gasoline, carbon tax, USD/L	0.078	0.174	0.040	0.142	0.339
Motor gasoline, total	0.898	0.809	0.546	0.893	0.764
Motor gasoline, VAT	25%	23%	25.5%	25%	25%
Heating oil, excise tax, USD/L	-	0.004	-	0.147	-
Heating oil, energy tax, USD/L	0.384	0.096	0.000	0.000	0.110
Heating oil, carbon tax, USD/L	0.080	0.100	0.056	0.096	0.418
Heating oil, total	0.464	0.200	0.056	0.243	0.528
Electricity , excise tax, USD/kWh	-	0.0002	-	0.018	0.040
Electricity, energy tax, USD/kWh	0.137	0.021	0.001	0.000	0.000
Electricity, carbon tax, USD/kWh	-	-	-	-	0.000
Electricity total	0.137	0.021	0.001	0.018	0.040
Electricity industry, excise tax, USD/kWh	-	0.0002	-	0.001	0.001
Electricity industry, energy tax, USD/kWh	0.007	0.009	-	-	-
Electricity industry, carbon tax, USD/kWh	0.011	-	-	-	-
Electricity industry, total	0.018	0.009	-	0.001	0.001

Sources: Denmark: Danish Energy Agency, 2011. Finland: Finnish Government, 2008. Iceland: Parliament of Iceland, 2004; 2009; 2011. Norway: IEA, 2011b; Norsk Lovdata, 2011. Sweden: SPBI, 2012; Swedish Tax Agency, 2012.

Key point *Energy and carbon taxes are present in all Nordic countries, but levels and exemptions vary.*

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5 Co-generation refers to the combined production of heat and power

A market-driven approach

A common Nordic power market for Denmark, Finland, Norway and Sweden

The development of the common Nordic power market began with the deregulation of the Norwegian power system in 1991. The liberalisation required a set of market rules including establishment of an hourly power market, regulation of electricity networks and third-party access to the transmission infrastructure. A power market exchange was formed including financial, spot and intraday markets while the transmission system operator (TSO) was made responsible for a short-term market known as the Balancing Power Market. In 1996, the Swedish power market was liberalised and a joint Norwegian-Swedish power exchange was established by the name of Nord Pool Spot. Finland joined Nord Pool Spot in 1998 and Denmark in 2000.

Nord Pool Spot was the world's first international market for trading power and is currently the largest market of its kind. It includes both the day-ahead and intraday markets, with 370 companies from 20 countries trading. In 2011, the market had a total turnover of 316 TWh.

Box 2.4 Components of the Nord Pool Spot markets

Day-ahead market (Elspot)
Each Nordic country is divided into several bidding areas, set by the national TSO, as follows: Denmark - 2; Finland - 1; Norway - 5; and Sweden - 4. Every day at noon, all actors send in spot bids, including both supply and demand bids for each hour in the day ahead. Based on the intersection of the aggregated supply and demand bids, Nord Pool Spot sets a Nordic system price. Before the regional market is cleared, each TSO determines the transmission capacity among the bidding areas and Nord Pool Spot calculates an area price that balances production and demand in each area to avoid congestion. Contracted volumes are set for the coming day.

Intraday market (Elbas)
Once the area price is set, the intraday market opens, with trading around the clock and trading for a specific operation hour closing one hour before the hour of operation. This market is similar to financial markets, with individual supply and demand bids. However, the prices are set based on a "first come, first served" principle in which the lowest sell price and highest buy price come first, regardless of when an order is placed.

Balancing Power Market
Based on the area price and their obligations in the day-ahead market, actors send in bids to the Balancing Power Market to increase or decrease production. If an imbalance arises between supply and demand within the actual operational hour, the TSO uses the bids to balance the system. The Balancing Power Market is also used for congestion management. The last activated unit in the Balancing Power Market sets the price for the imbalance for that hour, and any actor(s) that cause the imbalance pay for the regulations.

In 2009, the Norwegian TSO introduced a Balancing Power Option Market, in which both producers and consumers bid available capacity for the Balancing Power Market on a weekly or seasonal basis. The Danish TSO runs a similar scheme.

In the current market design, the electricity price differs for each hour within pre-defined geographical price zones (also termed "zonal pricing"). This provides incentives for the end-user to reduce electricity demand in periods with high prices, while price differences among zones provide incentives to build new transmission capacity. However, short periods with limited capacity and very high electricity prices (*e.g.* caused by an unexpected shutdown of a nuclear plant in the winter) often do not provide sufficient incentives to expand the transmission capacity. Internal congestion within a price zone is either managed through the capacity setting in the spot market and/or through the Balancing Power Market.

The available transmission capacity is set by the TSOs on a zone-by-zone basis and can therefore differ from the physical available transmission capacity of the actual power grid. This may lead to price differences among areas.

One way to assure that the capacity set by the TSO within a given market equals the physical capacity is by introducing so-called "nodal pricing". Each node in the electricity grid has a different electricity price: this helps to establish optimal use of the grid and also indicates more specifically where new investments are needed. Concerns exist regarding how nodal pricing will affect the liquidity of markets in which it is used. Nodal pricing is currently not discussed among the Nordic countries.

Strong targeted energy technology policies

Since 2012, Sweden and Norway have had a common green electricity certificate market that aims to increase renewable electricity production by 26.4 TWh during the period 2012-20. Sweden previously operated a national system (since 2003) that resulted in an increase of renewable electricity production of 12 TWh and still has a target of 25 TWh new renewable electricity production in 2020 compared to 2002. The electricity certificate system requires consumers to purchase a certain quota of certificates for every kilowatt hour they use. Electricity production qualifying for electricity certificates originate from wind power, certain forms of hydro power, certain biofuels, solar energy, geothermal energy, wave energy and peat in co-generation. The current price of electricity certificates is around USD 30/MWh, slightly lower than the average electricity certificate price of USD 33/MWh during the period 2003-10.

In Denmark, electricity generation from renewable resources is supported through price premiums and fixed feed-in tariffs. Price premiums provide a fixed premium per kilowatt hour of power production. In Finland, wind and biogas receive feed-in tariffs, which ensure that those producers receive a fixed price for their electricity (*i.e.* the level of feed-in depends on the electricity market price). In Finland, wind-, biogas- and woodchip-based electricity generation receive a premium on top of the electricity market price to guarantee a certain revenue level for the generation. For wind and biogas, the premiums vary according to the electricity market price; for woodchips, price varies according to the value of emissions allowance in EU ETS. Wide-scale deployment of wind power in Denmark is a result of a portfolio of policies, such as efficient remuneration policy, simple grid connection procedures, interconnection with hydro-dominated power systems and a strong local industry.

In Iceland, the state allocates funding to the Geothermal Research Group, a research cluster in the field of geothermal energy. The state partly funds the Icelandic Deep Drilling Project, a consortium with the purpose to drill into a high-temperature hydrothermal system to reach supercritical hot hydrous fluids. Finland has a long tradition of supporting RD&D of bio-based energy across the entire value chain, from wood harvesting to energy production (Box 2.5).

Technology policies increasingly focus greater attention on the transport sector with policy regulations extending beyond energy and carbon taxes. All Nordic countries have differentiated tax on vehicles based on CO_2 emissions per kilometre. Sweden has been the most successful of the Nordic countries in introducing renewable transport fuels, with 7.7% share in 2010 compared to 3.9% in Finland and Norway and 0.3% in Denmark (Eurostat, 2012 [Iceland missing]). One of the key factors behind the Swedish success is the low-blending of biofuels with fossil fuels, which is now practice in all the Nordic countries (see Chapter 5, Transport). In addition, Sweden has exempted biofuel cars from the energy and carbon tax until 2013. In Norway, biodiesel is subject to only 50% of the tax of gasoline; ethanol blended in gasoline is subject to the gasoline tax while ethanol for all other use is exempted completely. Electric vehicles (battery electric and hydrogen fuel cell) in Norway are exempted from road tax, can drive in bus lanes and can park for free in public parking areas (see also Box 5.1 in Chapter 5, Transport). Private transport in Denmark is subject to a high vehicle registration fee; the fee can be reduced through awards to energy efficient vehicles that have low fuel consumption. Electric and hydrogen vehicles are currently totally exempted from the registration fee and the ownership tax. Iceland imposes four taxes and excise taxes on carbon-based fuel, but no such taxes are imposed on hydrogen methane or other biofuels, and excise taxes on all methane-powered vehicles are reimbursed. Owners who modify their petrol- or diesel-powered vehicles for methane use receive excise tax refunds.

Although policies have been tightened in Sweden, emissions from the transport sector have increased since 1990, largely reflecting growth in the transport volume. Without these policies, emissions probably would have been even higher. The estimated reduction in emissions from the increased tax levels for the vehicle fleet since 1990 is 1.9 million tonnes of CO_2 ($MtCO_2$) per year in 2010 and 2.4 $MtCO_2$/yr in 2020 (Swedish Government, 2009).

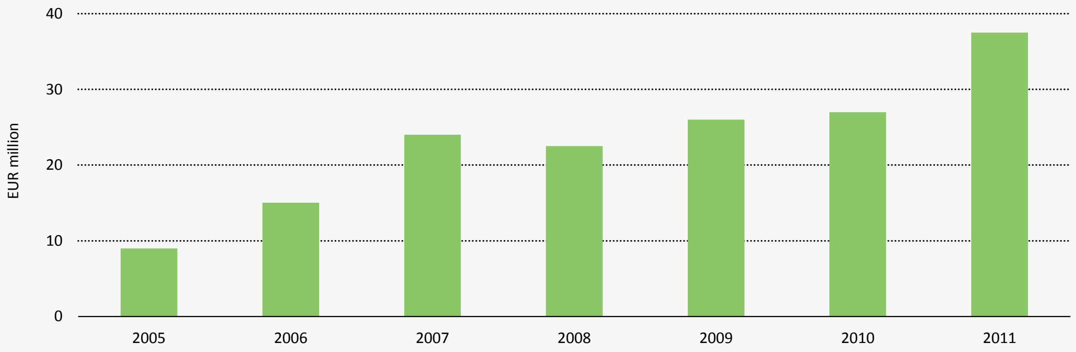
Box 2.5

Bioenergy in Finland

The bioenergy sector in Finland has strong traditional competences mainly developed within the pulp and paper industry. The knowledge and knowhow in bioenergy technologies is high and covers the whole bioenergy value chain, *e.g.* biomass procurement, biofuel production and bioenergy production with various technologies in all scales. The share of biomass fuel in electricity production is today, and has long been, the highest in the world (13% in 2010). The largest user of bioenergy in Finland is the pulp and paper industry, where biomass and spent liquors are used to cover the energy need in pulp and paper production. Biomass is also used in municipal combined heat and power (CHP) production, where biomass is often co-fired with peat, the other main indigenous energy source in Finland.

The success story of the Finnish bioenergy is largely based on intensive research, development & innovation (RD&I) on various bioenergy technologies. Tekes – the Finnish Funding Agency for Technology and Innovation is the major financier of bioenergy related technology development. Since 2005, the Tekes funding on bio-energy RD&I has more than triplicated being about 37 M€ in 2011 (Figure 2.9). In addition, the Ministry of Employment and Economy grants promoting the use of indigenous fuels.

Figure 2.9 Tekes funding on bioenergy RD&I



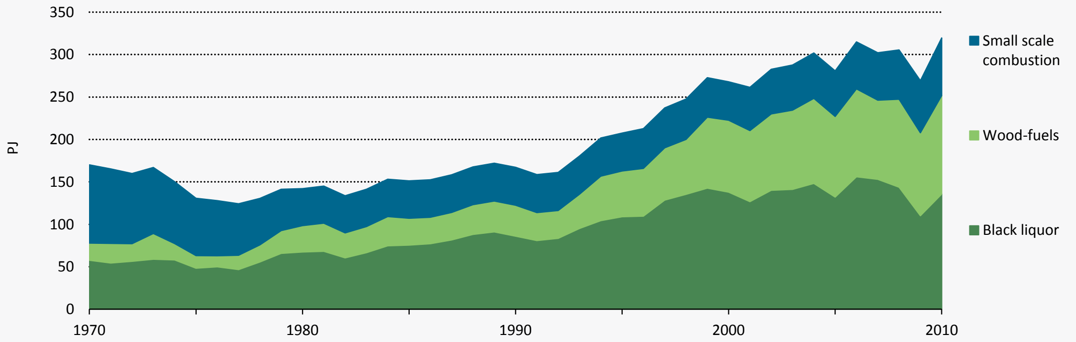
Source: Data from Tekes – the Finnish Funding Agency for Technology and Innovation.

Key point *Finland has strong RD&I policy on bioenergy.*

Finland has offered favourable demonstration environment on bioenergy technologies, which has led to several success stories. A good example is Alholmen Kraft's power plant, which is the world's largest power plant using biomass fuel with the world's largest circulating fluidized boiler (CFB). As a result of long term R&D Finnish boiler industries have grown to be the global market leader in fluidized boilers. In addition, Finland is also a major supplier of biomass procurement machinery.

Since 1980's bioenergy consumption in Finland has more than doubled mainly due to expansion of pulp and paper industries (Figure 2.10). The expansion is still expected to continue but his time largely because of EU's renewable energy targets by 2020. According to Finland's National Renewable Allocation Plan, a major part of Finland's renewable target will be fulfilled by increased use of bioenergy and biofuels.

Figure 2.10 Bioenergy consumption in Finland by biomass fuel



Source: Data: Energy Statistics. Yearbook 2011. Official statistics of Finland

Key point *Bioenergy consumption has doubled since 1980's in Finland*

Table 2.3 Mapping of selected Nordic energy policies

Sector	Denmark	Finland	Iceland	Norway	Sweden
Cross-sectoral					
Energy and carbon tax	✓	✓	✓	✓	✓
EU ETS	✓	✓	✓	✓	✓
Technology-specific support policies for power and heat	Renewable energy price premiums; fixed feed-in tariffs and tenders; local energy planning	Feed-in tariffs; investment supports	Electrical safety fee; surveillance fee	Renewable electricity certificates; funding scheme for renewable heat and electricity	Renewable electricity certificates
Industry energy efficiency					
Energy management protocols	Energy-saving obligations	Voluntary agreements			
Support for energy efficiency investments	Support to energy efficient renewable energy solutions	Support for energy efficiency investments; energy analysis and energy inspections		Grants for energy efficiency; programme for energy efficiency in pulp and paper; grants to renewable heat and district heat	PFE - programme for improving energy efficiency; energy efficiency support
Buildings energy efficiency					
Building codes (min. energy performance requirements)	For new buildings and deep renovations	EU targets to be fulfilled by 2020	Maximum allowed U-values in new buildings		
Energy labelling	Mandatory energy labelling	Mandatory energy labelling	Energy labelling of household appliances	Mandatory energy labelling	Mandatory energy labelling
Support schemes for building energy efficiency	Supports for renovation of buildings to increase energy efficiency; investment support for heat pumps	Energy saving obligations	Cost-differentiated VAT on space heat energy; subsidised electricity for space heating in sparsely populated areas; grants for insulation improvements; grants for shifting to geothermal heating; grants for heat pump installation	Grants for energy efficiency; energy saving loans; grants to renewable heat production and district heating	Support for investments; support reduced energy use; technology procurement; energy efficiency support
Low-emission transport					
Biofuels support schemes	Obligation on certain share of biofuels on vendors of transport fuels	Feed-in tariff for biogas	Special petrol tax; excise tax and VAT on fossil fuel; exceptions from tax on H2 and biofuels; free parking for eco-friendly cars; differentiated vehicle excise tax	Gasoline and diesel tax; funding of pilot and demonstration projects	Exceptions from tax for biofuels
Preferential vehicle purchase/ registration schemes	Ownership tax and registration fee depend on CO_2 emissions per km; exemption for electric vehicles (EVs) and hydrogen EVs	Differentiated vehicle tax based on CO_2 emissions per km	Excise tax reimbursement on methane- and hydrogen-powered vehicles	Differentiated vehicle tax; labelling, new passenger vehicles; reward scheme; increased public transportation	Car premium (2007-09); differentiated vehicle tax

Source: Various energy policy documents, information gathered by Nordic ETP Working Group.

Key point *The Nordic countries have a broad set of energy policies, some of which are common for all countries (such as energy and carbon tax) and some that are nation-specific.*

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.*

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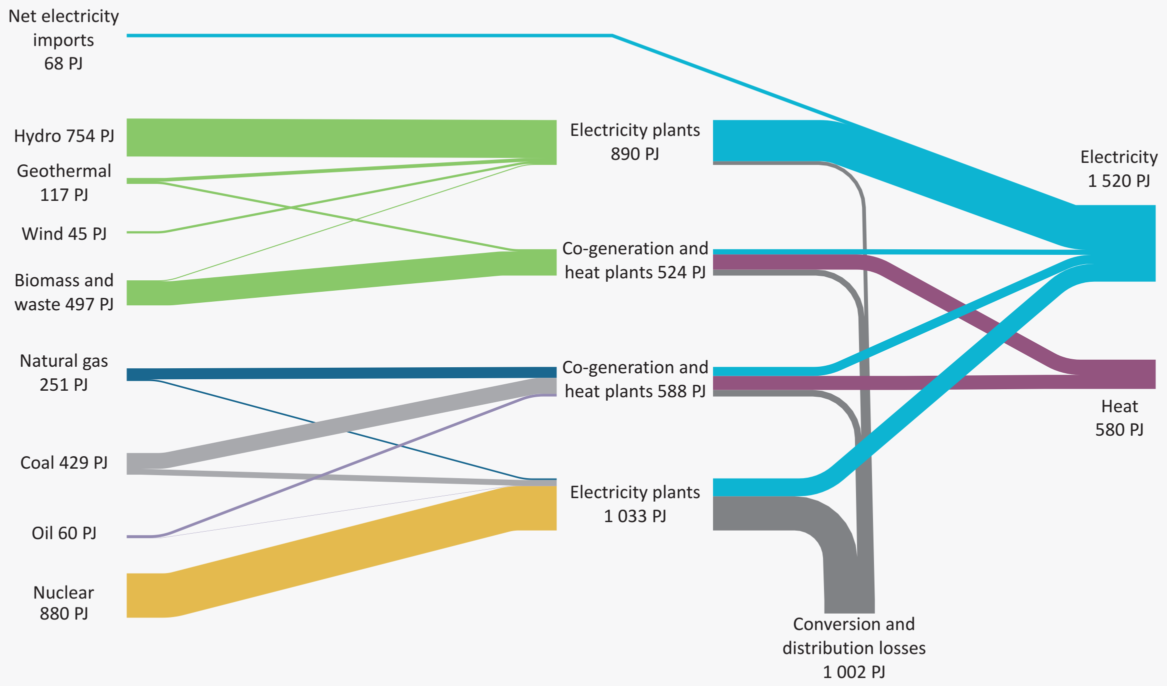
[1] Co-generation refers to the combined production of heat and power (CHP).

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.

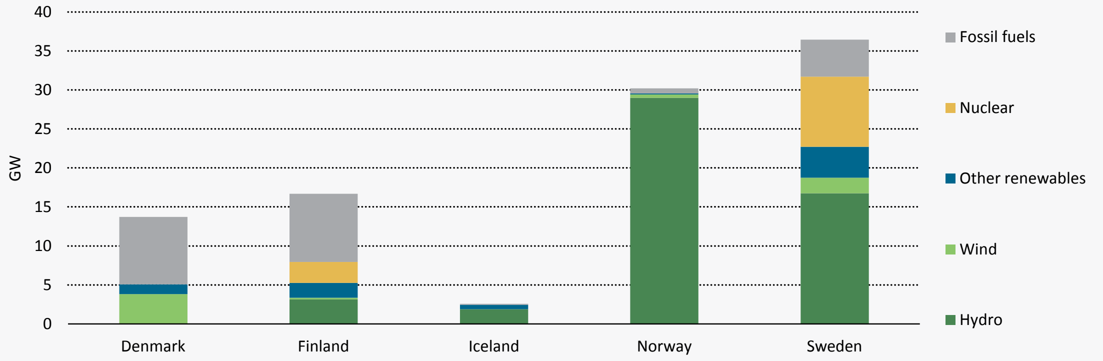
Figure 3.1 Energy flows in the Nordic electricity and heat sector, 2010



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

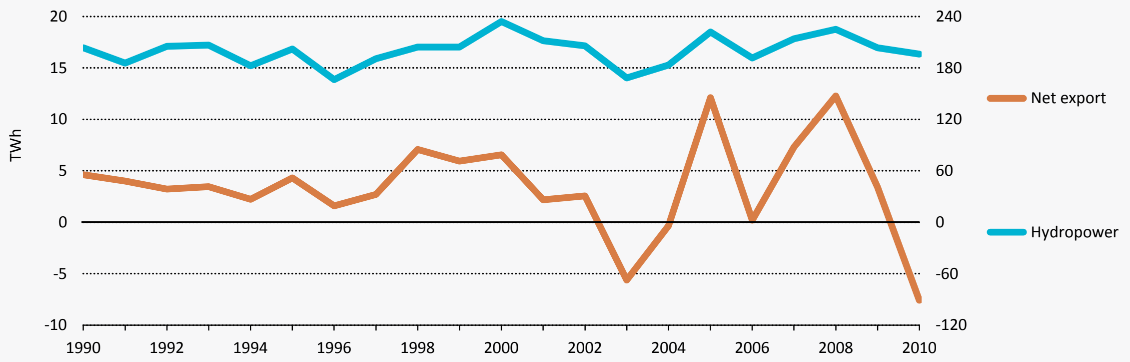
The European Union (EU) is striving towards an integrated European electricity market. Above all, this implies a market-orientated model that encourages the efficient trade of electricity among market players and across EU member states, and creates a basis for managing resources more efficiently. In 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

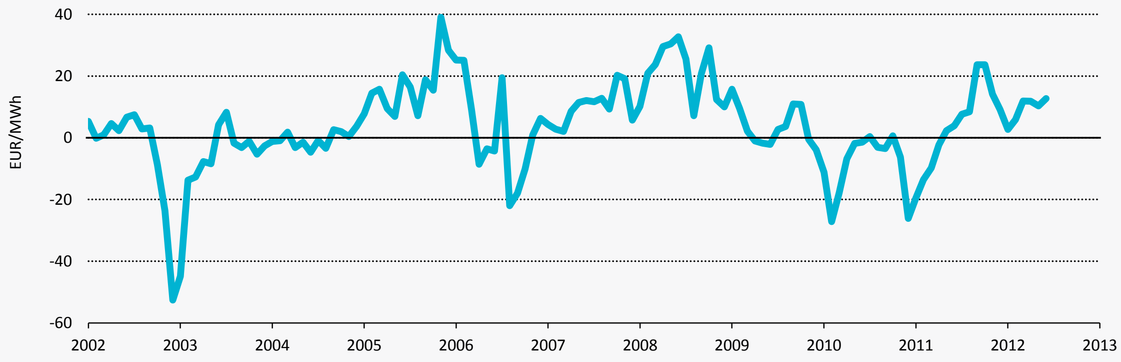


Notes: TWh = terawatt hour. Imports to Finland from Russia are not included in this chart.
Source: EUROSTAT, 2012.

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.

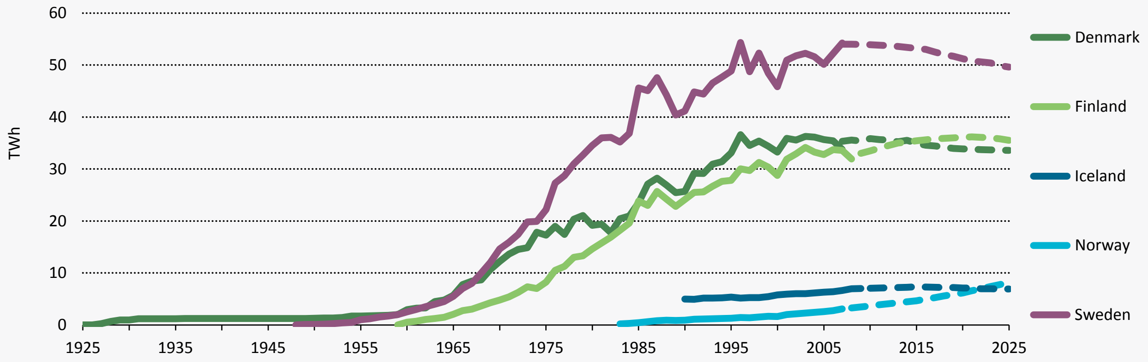
Key point *Wholesale electricity prices are generally higher in the German market than in the Nordic market. This price difference drives cross-border trading.*

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

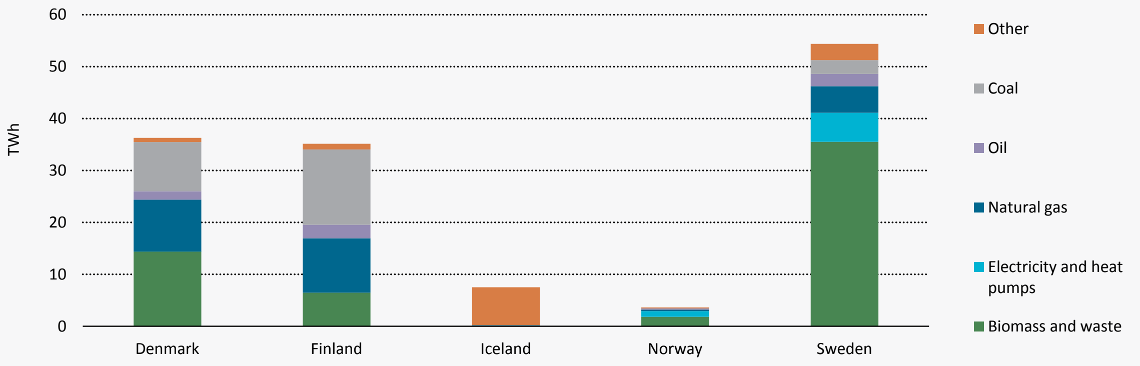


Note: TWh = terawatt hour.
Source: Nordic Energy Perspectives, 2010.

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.

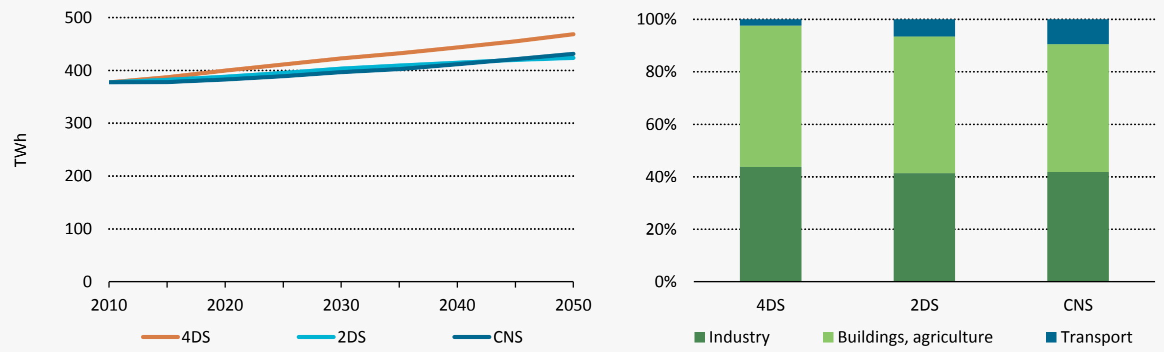
Two variants of the ambitious CNS targets for reducing CO_2 emissions are considered in the power sector:

- *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.

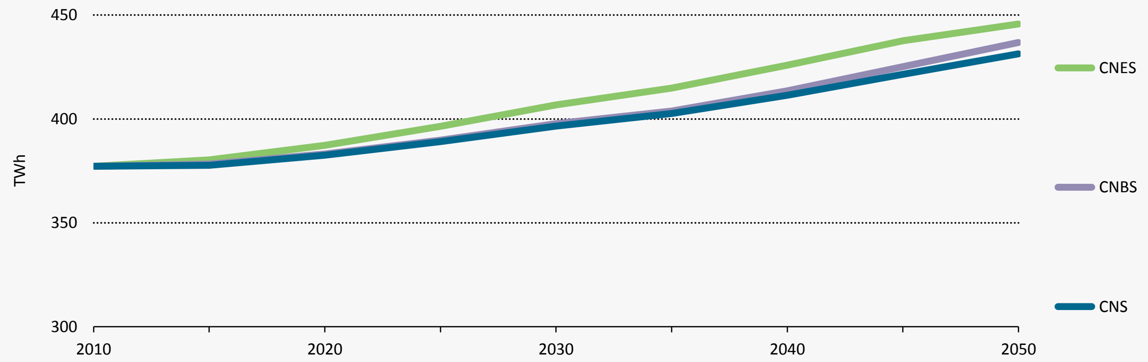
Figure 3.7 Development of final electricity demand (left) and its breakdown by sector in 2050 (right)



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

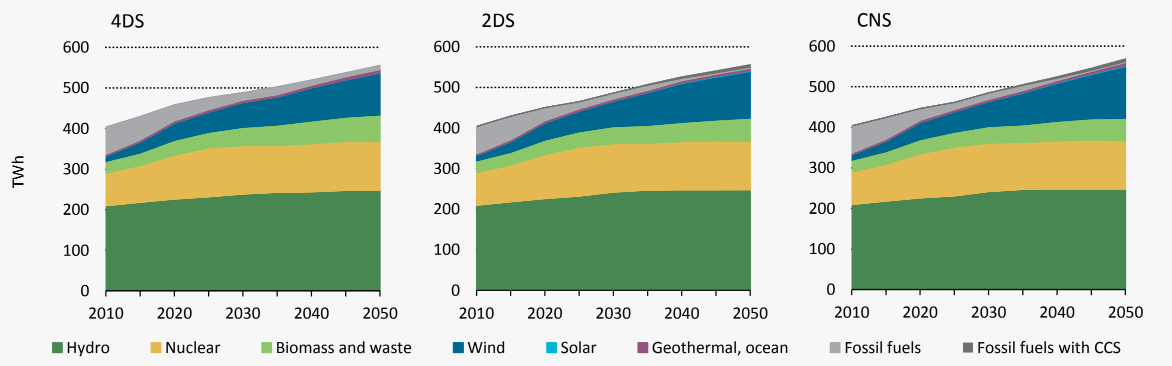


Key point *The CNES has a modest increase in electricity demand compared to the CNS.*

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.

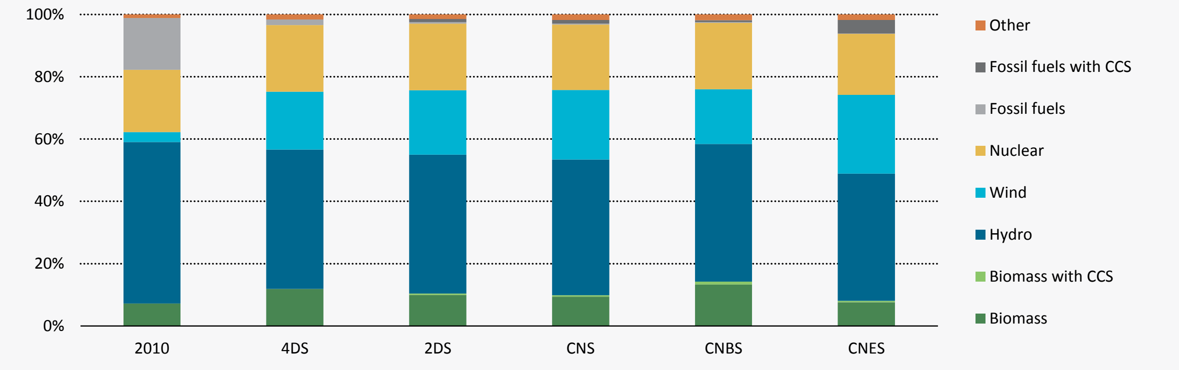
Figure 3.9 Nordic net electricity generation by scenario



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.

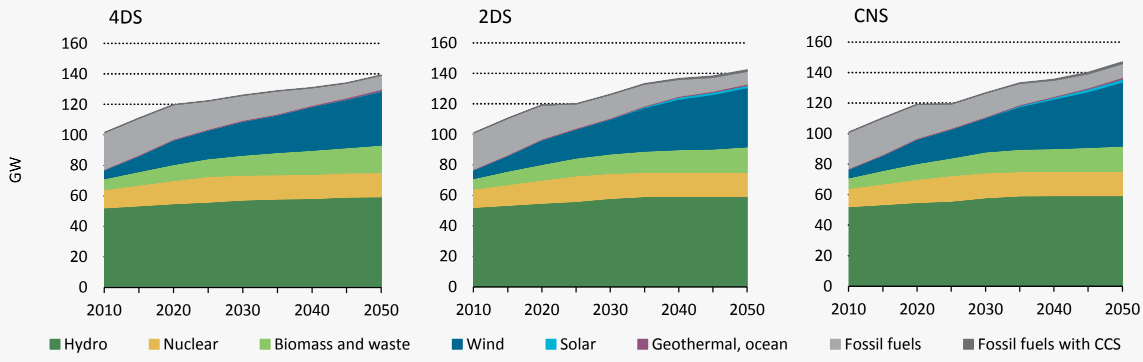
Figure 3.10 Electricity generation mix in 2050



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.

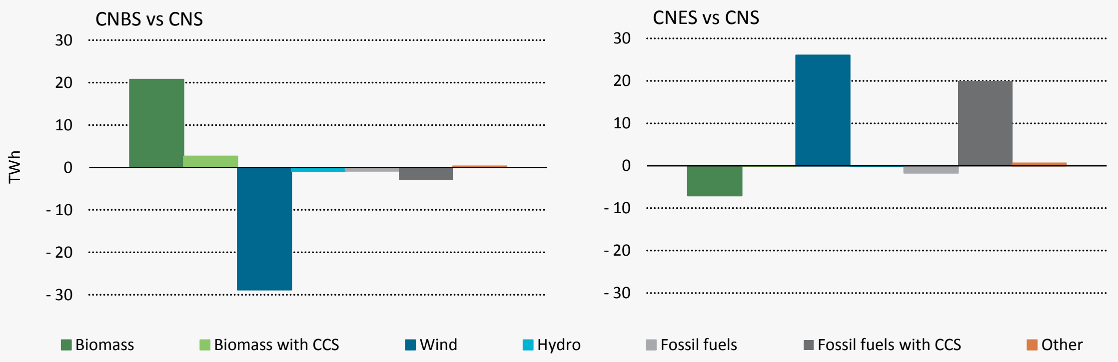
Figure 3.11 Nordic net electricity capacity by scenario



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

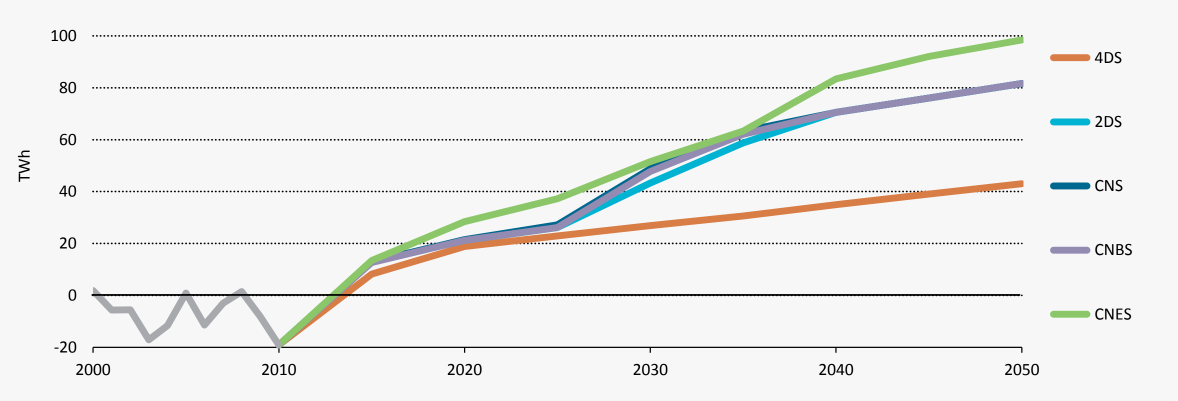


Key point *More available biomass in the CNBS leads to a switch from wind to biomass-fired generation, whereas increased transmission capacities for exports in the CNES drive the increased electricity generation by wind.*

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.

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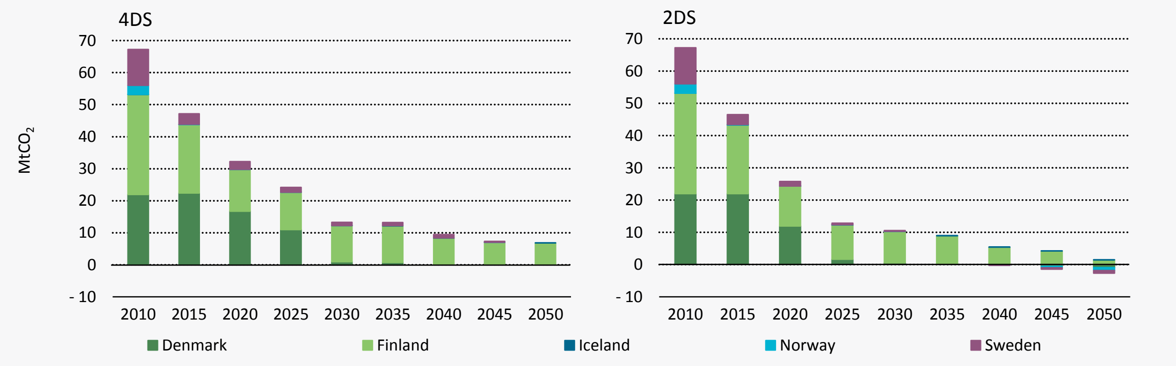
[2] Unless otherwise stated, all costs and prices are in real 2010 USD, i.e. excluding inflation. Other currencies have been converted into USD using purchasing power parity (PPP) exchange rates.

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

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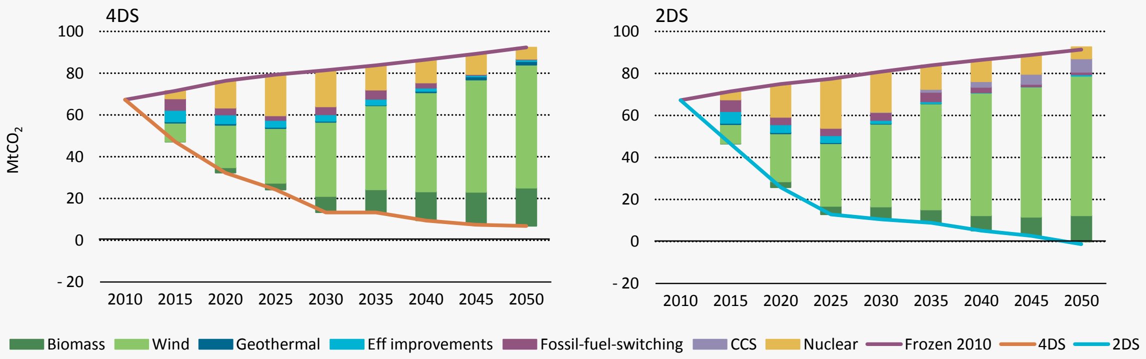
[3] The indicator is defined as CO_2 emissions from electricity generation divided by electricity generation. For co-generation plants, CO_2 emissions from electricity have been calculated by assuming that the heat would have been generated in a heat boiler with an efficiency of 90%. CO_2 emissions allocated 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



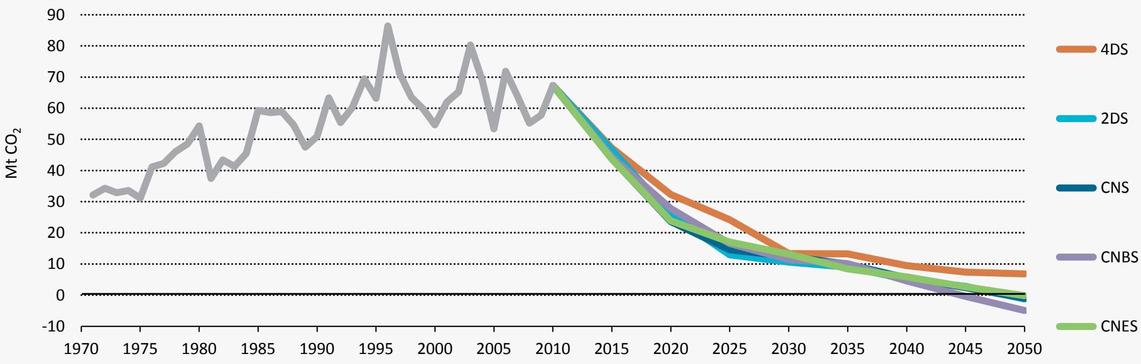
Note: Eff improvements = efficiency improvements.

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)

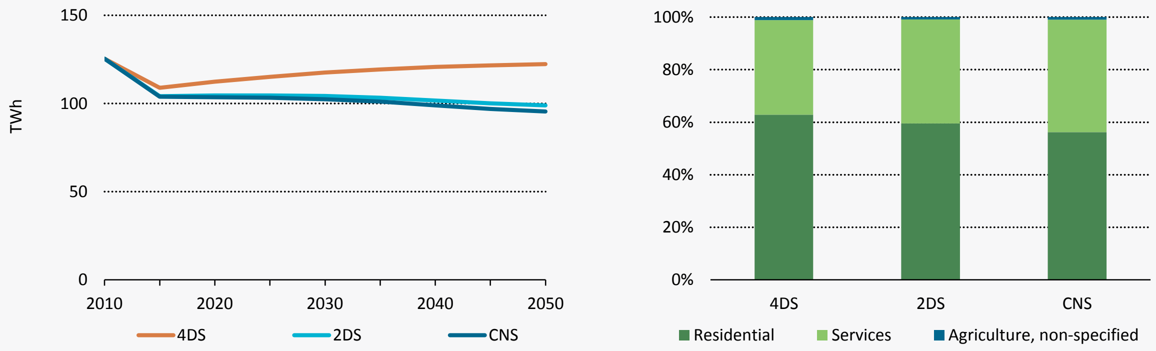


Key point *The power sector becomes completely decarbonised in all scenarios, except the 4DS.*

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.

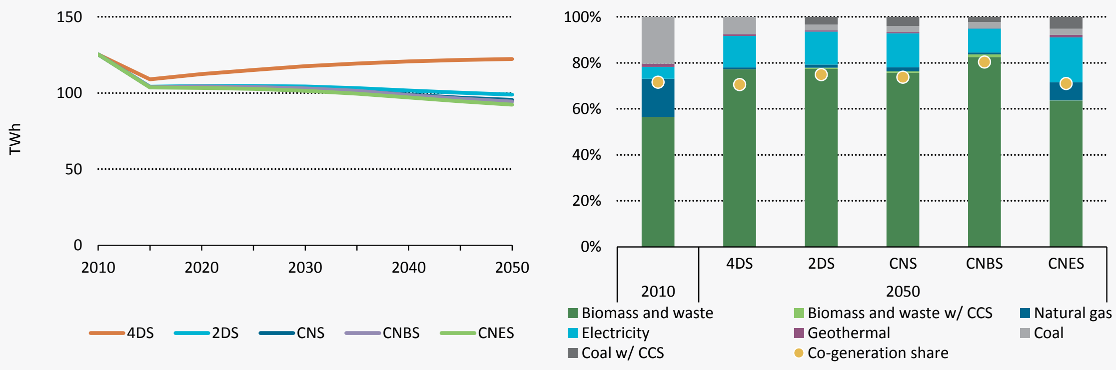
In the more climate-ambitious 2DS and CNS, the use of district heating decreases slightly between 2015 and 2050. This does not indicate that district heating loses large market share. Instead the total heating market decreases due to increased energy efficiency efforts for space and water heating in 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)

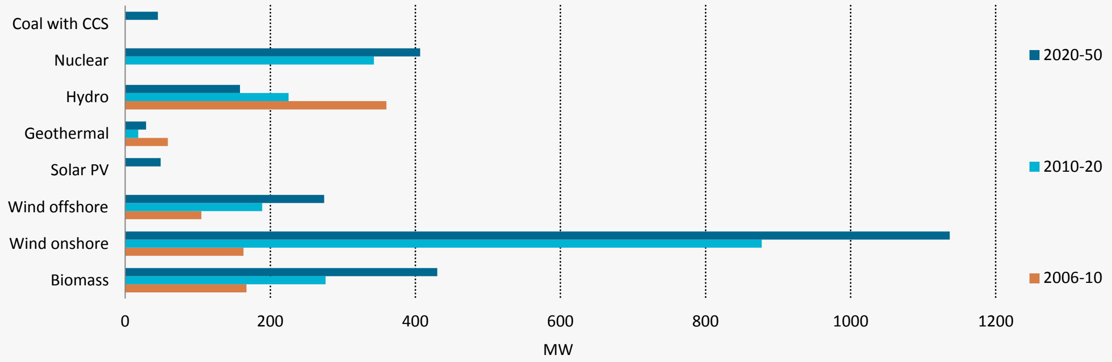


Key point *Demand for district heating does not alter in the CNS and its variants, but the fuel mix of its supply changes.*

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).

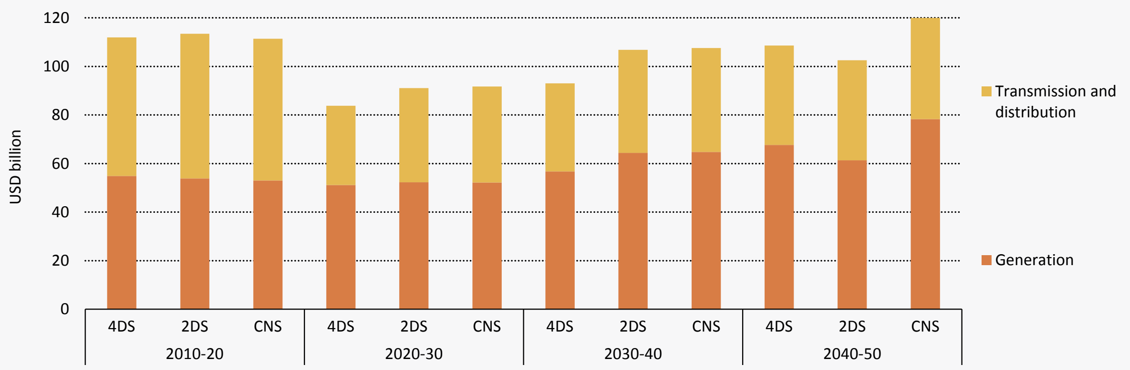
Figure 3.19 Annual new capacity additions of low-carbon power technologies in the Nordic region in the 2DS



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

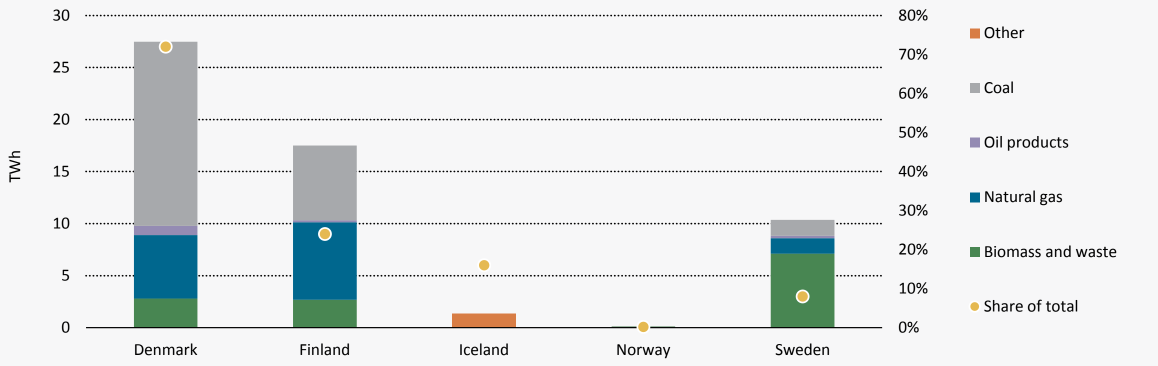
Co-generation – an efficient technology linking several energy markets

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.*

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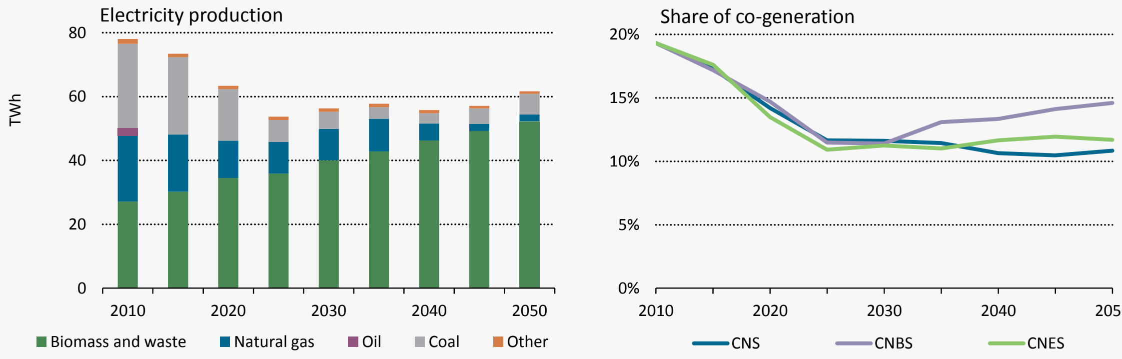
[4] The definition of co-generation includes, however, a rather large variety of power and heat plant configurations. In Denmark, for instance, large centralised co-generation schemes, which are primarily used for electricity production and often operated in condensing mode, account for a large share 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.

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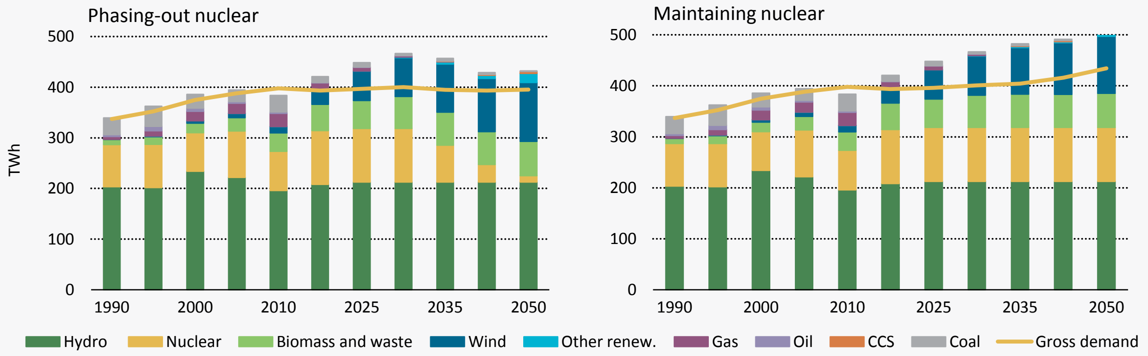
[5] Fennovoima is a joint venture among several energy and industry companies.

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 4

Industry

Energy-intensive industries provide the backbone of the Nordic economy. Decarbonising industrial processes and reducing carbon dioxide (CO_2) emissions is proving more challenging and more costly in industry than in other sectors. *NETP* analysis indicates that significant investment has already gone into making these industries more energy efficient, but further action is needed to achieve the desired results.

Key findings

- ***Industry used approximately 35% of the total Nordic final energy consumption in 2010,***[1] *which is relatively high compared with other European countries. Both the 2°C Scenario (2DS) and the Nordic Carbon Neutral Scenario (CNS) place great importance on improving energy efficiency and further reducing CO_2 emissions in Nordic industry.*
- ***Significant reduction in CO_2 emissions in Nordic industry will be possible only if all industrial sectors reduce their emissions.*** *Reductions could be gained by improving the efficiency of processes, investing in new production technologies, switching fuels, implementing carbon capture and storage (CCS), and using more recycled and waste materials.*
- ***Less than one-quarter of energy demand in industry is met by fossil fuels in 2050 in the 2DS. The major fuel in industrial co-generation is biomass*** *and according to the scenarios its share must be even higher in the future.*
- ***In the 2DS, energy demand in industry peaks before 2020 and by 2050 it decreases to close to 2010 levels.***
- ***In the CNS it is assumed that new technologies will be available earlier than expected in the 4°C Scenario (4DS) and 2DS,*** *and further improvement will be achieved by using best available technologies (BAT). In order to achieve this, investment in industrial research, development and demonstration (RD&D) needs to increase.*
- ***Carbon capture and storage (CCS) represents the most important option among new technologies for reducing industrial CO_2 emissions after 2030.*** *Currently, great uncertainties exist as to how to deploy CCS, and therefore both CCS demonstrations and closer Nordic collaboration would be needed to overcome the barriers.*

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[1] Industrial energy consumption includes fuels used as feedstocks (non-energy use) in the chemical and petrochemical sector, as well as energy consumption in coke ovens and blast furnaces. Other fuel-processing sectors, such as refining, are not included in the industry sector analysis.

Recent trends

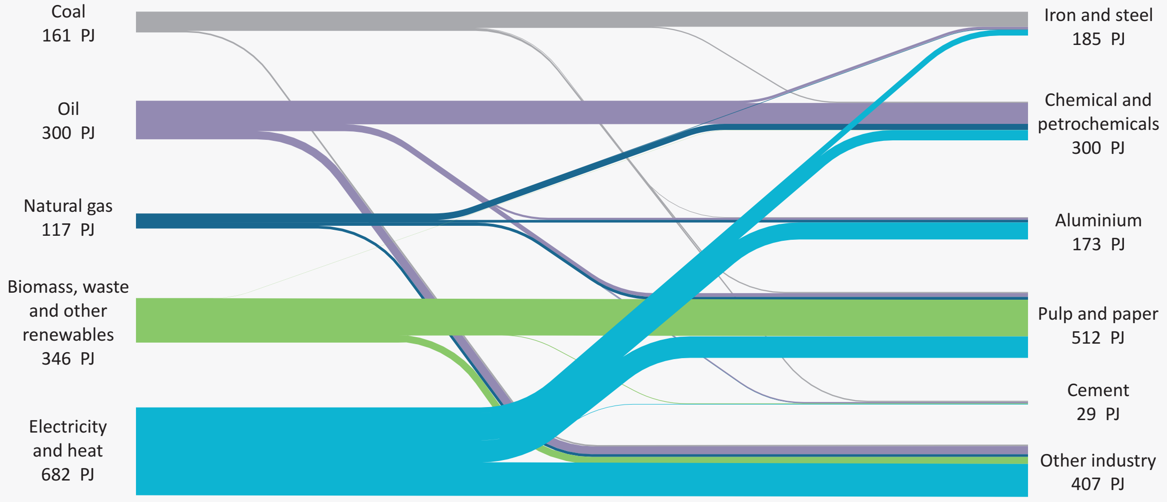
The Nordic economies have long been largely dependent on energy-intensive industries, such as pulp and paper production, iron and steel, chemicals and petrochemicals, aluminium, and cement. In recent years, Nordic industry has undergone some structural changes as the emerging economies in Asia and South America have increased their own production of industrial goods, thus changing global industrial markets. Nordic countries benefit from rich natural mineral and forest resources and have the possibility to produce low-cost and carbon-free energy, which would increase the competitiveness of energy-intensive industries in a future carbon-constrained economy.

For the purposes of this study, industry comprises manufacturing, construction and mining. Total final energy demand of the Nordic industrial sector was 1 606 petajoules (PJ) in 2010, which represented 35% of total final energy use in the Nordic countries. Approximately 70% of Nordic industrial energy was consumed in Sweden (612 PJ) and Finland (518 PJ) in 2010, which produce pulp and paper as well steel, iron and other metals. In Iceland and Norway, the aluminium industry is a major consumer of energy and is responsible for over 60% of greenhouse-gas emissions from the Icelandic industrial sector. Nordic countries also produce cement, petrochemicals and chemicals, which also consume large quantities of energy and are thereby responsible for significant CO_2 emissions in the region.

Fossil fuel use in Nordic industry is already low, representing about 36% of the total energy used in industry (Figure 4.1). Nordic industry, therefore, accounts for only about 20% of total CO_2 emissions. The largest Nordic industry sector, pulp and paper, mainly uses biomass for energy production, *i.e.* wood side products (such as bark, branches and chips) and spent liquors (black liquor). Aluminium production requires electricity, which is largely produced from renewable energy sources in both Iceland and Norway. Part of electricity and heat is, however, produced from fossil-fuel sources, which should be kept in mind when analysing the greenhouse-gas balance of the whole energy system. Globally, industrial energy use comprises 70% of fossil fuels. In the Nordic region, the majority of oil used in industry is used in the petrochemical sector, while coal is mainly used in the iron and steel industries (Figure 4.1). Both industries are large emitters of CO_2 in the region.

The analysis included in this chapter centres on the five major energy-intensive industrial sectors, which are also responsible for the highest quantities of industrial CO_2 emissions: iron and steel, chemicals and petrochemicals, aluminium, pulp and paper, and cement. In 2010, the energy consumption of “other industry” sector was 25%, but due to the low share of fossil-fuel consumption, its impact on the region’s greenhouse-gas emissions is low and therefore the focus has been placed on the five major industrial CO_2 emitters.

Figure 4.1 Energy flows in Nordic industry, 2010



Source: Unless otherwise noted, all tables and figures in this report derive from IEA data and analysis.
Notes: Includes energy use as petrochemical feedstock and energy use in coke ovens and blast furnaces. "Other industry" includes non-ferrous metals (excluding aluminium), non-metallic minerals (excluding cement), transport equipment, machinery, mining and quarrying, food and tobacco, printing, wood and wood products, construction, and textile and leather. Figures and data that appear in this report can be downloaded from www.iea.org/etp/nordic

Key point *The share of fossil fuels is less than 40% of total energy used by Nordic industry, while globally, fossil fuels account for more than 70% of industrial energy use.*

Nordic industry, particularly in Finland and Iceland, is significantly more energy intensive than the OECD average because of a high share of pulp and paper as well as iron and steel industries in Finland, and aluminium industry in Iceland (Figure 4.2). Only in Denmark is the energy intensity far below the OECD average. Industrial energy intensity in Denmark, Norway and Sweden has gradually decreased since the 1970s as energy efficiency has improved. In Finland, the energy intensity started to decline in the 1990s. In Iceland, however, the trend has been very different: energy intensity has been increasing since the 1990s due to structural shifts in the economy towards energy-intensive industries, and now most recently due to economic turmoil affecting the banking sector. In addition, Iceland has increased its aluminium production, which has, in turn, increased its industrial energy consumption. The impact of the financial crisis in 2008 is shown in the figure as a slight increase in energy intensity due to a decrease in gross domestic product (GDP), which was partly caused by a decrease in exports. The increase is, however, insignificant in Denmark, Finland, Norway and Sweden because production of industrial products decreased and a number of the most outdated, inefficient industrial facilities closed permanently. Even though energy intensity is high, energy efficiency of the region's industry is also high compared with the OECD average. In Finland and Sweden this is largely due to a high share of industrial co-generation.[2] In Iceland and Norway, the energy efficiency of the aluminium industry is among the best in the world.

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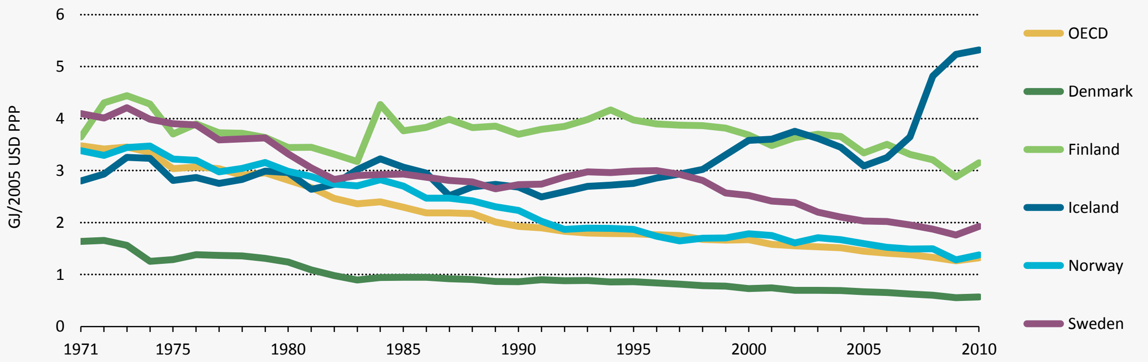
[2] Co-generation refers to the combined production of heat and power.

Figure 4.2 Evolution of aggregate industrial energy intensity



Notes: GJ = gigajoules, PPP = purchasing power parity.
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.

Key point *Nordic economies, especially Finland and Iceland, are largely dependent on energy-intensive industries, which results in high energy intensity compared with the OECD average.*

Saving energy and reducing CO_2 emissions with BATs

Significant savings in energy use and reductions in CO_2 emissions in industry are possible if the best available technologies (BATs) are used. Table 4.1 shows the results for the five most energy intensive sectors in the Nordic region specifically analysed in this section. In summary, it is estimated that using BATs could reduce final energy use by between 8% and 27% in different sectors in the Nordic region. Total estimated savings for the five sectors analysed amount to 172 PJ per year, which is equivalent to 11% of industrial energy use in 2010 and 3.7% of total Nordic energy consumption in the same year. Potential direct CO_2 savings vary from 2% to 38%, a total equivalent to 8.1 million tonnes of CO_2 ($MtCO_2$), which amounts to a reduction of 18% of total CO_2 emissions from industry and 4% of total energy related Nordic emissions in 2010. In the 2DS and CNS, some improvements in BATs are assumed from the existing level shown in Table 4.1.

In the cement industry, most of the energy savings (approximately 60%) can be achieved by improving the thermal energy efficiency of kilns.[3] For example, energy efficiency can be improved by using waste heat for the drying of raw material and energy production. CO_2 emissions from cement production can also be reduced by substituting the clinker[4] in the clinker-to-cement ratio with materials such as blast furnace slag, fly ash, natural pozzolans[5] or limestone. The increase of clinker substitute is an important option, particularly in Sweden.

For iron and steel, almost 65% of the savings could be achieved by making blast furnaces more efficient. Improving efficiency in producing and using heat needed in the iron and steel process, and increasing energy recovery in the chemicals sector, would account for more than 55% of savings.

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[3] Expressed as dissipated energy related to energy input for cement clinker manufacturing.

[4] Clinker is lumps or nodules, usually 3–25 mm in diameter, produced by sintering limestone and alumino-silicate (clay) during the cement kiln stage.

[5] A pozzolan is a siliceous or siliceous and aluminous material that will react chemically with calcium hydroxide in the presence of water to form compounds possessing cementitious properties.

For pulp and paper, the efficient use of electricity and increased use of recycled paper also account for 60% of savings.

Such savings cannot be achieved immediately. The rate at which current BATs are implemented in practice depends on various factors including capital stock turnover, relative energy costs, availability of raw materials, rates of return on investment, and regulation.

Table 4.1 Estimated potential savings from adoption of BATs in Nordic industry

	Energy savings potential (PJ/year)	Share of 2010 industrial energy use	CO_2 savings potential ($MtCO_2$/year)	Share of 2010 industrial emissions
Cement	7.9	27%	2.1	38%
Iron and steel	27.1	15%	3.4	22%
Chemicals and petrochemicals	69.1	23%	2.2	53%
Pulp and paper	54.8	11%	0.1	2%
Aluminium	13.5	8%	0.3	11%
Total	172.4	11%	8.1	18%

Notes: Savings for the chemicals and petrochemicals sectors are based on the average product mix of OECD Europe countries. The data are based on the IEA analysis, which is reviewed by industry partners.

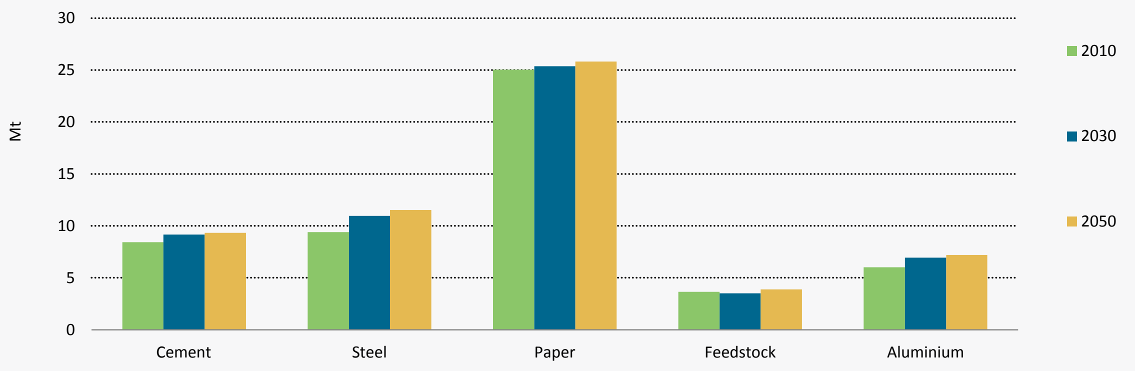
Applying BAT is not the only means to reduce CO_2 emissions in industry. All five industries produce energy-related CO_2 emissions but some industries, such as the aluminium and steel industries, use carbon as a reductant in the production process and therefore produce "process emissions". Industrial CO_2 emissions could be reduced by improving energy efficiency, switching to biomass or electricity instead of fossil fuels, and eliminating the use of carbon in production processes to cut process-related CO_2 emissions. For example, electric arc furnaces are a common method of reprocessing scrap metal to create new steel but they use a lot of electricity. CO_2 emissions could be reduced if the process was less dependent on fossil fuels, such as coal and coke. The aluminium industry is looking for carbon-neutral electrodes to radically decrease CO_2 emissions.

Scenario assumptions

An important assumption in the scenario analysis is that the industrial sector in the Nordic region will remain relatively stable. Long-term scenario assessments for the industrial sector can often be challenging because of possible changes in industrial structures and production volumes. The introduction of new products can also add to the challenge as they often require different processes and balance of energy compared with existing ones. In the technology spotlights, presented at the end of this chapter, an example of the renewal of the pulp and paper industry reveals its impact on Nordic energy systems. The pulp and paper industry has recently undergone structural changes as some of the region's production has moved to Latin America and Asia.

For the purposes of this study, the scenarios are based on assumptions about the future materials production. Given the maturity of the Nordic economy, production volumes are primarily expected to be driven by population growth and, to a lesser extent, by GDP development, resulting in moderate increases (Figure 4.3). In addition, assumptions on production volumes were justified according to country-specific information on the future industrial structure. Despite the different processes and raw materials used, the various scenarios all assume the same level of production to ensure that accurate comparisons can be made across scenarios. For example, the 2DS and the CNS both assume that a higher share of recycled materials will be used in all industries studied.

Figure 4.3 Materials production in the Nordic countries



Notes: Feedstock = chemicals and petrochemicals feedstock. Aluminium includes the production of aluminium that is not transferable in final product, but reused by the industry as "new scrap".

Key point *Given the economic and industrial maturity of Nordic countries, a very moderate increase in production volumes is expected.*

Developments in the 4DS reflect a future scenario that includes climate policies that governments have pledged to implement worldwide. According to current national policies, the use of biomass and alternative energy sources increases largely due to the European Union's 2020 energy and climate policies (Chapter 2). All of the energy-intensive industries in the Nordic region, except those in Iceland, are included in the EU Emissions Trading Scheme (ETS) meaning that industries need to either reduce their CO_2 emissions or buy the emissions allowance from the EU market. Until now, industries have received a large share of the required emissions allowances for free but the share of free allowances decreases by 2020. The cap for the EU ETS as a whole decreases by 21% in the period 2013-20.

In the 2DS, the global CO_2 emissions are halved in 2050 compared with existing emissions levels. According to *Energy Technology Perspectives 2012* (*ETP 2012*), global industrial emissions would be approximately 20% lower than current levels. This reflects that, on average, deep emissions reductions in industry are more challenging and costly than reducing CO_2 emissions in other sectors covered in this analysis, except for the transport sector. It also highlights the limitations of the industry to switch to using electricity in industrial processes. For example, there are currently no options to introduce electrification in the cement-sector, and such options for blast furnaces are still decades away. Biomass is hardly used in the region's industrial sectors except in the pulp and paper industry due to limitations on the amount of low-cost biomass resources needed. Nordic industry should also increase its share of recycled materials (*e.g.* steel, aluminium, plastics) to reduce the emissions of industrial production. However, the slight increase in material consumption in the region means that the availability of waste material is not expected to increase dramatically and, as such, recycled materials would need to be imported. In the scenarios, the amount of recycled materials available and used are model inputs.

In the more ambitious CNS, total Nordic CO_2 emissions are reduced by 85% compared with 1990. For industry, this scenario requires that new technologies will be available earlier than expected in either 4DS or the 2DS, and further improvement will be achieved by using BATs (Table 4.2). The CNS sets out very ambitious goals for reducing emissions in the industry and assumes a shift to carbon-neutral sources of energy for the different processes where this option exists.

Table 4.2 Status of technology and key indicators for the industrial sector under the different scenarios

Sector	4DS status in 2050	2DS status in 2050	CNS status in 2050
Cement	New kilns built in 2050 perform at 3.0 GJ/t clinker and 95 kWh/t cement (3.7 GJ/t clinker and 122 kWh/t cement in 2010). Alternative fuels reach 20% (17% in 2010) and clinker-to-cement ratio declines to 0.77 (0.81 in 2010). CCS is installed in 6% of plants by 2050.	Alternative fuel use represents 38% of total energy consumption and clinker-to-cement ratio declines to 0.75. CCS is installed in 35% of plants by 2050.	New kilns built in 2050 perform at 2.5 GJ/t clinker. Alternative fuels reach about 50% and clinker-to-cement ratio declines to 0.66. CCS is installed in about 50% of plants by 2050.
Iron and steel	Average intensity of crude steel production is 21.3 GJ/t crude steel (19.71 GJ/t in 2010). Electric arc furnaces account for 58% of production by 2050 (51% in 2010). CCS is equipped in less than 15% of the plants by 2050.	Average intensity of crude steel production decreases to 15.8 GJ/t crude steel. CCS is equipped in about 30% of the plants by 2050. Electrolysis and hydrogen reach only marginal levels by 2050.	Smelting reduction to account for about 15% of production by 2050. Average intensity reaches 11.1 GJ/t in 2050. CCS is equipped in over 30% of the plants by 2050. Electrolysis and hydrogen reach only marginal levels by 2050.
Chemicals and petrochemicals	Catalysis and process intensification reduces energy intensity by 7%. CCS deployed in 25% of ammonia plants and over 15% of ethylene plants.	Catalysis and process intensification reduces energy intensity by about 10% and facilitates the use of bio-based feedstock, which reaches 6% of total feedstock use. Energy recovery helps prevent about 10% of CO_2 emissions in 2050. CCS deployed in 50% of ammonia plants and over 30% of ethylene plants.	No major differences between the 2DS and the CNS.
Pulp and paper	Improvement of BAT by 10% from current levels. Biomass accounts for 55% of total energy consumption (same level as in 2010, despite increase in production). Average energy intensity reaches 18.7 GJ/t paper and paperboard (20.4 Gt in 2010). CCS deployed in 3% of chemical pulp plants.	Biomass accounts for 60% of total energy consumption. Average energy intensity reaches 17.1 GJ/t paper and paperboard and emissions intensity reaches 1.5 $MtCO_2$/t paper and board. CCS deployed in 10% of chemical pulp plants.	No major differences between the 2DS and the CNS.
Aluminium	Electricity intensity of primary aluminium production decreases to 12 617 kWh/t aluminium (15 027 kWh/t in 2010).	Electricity intensity of primary aluminium production decreases to 11 674 kWh/t aluminium.	Electricity intensity of primary aluminium production decreases to 11 276 kWh/t aluminium.

Notes: GJ/t = gigajoules per tonne. kWh/t = kilowatt hour per tonne.

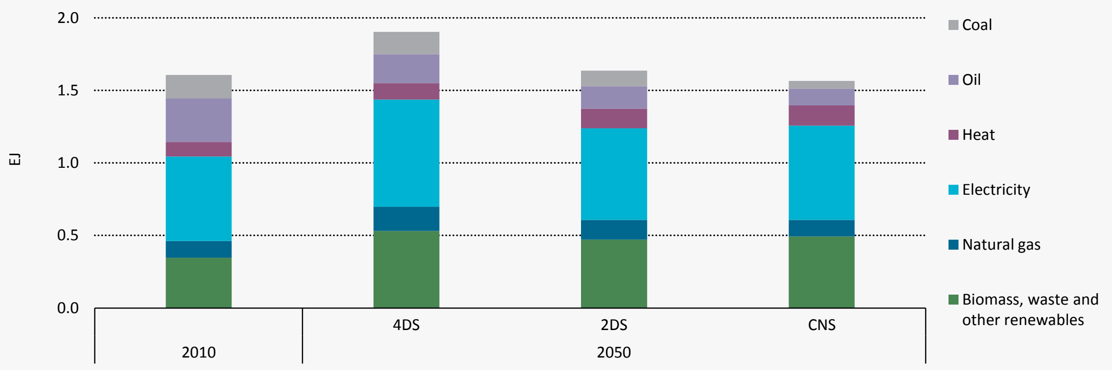
Scenario results for industrial energy use

The increase in production of materials, most noticeably of crude steel and cement, will drive the 20% increase in energy use in Nordic industry between 2010 and 2050 in 4DS. However, the share of fossil fuels used decreases from 36% in 2010 to 27% in 2050, which is driven by improving energy efficiency in industrial processes, as well as increasing the use of alternative fuels in the cement industry and by increasing the use of biomass in the pulp and paper industry (Table 4.2)

By contrast, in the 2DS the industrial energy demand peaks before 2020 and declines close to 2010 levels by 2050 (Figure 4.4). Less than one-quarter of industrial energy demand is met by fossil fuels in the 2DS. Further use of recycled materials, quicker turnover of equipment, and the adoption of BATs for all new and refurbished plants explain, in part, this decrease in energy consumption. In 2050, the energy consumption is nearly 15% lower in the 2DS than in the 4DS.

In the CNS, energy consumption is further reduced and reaches 1 600 PJ in 2050, which is a reduction of 18% compared with the 4DS. The use of fossil fuels is substantially reduced and accounts for only 17% of total industrial energy consumption in 2050.

Figure 4.4 Final energy consumption, by industry



Key point *The share of fossil fuel use in Nordic industry decreases in all scenarios and reaches 17% in CNS in 2050.*

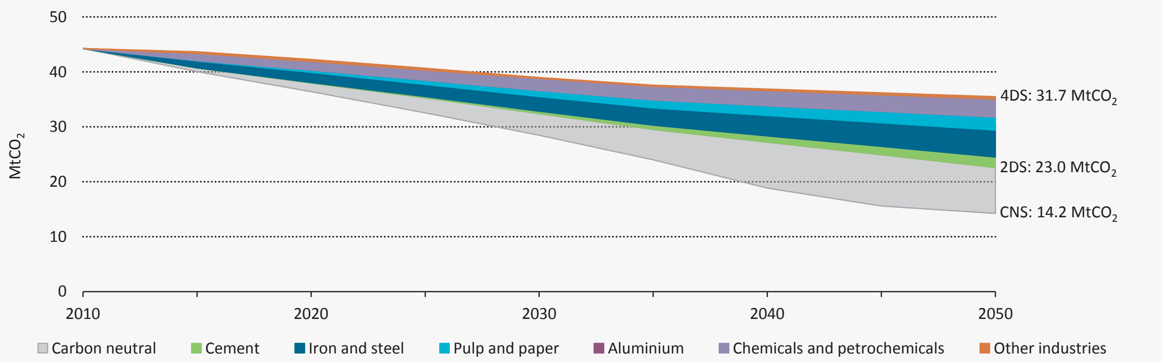
Scenario results for industrial CO_2 emissions

Direct CO_2 emissions reveal a downward trend compared with the existing levels in all scenarios analysed (Figure 4.5). A significant reduction in CO_2 emissions in industry by 2050 compared with 2010 emissions levels can be achieved only if all industries reduce emissions by improving efficiency in processes; investing in new production technologies (*e.g.* smelting reduction in the iron and steel industry or black liquor gasification in the pulp and paper industry); switching fuels; implementing CCS; and using more recycled and waste materials.

In the 4DS, the CO_2 emissions are reduced by approximately 10 $MtCO_2$ by 2050 compared with 2010 levels. In the 2DS, reductions amount to 22 $MtCO_2$ (49% lower than 2010) and in the CNS reductions reach 30 $MtCO_2$ (68% lower than 2010) (Figure 4.5). Between 20% and 30% of reductions will be achieved by using CCS in the iron and steel, pulp and paper, chemicals, and cement sectors. Further reductions could be achieved by improving efficiency in processes; investing in new production technologies; fuel switching; and using more recycled and waste materials. This scenario assumes that the chemicals industry will move towards bio-based raw materials. From the technical point of view, almost all industrial materials (*e.g.* plastics, composites and organic chemicals) made from fossil fuels could be derived from biomass.

Achieving the targets for reducing emissions in the 2DS and CNS requires that all industries in the region reduce emissions and that all the necessary technological options will be available. Particular challenges face industry in the CNS. It is assumed that several new technologies will be commercially available and feasible earlier in CNS than expected in the 2DS (Table 4.2). On the other hand, near-term actions for RD&D of these technologies is required.

Figure 4.5 Direct CO_2 emissions reduction in the 4DS, 2DS and CNS scenarios, by industry



Notes: Aluminium includes combustion-related emissions only. Other industries include non-ferrous metals (excluding aluminium), non-metallic minerals (excluding cement), transport equipment, machinery, mining and quarrying, food and tobacco, printing, wood and wood products, construction, and textile and leather.

Key point *A 50% to 70% reduction in CO_2 emissions could be achieved by 2050 compared with current levels.*

Investment needed to decarbonise Nordic industry

In the 2DS, investment needed by 2050 is estimated to be between USD 30 billion and USD 36 billion higher than in the 4DS. Most of that investment will be needed in the pulp and paper industry as the scenario assumes the complete integration of chemical pulp and paper production in the 2DS and CNS (Table 4.3). Investment in new technologies would yield significant savings in fossil-fuel consumption but would lead to increased costs for biofuel and feedstock. Many of the energy efficiency investments are already competitive based on life cycle, meaning that energy savings over the assumed life cycle of an industrial plant can offset the investment costs to improve energy efficiency.

Table 4.3 Additional investment required by industry between 2010 and 2050 (USD billion)

	Investment required		
	4DS	2DS	CNS
Cement	1.3 to 1.6	2.6 to 2.8	2.4 to 2.9
Iron and steel	5.3 to 5.8	5.6 to 6.3	6.9 to 7.5
Chemicals and petrochemicals	17 to 18	18 to 19	18 to 19
Pulp and paper	45 to 56	71 to 89	71 to 89
Aluminium	15 to 17	17 to 18	17 to 19
Total	83 to 98	113 to 135	115 to 137

Notes: The investment analysis covers only major energy-consuming equipment and devices. The relative increase or decrease in required investment among the different scenarios is therefore less uncertain than the overall level of required investment.

Key point *The pulp and paper industry requires the most investment.*

Technology spotlights

Renewal of Nordic pulp and paper industry with new products

The 4DS and 2DS assume that there is a stable industrial structure in which industries produce about the same type of products as today. This technology spotlight highlights the impact that structural changes in the pulp and paper industry could have on Nordic energy systems.

The pulp and paper industry is the largest consumer of the Nordic region's industrial energy in the 4DS, 2DS and CNS until 2050. This sector is also where the most investment is needed in both the 4DS and the 2DS. The scenarios for the case study have been run with the TIMES-VTT model[6] and the data behind the scenarios have been modified using the study by the VTT Technical Research Centre of Finland titled "Low Carbon Finland 2050" (Koljonen, T., et al., 2012).

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[6] TIMES-VTT model is a global energy system model based on the TIMES energy system modeling framework (The Integrated MARKAL-EFOM System) developed under the IEA Energy Technology Systems Analysis Programme (ETSAP), and the global ETSAP-TIAM model (The TIMES Integrated Assessment Model). TIMES-VTT includes a detailed description of the Nordic energy system, excluding Iceland. As is the case in energy system modelling, the economic structure is assumed to be constant throughout the scenario period.

This case study considers three different scenarios: Baseline (comparable with the 4DS), Tonni (comparable with the 2DS) and Inno (comparable with the CNS). In the Baseline and Tonni scenarios, the production mix and volumes of pulp and paper products are similar to those in 4DS and 2DS. The Inno Scenario foresees new innovative pulp and paper products and lower production volumes. In addition, this scenario assumes that there is increased investment in bio-refinery concepts to produce biodiesel for transport. In this example, special focus has been placed on biodiesel because decarbonising heavy road and air transport would require biodiesel. For light road transport, there are more options to be considered, such as bio-ethanol, electric and fuel cell vehicles, etc. (Chapter 5).

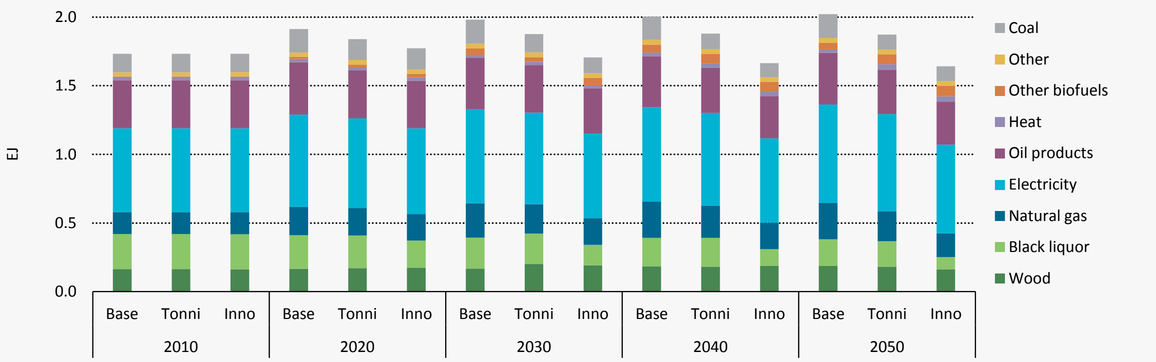
Globalisation has proved a particular challenge for the Nordic pulp and paper industry, which tends to move the production of bulk products closer to end-users in Asia and South America. In these regions, cheaper raw materials are also usually available for pulp and paper production. On the other hand, the pulp and paper industry is the largest producer of bioenergy in the Nordic region, and significant opportunities exist to increase the synergies between the pulp and paper industry and the energy industry. In fact, this is already happening as the pulp and paper industry is steering its strategies more towards energy business. Currently, the focus of RD&D in biofuel production is on developing and demonstrating production technologies for so-called “second-generation” or “advanced” biofuels. For example, the integration of biofuel production in pulp and paper mills is typical of some of the new concepts currently under development.

This case study includes some hypothetical assumptions for the production of new, high-value pulp and paper products, as well as deployment of advanced (*i.e.* second-generation) biofuel plants that are integrated in pulp and paper mills in Finland and Sweden. In addition, it assumes that with added value of products the industrial energy intensity is reduced, as the same income could be achieved with much lower production volumes and energy consumption. Unlike in the 2DS and CNS, the assumed production of pulp and paper materials gradually decreases throughout the whole scenario period so that by 2050, Finland and Sweden produce 50% less pulp and paper materials than today.

In the Inno Scenario, the final energy use is about 10% lower than in the Tonni Scenario (Figure 4.6) but the co-generation is reduced by nearly 20% (Figure 4.7). The assumed new products in the pulp and paper industry consume more electricity per product tonne and, therefore, the Nordic energy balance is not affected to any great extent. In the Inno Scenario heat demand decreases with the assumed product portfolio, which results in lower co-generation potential. According to Inno Scenario results, however, fuels used for co-generation are 100% renewable.

The Inno Scenario results indicate that significant opportunities exist to fully decarbonise the pulp and paper sector by introducing electrification and increasing the use of biomass in industrial co-generation. At the same time, the value added of new products could enhance the competitiveness of the region’s pulp and paper industry.

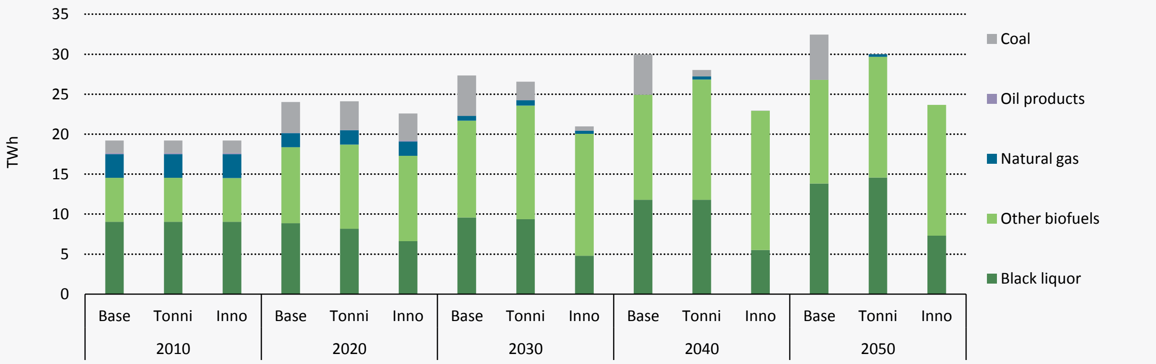
Figure 4.6 Industrial final energy use in the Baseline, Tonni and Inno scenarios



Notes: Includes all Nordic industries in Denmark, Finland, Norway and Sweden and also Nordic oil refining. "Other biofuel" includes liquid and gaseous biofuels.
Source: VTT Scenario calculations with the TIMES-VTT model.

Key point *Production of new higher-value products may result in higher energy consumption per product tonne.*

Figure 4.7 Industrial co-generation in the Baseline, Tonni and Inno scenarios



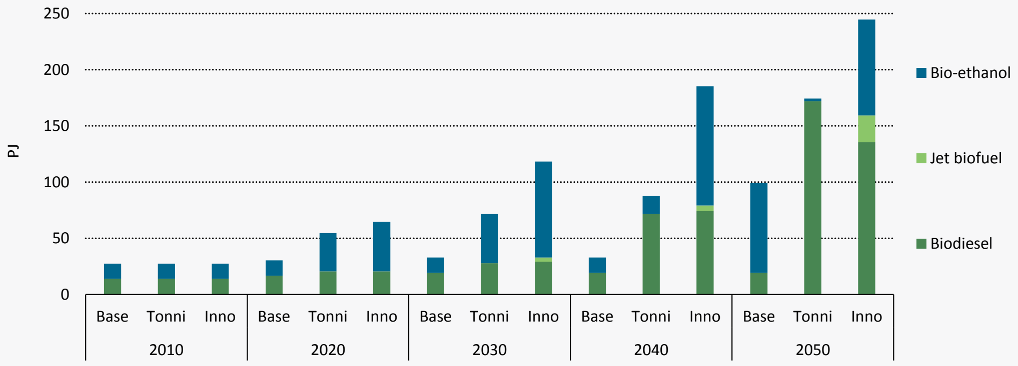
Note: Includes all Nordic industries in Denmark, Finland, Norway and Sweden and also Nordic oil refining.
Source: VTT Scenario calculations with the TIMES-VTT model.

Key point *Transformation of industrial co-generation to 100% biofuels can be achieved if RD&D in the forestry sector is accelerated.*

Scenario results indicate that biofuel production will increase in all scenarios but in this case there is a huge difference between the Tonni and Inno scenarios due to accelerated RD&D in the Inno Scenario. In addition to biodiesel production from wood raw materials, there is also a remarkable bio-ethanol production especially in the Inno Scenario. Here, bio-ethanol is mainly produced from indigenous agro-biomasses and bio-wastes. Especially in Denmark and Sweden, there is noticeable potential to produce bio-ethanol from agricultural side products, side streams and bio-wastes, from the food-processing industry, agriculture and municipal waste. It should be noted that, especially for agro-biomasses, great uncertainty exists as to the potential sustainability in the long term. For example, in the Nordic countries, the largest field crop residue potential is in Denmark. A major constraint in adopting usage of straw material for bioenergy is the maintenance and productivity of organic soil matter. In addition, production of field biomass for non-food purposes should not have a negative impact on the development of food production for the increasing global population.

The Inno Scenario reveals the huge potential in Nordic biofuel production but also highlights the extensive investment in technology that would be required. However, even in the Inno Scenario, about 60% of Nordic biofuel demand in transportation is covered by domestic sources in all the scenarios and throughout the whole period studied in 2050. The high share of biodiesel in the Tonni Scenario is explained by the higher demand for low-carbon fuels for heavy road transport than in the Inno Scenario, and on the other hand, the lower competitiveness of advanced (*i.e.* second generation) bio-ethanol concepts.

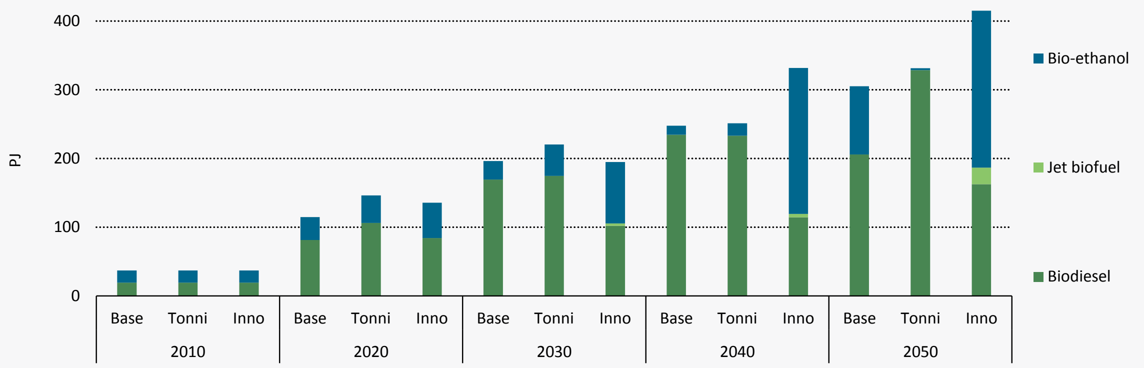
Figure 4.8 Biofuel production in the Baseline, Tonni and Inno scenarios



Notes: Includes all Nordic industries in Denmark, Finland, Norway and Sweden and also Nordic oil refining. “Other biofuel” includes liquid and gaseous biofuels.
Source: VTT Scenario calculations with the TIMES-VTT model.

Key point *The potential of Nordic biofuel production is significant but extensive investment in technology would be required for deployment.*

Figure 4.9 Biofuel consumption in transport in the Baseline, Tonni and Inno scenarios



Note: Includes biofuel consumption in Denmark, Finland, Norway and Sweden.
Source: VTT Scenario calculations with the TIMES-VTT model.

Key point *Even with increased investment in technology in Nordic biofuel production, about 40% of biofuel would still need to be imported.*

The role of CCS in reducing industrial CO_2 emissions

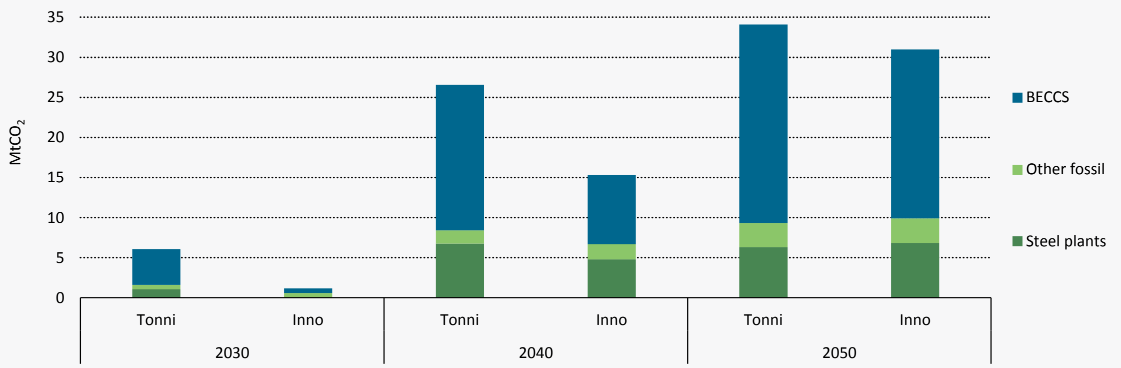
In the 2DS and CNS scenarios, between 20% and 30% of the reduction in industrial CO_2 is achieved by using CCS in the iron and steel, pulp and paper, chemicals, and cement sectors by 2050. In the 2DS, some 7 MtCO_2 is captured by Nordic industry by 2050. In the CNS, the captured volumes are lower (6 MtCO_2), which may be surprising at first glance. However, the CNS assumes greater electrification and use of biomass to reduce industrial CO_2 emissions compared with the 2DS. Carbon capture and storage also plays a less significant role, thus indicating that it could be particularly important in industries that are not radically decarbonised by electrification or by increased use of recycled materials and renewables.

In the 2DS and CNS, most of the investment in industrial CCS is concentrated in Sweden and Finland, which are the biggest producers of iron and steel as well as pulp and paper in the Nordic region. However, neither Finland nor Sweden has suitable storage sites for CO_2, which means that captured CO_2 must be transported by tankers or by offshore pipelines to the North Sea or to some other storage site. In Finland, CO_2 is already captured in hydrogen production from natural gas by steam reforming, in which hydrogen is produced for oil refining processes. Since the flue gas is relatively pure CO_2,capture is less costly in this case than in most other processes. In addition, the pulp and paper industry captures CO_2 from flue gases to produce precipitated calcium carbonate, which is used as a filling agent in paper production. Food (*e.g.* the beverage industry) and chemical industries (*e.g.* the calcium chloride industry) also already use CO_2 capture. In these examples, CO_2 is either used directly as a feedstock on site or used as a process gas in other industries. In these cases CO_2 is released back into the atmosphere after a short lead time and, therefore, it doesn't have an impact on greenhouse-gas mitigation. The above examples indicate, however, that capturing CO_2 is already a mature technology in the Nordic region and, therefore, the challenge would be in transporting and storing CO_2 underground. An interesting option for Nordic countries is bioenergy with CCS (BECCS), which could be implemented in the pulp and paper industry and in biodiesel production using the

Fischer-Tropsch synthesis (*i.e.* second-generation biodiesel production).[7] Assuming that the calculation takes into account the existing rules by the United Nations Framework Convention on Climate Change (UNFCCC) for calculating greenhouse-gas emissions, the net CO_2 emissions with BECCS are negative. Usually biomass is used for energy production at relatively small scale, but the pulp and paper industry produces large quantities of CO_2 that benefit from the economy of scale. In other words, the cost of one tonne of captured and stored CO_2 is lower the larger the CO_2 capture plant and CO_2 infrastructure is. In biodiesel production, the gaseous emission is nearly pure CO_2 and therefore there is no need to invest in a costly and energy-intensive capture process. The amount of captured CO_2 in the Nordic region in both the Tonni and Inno scenarios is significant largely because of BECCS.

Both the Tonni and Inno scenarios represent a more optimistic view on CCS compared with the *NETP* scenarios (Figure 4.10). The difference is largely due to BECCS, which is mainly applied in biodiesel plants in this example. Instead, CCS integrated into steel plants and other fossil-fuel-based industrial CO_2 emissions is well in line with the *NETP* scenarios. Even in the most optimistic case for example, in the Inno Scenario, the fossil-fuel-based industrial CCS is only 3 $MtCO_2$ higher in 2050 than indicated in the *NETP* 2DS.

Figure 4.10 Industrial CCS in the Nordic countries in the Tonni and Inno scenarios



Notes: Tg = teragrams = 1012 g = 106 tonnes. Includes CCS in Denmark, Finland, Norway and Sweden.
Source: VTT Scenario calculations with the TIMES-VTT model. Includes CCS in Denmark, Finland, Norway and Sweden.

Key point *BECCS and CCS in steel plants could become particularly important in mitigation scenarios in which industries produce basic products.*

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[7] Fischer-Tropsch synthesis is a widely used industrial application to produce syngas from fossil fuels and biomass. Syngas can be used to produce power or can be converted into lower alcohols, diesel and other chemical products.

Critical challenges

The Nordic economies are largely dependent on energy-intensive industries that would face significant challenges if the region, along with other European countries, implemented strong mitigation policies such as those outlined in the 2DS and CNS. Some industries, such as the aluminium industry, also produce process-related emissions that cannot be reduced without radically changing the production processes. The competitiveness of Nordic energy-intensive industries is also dependent on the energy prices, which tend to increase with more ambitious climate policies. However, long term competitiveness also hinges on how other regions develop. In a global low carbon scenario Nordic industry can have comparative advantages due to their relatively efficient processes.

To achieve significant reductions in CO_2 emissions in Nordic industry by 2050, all the industrial sectors need to contribute and all the emissions reduction measures should be utilised. More RD&D in technology would be essential as well as intelligent national energy and climate policies that take account of local circumstances, such as the availability of raw and recycled materials or the possibility to produce carbon-free energy for industrial energy use.

The scenario results indicate that, despite the Nordic region's relatively high level of energy efficiency (particularly in *e.g.* the pulp and paper and steel industries due to high share of co-generation) compared with other OECD countries, there is significant potential for improving energy efficiency in industrial processes still further. The high efficiency is largely due to industrial co-generation, which is exceptionally high in Finland and Sweden. The potential for co-generation could be reduced in the future due to the electrification of the industrial processes and decreased production volumes of industrial products.

Energy-intensive industries are currently included in the EU ETS, which would steer investment if the CO_2 price level were high enough. Today, the low emissions-allowance price levels do not steer investment but in the 2DS, and especially in the CNS, the marginal costs of emissions abatement increases indicating high levels of CO_2 allowance prices by 2050. Nordic countries could also draft voluntary agreements among industries and authorities in which industrial operators commit to making certain improvements. In Finland, such voluntary agreements have already been implemented with positive results. However, in the case of deep emissions-reduction targets, such as in the 2DS and the CNS, early actions are needed to avoid lock-in in carbon-intensive industrial processes. In such cases, voluntary agreements might not result in the required level of emissions reduction within the necessary time frame.

The CNS assumes that new technologies will be available earlier than expected in the 4DS and 2DS, and that further improvement will be achieved by using BATs. The CNS would be especially challenging for the aluminium, cement, and iron and steel industries, which would require an overhaul of industrial processes. Also, greater implementation of CCS would be needed to achieve the required CO_2 emissions reduction. To prevent unsustainable high costs of reducing emissions, energy-intensive industries should have the opportunity to use flexible mechanisms, such as the Clean Development Mechanism defined in the UN Kyoto Protocol, to buy emissions allowances from the global emissions market.

The Nordic countries have significant potential to produce biodiesel and bio-ethanol from indigenous raw materials, but extensive investment in technology would be required for full deployment. The capital expenditures of the first plants are very high, and before full demonstration of second-generation biodiesel and bio-ethanol plants, the costs of biofuel production are too high compared with the market prices of mineral oil. Also, the market for biofuels is largely set by policies to increase the share of renewables in transportation. The European Union has defined its renewable policy until 2020, but it is not clear how the policy will develop after that. To overcome the risk of investing in the first biodiesel and bio-ethanol plants, more support for investment is needed as well as long-term energy and climate policies that would also ensure the demand for biofuels in the future.

In the long term, CCS seems to be the most important single technology to reduce industrial CO_2 emissions. It would become particularly important if future policies were to include BECCS as an option to reduce greenhouse gases. However, full-scale CCS deployment in the metal, pulp and paper, and cement industries requires demonstration projects and operation experience. On the other hand, industrial CCS including BECCS would become particularly important in 2DS for Sweden and Finland, two countries that do not have their own CO_2 storage sites. The possible legal barriers for transporting and storing CO_2 abroad should, therefore, be removed to encourage CCS investment in these countries. From the Nordic region, Norway is the one of the global leaders in RD&D of CCS and also has the greatest storage potential in Europe. Although there is significant capacity to store CO_2 underground in the North Sea, the greatest challenge seems to be in developing the infrastructure for transporting CO_2. Developing offshore pipeline infrastructure across country borders remains a challenge and requires intensive collaboration in the region.

In the 2DS, the required investment by 2050 is estimated to be between USD 30 billion and USD 36 billion higher than in the 4DS. The majority of this investment would be needed in the pulp and paper, chemicals, and aluminium industries. Much of the investment in energy efficiency is already competitive if we take into account cumulative undiscounted fuel savings throughout the life cycle of the plant. There is a need to facilitate investment through policies or voluntary agreements in order to encourage enough investment to make the necessary changes to industry in the near future.

Chapter 5

Transport

The transport sector contributes to more than one-third of energy-related carbon dioxide (CO_2) emissions in the Nordic countries. Enabling a reduced growth in travel demand, the electrification of passenger transport, a move to biofuels for long-haul and freight transport, and a higher share of rail transport for freight are the primary building blocks in a low-carbon Nordic transport system

Key findings

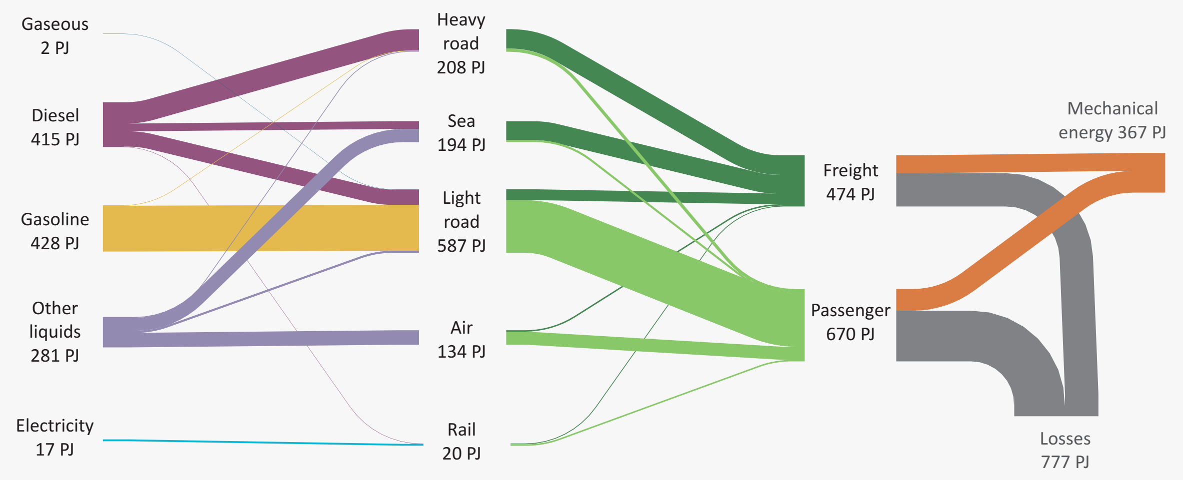
- ***The transport sector remains dependent on high-energy-dense liquid fuels such as gasoline, diesel and biofuels.*** *Certain modes of transport (e.g. long-haul road freight, aviation and shipping) require breakthroughs in technology before large-scale decarbonisation can be achieved.*
- ***Biofuels will play a significant role in the future transport sector*** *in all the Nordic countries. The share of biofuels of total fuels used for transport by 2050 varies from some 25% in the 2°C Scenario (2DS) to 70% in the Carbon-Neutral high Bioenergy Scenario (CNBS).*
- ***All Nordic countries have ambitious long-term targets to reduce CO_2 emissions from transport.*** *However, current policies and pathways to back up the long-term target are insufficient and need to be improved.*
- ***Internal combustion engine (ICE) vehicles*** *provide great potential to reduce fuel consumption by using cost-effective technologies. In the period from 2010 until 2050, the average fuel consumption for new cars is expected to decrease from 7 litres per 100 kilometres (L/100km) to 3 L/100km.*
- ***Electric cars play a key role in reducing CO_2 emissions and dependency on liquid fuels within individual passenger transport in the longer term.*** *To support this development, timely introduction is imperative. Beyond 2040, fuel-cell electric vehicles (FCEV) might offer some of the same advantages and even better options within long-haul transport.*
- ***Compressed natural gas (CNG) and biogas can reduce emissions in long-distance transport.*** *Sweden is currently testing biogas for transport; in the 2DS and in the Carbon-Neutral Scenario (CNS) variants, biogas and CNG cover up to 7% of total fuels used for transport.*
- ***Modal shift to bus and rail within passenger transport and rail within freight transport offers potential to increase transport efficiency*** *and provides some hedging against the uncertainty of when and how alternative technologies (such as electric and hydrogen-fuelled vehicles) will have a breakthrough.*
- ***Critical challenges to achieving long-term CO_2 emissions reduction*** *include enabling a lower future growth of transport demand, achieving technology breakthrough (economic competitiveness) of alternative technologies (such as electric vehicles), securing the sustainability of biofuels and ensuring the effectiveness of modal shifts.*

Recent trends

An effective transport infrastructure is essential to a modern society. The transport back and forth from work, leisure activities and holidays is a natural part of daily life. The Nordic countries are relatively rich, which enables travelling abroad and substantial international trade of food products and other commodities. The use of energy for transport in the Nordic countries is almost equally divided between passenger and freight transport (Figure 5.1); compared to a global average, the shares of international travel and freight transport are relatively high.

This chapter examines the historic development in activity and energy use for transport in the Nordic countries, then discusses transport policies in place and the future *Nordic Energy Technology Perspective* (*NETP*) scenarios.

Figure 5.1 Energy flows in the Nordic transport sector in 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 *The transport system in the Nordic countries relies mainly on fossil fuels. Shipping and aviation combined are responsible for 29% of the energy used for transport, while road transport accounts for 70%.*

The transport sector[1] was responsible for 36% of total energy-related CO_2 emissions in the Nordic countries in 2010. The corresponding figure in Sweden was 50% while the other countries showed somewhat lower shares: Iceland (44%), Norway (38%), Denmark (33%) and Finland (23%).

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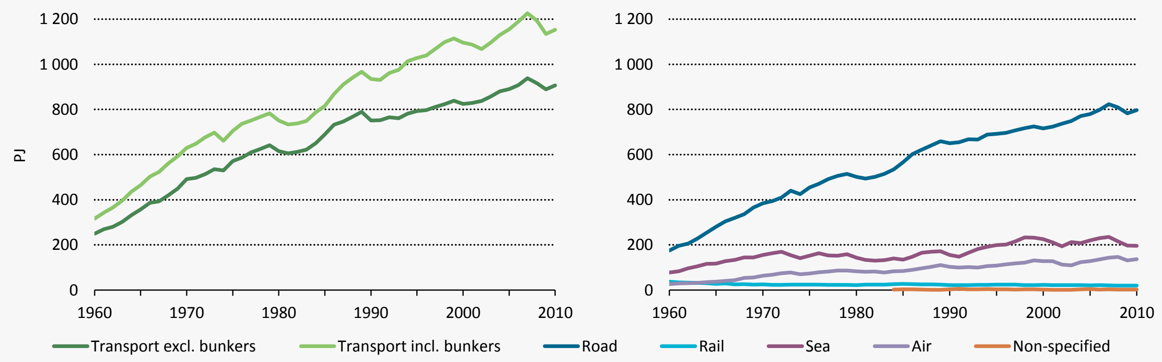
[1] In this context transport include all land transport, 50% of emissions from all international aviation and shipping departing or arriving at Nordic ports, but *not* fishery

Total energy use for transport in the Nordic countries has increased by 260% since 1960, an average yearly growth of 2.6% (Figure 5.2). Temporary declines in demand for transport energy coincide with the high oil prices of 1974, 1979, 1990 and 2001. In 2009, the financial crisis caused an additional dip in the use of energy for transport, especially in international transport.

The total amount of energy used for transport among the Nordic countries differs greatly due to population and export industries. Sweden, the country with the highest population, represented approximately 40% of the total energy use for transport in the region in 2010 (including international transport). Denmark, Finland and Norway each accounted for 20% of total energy consumption in transport while Iceland used the least amount at 1.5%.

Figure 5.2 Nordic transport energy consumption



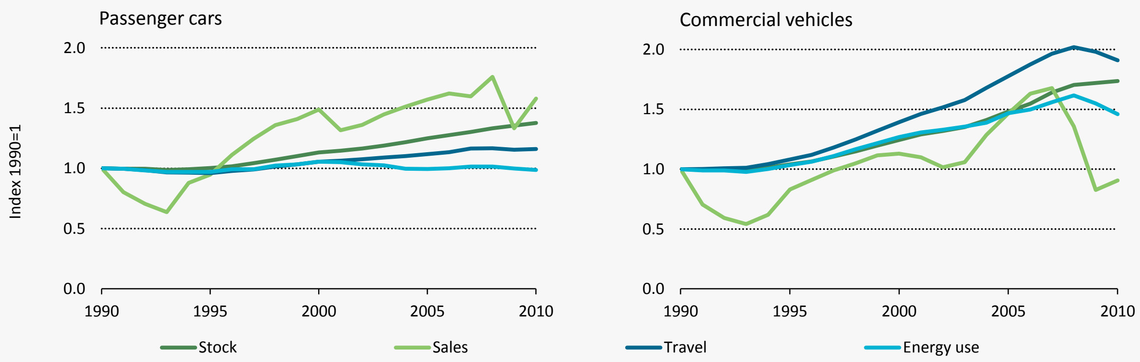
Notes: The graph to the left includes international aviation and shipping in the upper line. On the right graph, international aviation and shipping are included in the respective categories.

Key point *Energy use within the transport sector grew an average 2.6% per year from 1960 to 2010, but only around 1% for the past 20 years. Since the 1980s, road transport has accounted for around 70% of total energy use (up from 55% in 1960).*

Since 1960, the share of energy use for international aviation and shipping has increased from 15% to 25% of the total energy use for transport (Figure 5.2). This reflects the energy efficiency of shipping (marine transport), as it covers more than 50% of the freight transport as measured in tonne-kilometre (t-km).

Sales of passenger cars and commercial vehicles are sensitive to economic development. The decrease (in Sweden) in sales reflects the economic downturn in the early 1990s, in 2001 and again during the financial crisis of 2008 (Figure 5.3). Despite the steady increase in the stock of cars, since 2007 signs of saturation in the demand for transport (vehicle kilometres or v-km) by passenger cars are visible, as is a downward trend in sales of commercial vehicles.

Figure 5.3 Overview of stock, sales, travel and energy use for passenger cars and commercial vehicles



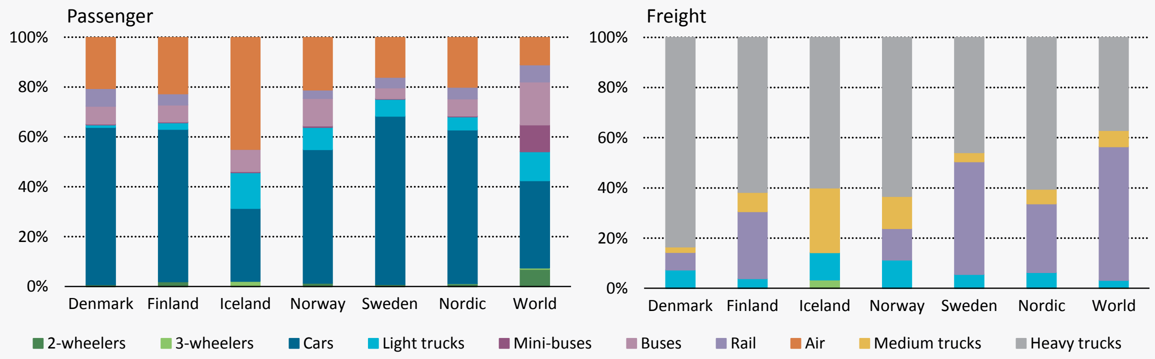
Key point *Vehicle sales fluctuate with economic circumstances, while trends in stock, travel (v-km) and energy use develop more smoothly.*

The share of the various modes of transport differs in the Nordic countries but cars remain the most popular mode of passenger transport in all countries except Iceland. Aviation is in second place (Figure 5.4). Iceland has no connecting roads to other parts of Europe and, thus, relies totally on shipping for international freight transport and aviation for international passenger transport. Iceland also has a high share of aviation due to its role as transit for international aviation (fuel use for all departing flights is counted as Icelandic). In the other Nordic countries, cars cover around 60% of the passenger transport; this is significantly higher than the global average of 40% but quite close to the OECD average.

Apart from shipping, trucks dominate freight transport in the Nordic countries. This is in contrast to the global average, in which rail transport plays a greater role. A rough estimate suggests that shipping accounts for about the same transport volume as all other means of freight transport combined.

In Denmark and Norway, around 90% of all freight transport is by truck; rail plays a major role in Sweden (55%) and Finland (25%) (when excluding shipping). On a global level, rail covers more than 50% of all land-based freight transport. As Iceland does not have a rail infrastructure, all land-based freight transport is by truck; as the distances are shorter, the volume of medium trucks and light commercial vehicles (LCV) is higher than in other Nordic countries (Figure 5.4).

Figure 5.4 Motorised passenger and tonne-km in 2010 by mode of transport



Notes: Shares are based on estimated total passenger- and tonne-kilometres. Shipping are not included in these graphs..

Key point *The share of passenger-kilometres travelled by car and plane in the Nordic countries is, on average, almost twice as high as the global average.*

Current policies and goals

The Nordic countries are characterised by ambitious long-term targets to reduce GHG emissions across all sectors including transport. As the most prominent example, the Swedish government aims to have a vehicle stock that is independent of fossil fuels by 2030. However, the government still needs to put into concrete terms what such a vehicle fleet actually entails. In Denmark, Norway and Sweden, the target is to reduce emissions across all sectors by 100% by 2050. In the case of Denmark, this target should be met by using only renewable energy. In Norway, this goal should be achieved by 2030 if an international climate agreement is reached.

The goals of these three Scandinavian countries imply that the transport sector should become independent of fossil-fuel consumption by 2050 at the latest. The goals of Iceland (50% to 70% emissions reduction) and Finland (80% emissions reduction) may still leave room for a substantial share of fossil fuels in the transport sector, depending on the how goals are distributed among the sectors.

In the short-term perspective towards 2020, all Nordic countries must comply with the EU target of 10% renewable energy in the transport sector. Iceland and Norway are subject to the same regulation as the Directive on the Promotion of the Use of Renewable Energy Sources has been incorporated into the European Economic Area (EEA) agreement. Finland and Sweden aim to surpass the minimum 10% EU target. Finland has set the biofuel distribution obligation as high as 20% in 2020 (Finnish Government, 2010). The Swedish government has set the share of renewable energy consumption in the transport sector at a minimum of 14% by 2020 (Swedish Government, 2010).

Table 5.1 Existing goals and policies related to the transport sector in each of the five Nordic countries

	Denmark	Finland	Iceland	Norway	Sweden
Goals					
Before 2020	10% RE	20% RE		10% RE	14% RE
Before 2030				-100% (if global climate agreement)	A vehicle stock that is independent of fossil fuels
Before 2050	Energy and transport: 100% RE	Energy and transport: -80% GHG	Energy and transport: -50 to -70% GHG	Energy and transport: 100% GHG	Energy and transport: -100% GHG (net)
Policies					
Energy fuel tax	Yes	Yes	Yes	Yes	Yes
Carbon fuel tax	Yes	Yes	Yes	Yes	Yes
"Green" ownership tax (annual)	Yes	Yes	No	Yes	Yes
"Green" registration fee	Yes	Yes	Yes	Yes	No registration fee (super-green car rebate to cars with very low CO_2-emission)
Other important policies	EVs and hydrogen vehicles exempted from registration fee until 2015.		Reykjavík city offers free parking for environmentally friendly vehicles.	Electric vehicles (BEV and FCEV) are exempted from registration taxes, VAT and road tax;[2] can drive in the bus lane; have free parking in public parking area; may use toll roads for free. Subsidies for the purchase of certain EV or HEV.	Super-green car rebate to cars with very low CO_2-emissions (<50 g/km). Large filling stations required to offer RE fuels.

Notes: RE = renewable energy. BEV= battery electric vehicle. FCEV = fuel cell electric vehicle. HEV = hybrid electric vehicle.

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[2] Norwegian tax reductions are valid until 2017, or until the number of zero-emissions vehicles reaches 50 000.

The above percentages have been calculated according to the special methodology specified in the EU renewable energy directive, in which second-generation biofuels produced from wastes, residues, non-food cellulosic material and lignocellulosic material (such as wood and straw) count double towards the target. In Finland, around 30% of renewables in the transport sector are expected to be produced from second-generation biofuels.[3] The Swedish projection shows the share of second-generation biofuels (primarily biogas) to be around 9%. According to the renewable energy action plans, EVs are not expected to play an important role by 2020 in Denmark, Finland or Sweden. In Norway, EVs play some part in achieving the 2020 target.

EU regulation also endeavours to bring more efficient vehicles to the market. The so-called "Cars Regulation" imposed on car manufacturers limits emissions to 130 grams of CO_2 per kilometre (gCO_2/km) as an average of all new passenger cars in the European Union by 2015. By 2020, this level is to be reduced to 95 gCO_2/km. Details of how the 2020 target will be reached have to be defined in a review, which should be completed by 2013 at the latest.

Looking beyond 2020, the European Parliament suggests a target of 70 gCO_2/km to be reached by 2025. All Nordic countries have backed the EU regulation with fiscal measures to support energy-efficient vehicles. In addition to the energy and CO_2 taxes that all Nordic countries impose on diesel and gasoline, they have also adopted either a CO_2-differentiated vehicle ownership tax or a CO_2-differentiated registration fee.

The specific methodologies used to benefit fuel-efficient vehicles differ among the countries: discrepancies mainly relate to the very diverse rates of car taxation. While Denmark and Norway have the highest registration fees in Europe, cars are not subject to any registration fee at all in Sweden. Rebates on registration fees provide a powerful incentive to promote efficient cars. For example, in Denmark a passenger diesel car that emits 130 gCO_2/km gets a discount of about USD 1 030[4] on the registration fee compared with a similar car emitting 140 gCO_2/km. In Norway, the discount is slightly higher at USD 1 260; in Finland, it is only about USD 190. In Norway and Denmark, EVs are totally exempt from registration fees.

CO_2-differentiated taxation is shown to have a significant impact on consumer choice. After changing tax systems to reflect CO_2 emissions, both Finland and Denmark achieved an 8% reduction in average emissions from new cars between 2007 and 2008. According to one Nordic research study, *A comparative analysis of taxes and CO_2 emissions from passenger cars in the Nordic countries*, this reduction was unmatched by any other European country and can probably be ascribed, at least to some degree, to the tax reforms (Duer, 2011). A similarly strong consumer response was observed in 2009 when the Norwegian differentiation concept was further developed such that vehicles emitting less than 120 gCO_2/km became entitled to a tax deduction. Sales of cars emitting less than 120 g/km doubled (15% rising to 30%) in the first six months of 2010, compared with the same period in 2009.

Sweden does not impose a registration fee on new cars but uses other measures to promote green cars. A "super-green car rebate" was introduced in 2012, which rewards cars that meet the latest EU exhaust requirements and emit a maximum of 50 gCO_2/km. For a private passenger car, the premium amounts to USD 5 970.

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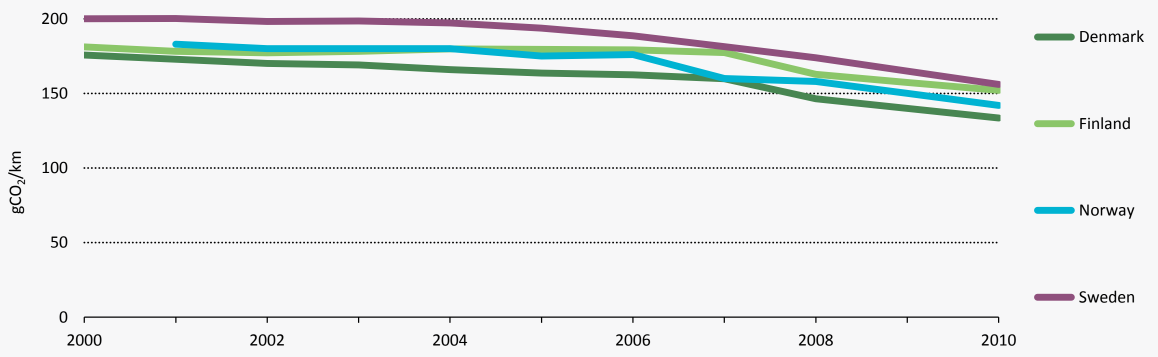
[3] Around 180 thousand tonnes of oil equivalent (ktoe) out of 600 ktoe.

[4] 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.

Strong policies have also been put in place to promote bioenergy in Sweden's transport sector. All large filling stations, for example, are required to offer at least one renewable fuel, and special subsidies are provided to filling stations offering fuels such as biogas, which has higher investment costs.

Swedish regulation does not, however, support efficient conventional cars at the point of purchase as in the other Nordic countries. This is likely to be one explanation of why new cars in Sweden, on average, demonstrate higher relative CO_2 emissions than in Denmark, Finland or Norway. Registration fees that are calculated as a percentage of the purchase price before taxes provide an incentive for more efficient cars because lower-cost cars are often smaller and therefore likely to be more efficient.

Figure 5.5 Development in average CO_2 emissions per kilometre for new cars



Notes: Average CO_2 emissions from new cars in gCO_2/km. No data were found for Iceland.
Sources: Duer, 2011; EA Energy Analysis, 2011.

Key point *CO_2 emissions from new cars have decreased substantially since 2004. Denmark and Norway, which provide the largest support to efficient cars, exhibit the lowest relative CO_2 emissions of new cars.*

Transport sector scenario results

The transport scenarios are modelled with the IEA transport model (MoMo). The basic drivers in the model are population and gross domestic product (GDP) projections. Demand for passenger and freight transport are projected and divided among the various modes of transport. The calculations also comprise each country's share of international transport. For air transport, all departures to other countries are included in the country's share of international air transport, which also comprises 50% of the passenger kilometres and fuel use. For international shipping, all bunkering in the countries is regarded as domestic consumption.

Such projections have a drawback for transit airports such as Copenhagen, Helsinki and Keflavik, as a relatively high share of global air transport is assigned to domestic energy consumption. For a small country such as Iceland, which hosts Keflavik International Airport, this problem becomes clear (Figure 5.4). There is no perfect way to allot international transport to single countries but this method is consistent with the guidelines on the use of emissions trading in aviation, published by the Intergovernmental Panel on Climate Change (IPCC), the International Civil Aviation Organization (ICAO), and in the IEA *Energy Technology Perspectives 2012* (IEA, 2012).

For all other passenger transport, demand and fuel use relates to the country in which the car, bus, train, etc. is registered.

Scenario assumptions

Measures to increase efficiency and reduce CO_2 emissions within the transport sector can be grouped in five main categories: avoid, improve, switch technology, switch fuel and shift modes.

- **Avoid:** avoidance of using all modes of transport will directly affect the projections for transport demand, which is the main driver for energy use and CO_2 emissions. Using remote communication instead of travelling to meetings is one way of avoiding transport. Another way would be to improve infrastructure planning to reduce distances between destinations and reduce the demand for transport. This measure will also address the energy usage of existing technologies.
- **Efficiency improvements:** improving existing technologies (such as ICEs) will lead to more efficient transport. However, as such improvements will mainly address new vehicles, vessels and aeroplanes, the efficiency effect is limited to the turnover of vehicle stock.
- **Technology switch:** switching technologies within a mode of transport can lead to greater efficiency or a reduction in CO_2 emissions, such as using electric passenger light-duty vehicles (EV PLDVs) instead of gasoline PLDVs. This effect is also limited by the vehicle stock turnover.
- **Fuel switch:** switching to low-carbon fuels such as natural gas or biofuels can reduce CO_2 emissions while using conventional technology and, in the case of biofuels, while relying on an existing fuel distribution infrastructure.
- **Modal shifts:** aim to shift transport from less efficient to more efficient modes, *e.g.* from individual passenger transport to bus or train.

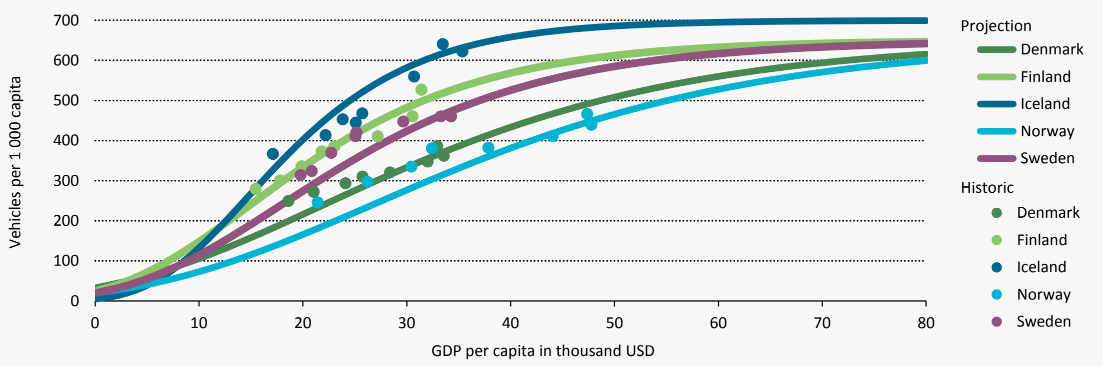
Improvements in technology are the easiest way to improve energy efficiency in transport. However, developments in technologies depend mainly on EU requirements for energy efficient technology. Such requirements are already in place for PLDVs and LCVs: across their product line, manufacturers of these vehicles must meet an average level of energy efficiency. In recent years, some countries have achieved a higher level of energy efficiency for new PLDVs. Denmark and Norway, for example, are among the countries with the highest energy efficiency (*i.e.* best fuel economy) for new PLDVs.

Increased use of biofuels could be implemented more extensively within a short time horizon. Fuel switching is not, however, the most effective means of improving energy efficiency in transport. The effect on GHG emissions from first-generation biofuels (*e.g.* biofuels made from sugar, starch or vegetable oil) is subject to debate.

The five measures mentioned to reduce CO_2 emissions in transport are implemented to different degrees in the scenarios. In the 4°C Scenario (4DS), measures mainly focus on improving the efficiency of existing technologies; there is no effort to avoid transport or to encourage modal shifts. In the 2DS, CNS, Carbon-Neutral high Electricity Scenario (CNES) and CNBS, approximately 4% of transport is avoided by 2050 while 20% of passenger transport shifts from individual transport to bus and train. Over the same period, 50% of freight transport shifts from road to rail, and efforts on efficiency improvement increases. The technology switch towards EVs is also stronger in the 2DS and especially in the CNS and CNES. The CNBS shows a higher introduction of biofuels in all means of transport (Table 5.2).

Saturation in car ownership per capita is not yet seen in the Nordic countries. By contrast, other OECD countries such as France, Japan, the United Kingdom and the United States have experienced saturation in vkm per capita since 2002 (IEA, 2012). The IEA transport model uses Gompertz curves to simulate saturation in car ownership based on historic data.[5] In the 4DS, this means that car ownership in Iceland, for example, ends up at 700 cars per 1 000 capita, while other Nordic countries stabilise at around 600 (Figure 5.6). One reason for the higher car ownership in Iceland is the lack of public transportation such as railways. In the 2DS, the car ownership will remain at the level of 2010 throughout the modelled period.

Figure 5.6 Projection of PLDV stock in the 4DS



Note: PLDV stock projection is based on projections for GDP and population, and is assumed to follow a Gompertz curve.

Key point *In the 4DS, based on income growth, Nordic car ownership reaches around 600 PLDVs per 1 000 capita by 2050 (from 500 today) except for Iceland, which shows more than 700 PLDVs per 1 000 capita.*

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[5] A Gompertz curve is a function in which growth is slowest at the beginning and the end. It is used to describe time series with a slow initial growth, high growth in the middle and then saturation in the end period.

Table 5.2 Measures and means in the NETP transport scenarios by 2050

Measures/means	4DS	2DS	CNS	CNES	CNBS
Avoid	No avoidance strategy.	4% reduction in passenger transport.	4% reduction in passenger transport.	Same as CNS.	Same as CNS.
Efficiency improvements	40% reduction of average tested new PLDV fleet fuel consumption.	55% reduction of average tested new PLDV fleet fuel consumption (excluding the effect of electrification).	60% reduction of average tested new PLDV fleet fuel consumption (excluding the effect of electrification).	Same as CNS.	Same as CNS.
	15% reduction of average tested new CV fleet fuel consumption.	30% reduction of average tested new CV fleet fuel consumption.	45% reduction of average tested new CV fleet fuel consumption.	Same as CNS.	Same as CNS. The substitution of FCEVs by hybrids and conventional ICE vehicles somewhat lowers overall fleet efficiency in the road transport sector.
	1% annual reduction on energy intensity per pkm in air transport.	1.5% annual reduction on energy intensity per pkm in air transport.	1.5% annual reduction on energy intensity per pkm in air transport.	Same as CNS.	Same as CNS.
	0.4% annual reduction on energy intensity per pkm in rail transport.	1% annual reduction on energy intensity per pkm in rail transport	1% annual reduction on energy intensity per pkm in rail transport	Same as CNS.	Same as CNS.
Technology switch	Stock of PLDVs by 2050: 15% EVs (PHEV and BEV), 30% conventional hybrids, 50% conventional ICE. Minor penetration of CNG trucks.	45% stock share of EVs (PHEV and BEV), 15% stock share of FCEVs, 15% stock share of conventional hybrids on PLDVs. 10% sales share of CNG trucks, progressive hybridisation of short- and medium-haul trucks, 10% sales share of FC trucks. Full electrification of rail.	55% stock share of EVs (PHEV and BEV), 15% stock share of FCEVs, 15% stock share of conventional hybrids on PLDVs. No conventional ICE LCV (<3.5t) sold, 75% sales share of alternative power-train configuration (hybridisation, CNG, FC) of medium- and long-haul trucks.	65% stock share of EVs (PHEV and BEV), the share of BEVs on stock is 50% higher than in the CNS (reducing the share of conventional hybrid vehicles). Same as CNS for all other transport modes.	Like CNS for PLDVs, FCEVs are substituted by PHEVs. Like CNS for road freight, FC trucks are substituted by hybrids and conventional ICE trucks. Same as CNS for all other transport modes.
Fuel switch	10% share of biofuels in petroleum blends.	35% share of biofuels in petroleum blends.	75% share of biofuels in petroleum blends.	Same as CNS.	100% share of biofuels in petroleum blends.
Modal shift	No shift strategy.	20% reduction in individual pkm, shifted equally to bus and rail. 50% of road freight transport growth is shifted to rail.	20% reduction in individual pkm, shifted equally to bus and rail. 50% of road freight transport growth is shifted to rail.	Same as CNS.	Same as CNS.

Notes: The measures mentioned are general descriptions across all the Nordic countries. In the detailed scenarios on country level, the level of the measures varies. Pkm = passenger kilometres. CV = commercial vehicle. BEV = battery-electric vehicle. FCEV = fuel-cell electric vehicle. HEV = hybrid electric vehicle. ICE = internal combustion engine. CNG = compressed natural gas. PLDV = passenger light-duty vehicles. FC = fuel cells. LCV = light commercial vehicles. PHEV = plug-in hybrid electric vehicle

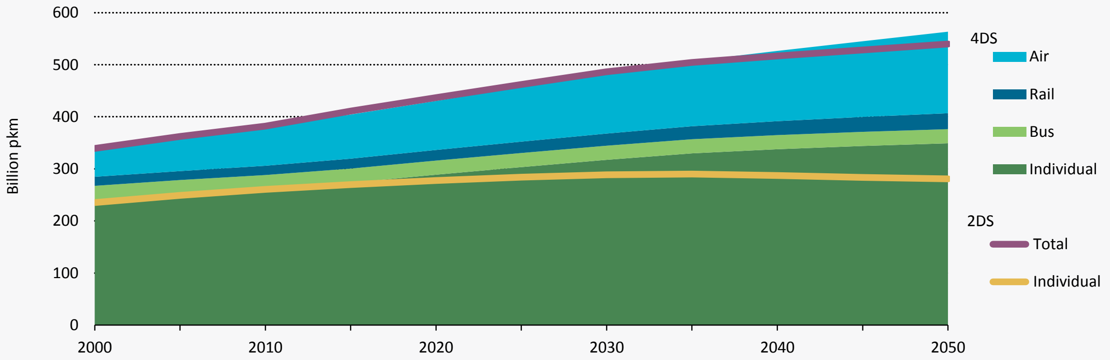
Table 5.3 Average annual increase of transport activity for different modes between 2010 and 2050

Transport mode (%/yr.)	4DS	2DS	CNS
Passenger			
Total	0.98	0.87	0.87
Individual	0.58	0.08	0.08
Rail	1.36	3.61	3.61
Bus	-0.04	2.27	2.27
Air	1.82	1.09	1.09
Freight			
Total	0.77	0.71	0.71
Road	0.80	0.52	-0.51
Rail	0.70	1.16	2.51
Shipping (energy use)	0.93	0.07	0.07

Notes: The activity is measured in passenger-kilometres for passenger transport and in tonne-kilometres for freight transport. For shipping, however, the projection is in energy units.

The 4DS assumes no special measures to reduce transport demand, yet signs of saturation for passenger transport are expected to materialise, limiting growth compared with previous decades. Growth rate for passenger travel with PLDVs would, therefore, be around 0.6% per year. The growth rate is higher for passenger transport by air (1.8%/yr) and by rail (1.4%/yr) between 2010 and 2050, reflecting a modal shift from PLDV to air and rail (Table 5.3).

Figure 5.7 Passenger transport in the 4DS compared with the 2DS



Note: The full coloured areas represent 4DS values and the lines show the comparable values in 2DS, which has the same development as the CNS variants.

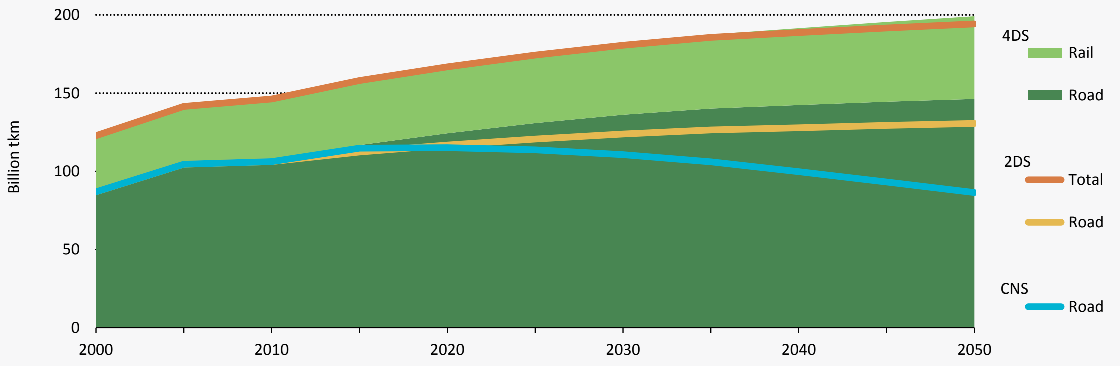
Key point *Differences between levels of individual transport in 4DS and 2DS (and the CNS variants) is larger in 2050 than for total transport, reflecting a modal shift (starting from 2015) from individual transport towards air, bus and mainly rail.*

In 4DS technology switching is limited until 2030. The only new technology within PLDVs to have penetrated the market significantly by then will be PHEVs. These vehicles account for 3% of sales by 2020 and 7% by 2030. By 2050, almost 70% of all new sales are still conventional ICEs (including hybrids) and these technologies still account for more than 80% of the total stock.

Overall growth in passenger transport is only slightly lower in the 2DS and CNS compared with the 4DS. The big difference is the shift in modes of transport from car to rail, which stabilises individual passenger road transport at a level only a few percentage points higher than today (Figure 5.7).

Freight transport in the 4DS shows a steady increase between 2010 and 2050, ending up 36% higher in 2050. Road transport accounts for the main part of the growth. When compared with the development in CNS and its variants, the modal shift needed from the 4DS to the CNS is substantial. All future growth in freight transport is here taken up by rail (Figure 5.8).

Figure 5.8 Freight transport in the 4DS compared with the 2DS and CNS



Note: The full coloured areas represent 4DS values and the lines show the comparable values in the 2DS and CNS. Shipping is not included in this graph.

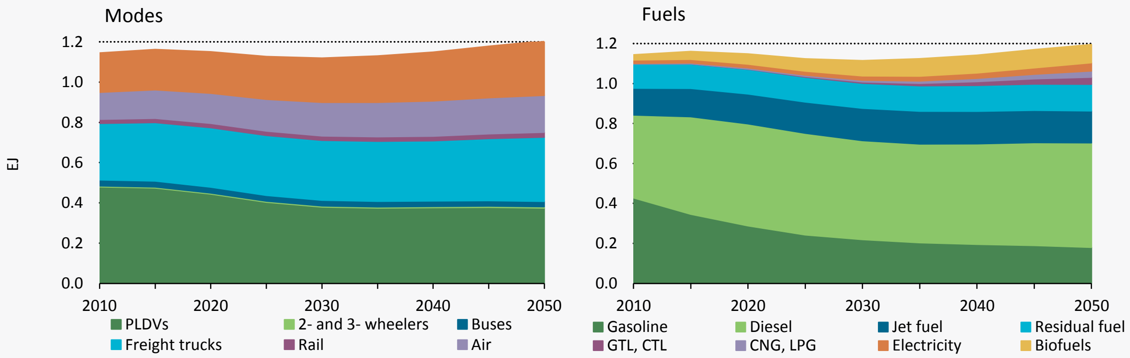
Key point *The large difference between the levels of road transport in the 4DS and CNS reflects a modal shift from road to rail (starting from 2015).*

The total increase in freight transport between 2010 and 2050 is almost equal in the CNS and the 4DS, but the shift from road transport to rail increases the total efficiency. Electrification of highways for hybrid trucks can also decarbonise freight transport and reduce the need for new railways. This solution is not taken into account in the modelling.

The modal shift for both individual passenger and freight transport takes off in 2015. To achieve this, relevant policies must be in place to support the increasing volumes of passengers and freight transported by rail. Plans in rail infrastructure would need to be improved, as would the use of pricing mechanisms to make rail transport less costly than road transport.

In the 4DS, efficiency improvements limit growth in energy use until around 2035, at which point total energy use has declined to match the level seen for 2010, despite population and economic growth. After 2035, the continued rise in transport demand and the slower development of efficiency improvements result in rising energy consumption. By 2050, low-emission fuels (such as electricity and biofuels) still have a very limited share; thus, the development of CO_2 emissions from the transport sector increases, following the trend of energy consumption (Figure 5.9).

Figure 5.9 Energy use for transport in 4DS divided by mode and fuel type

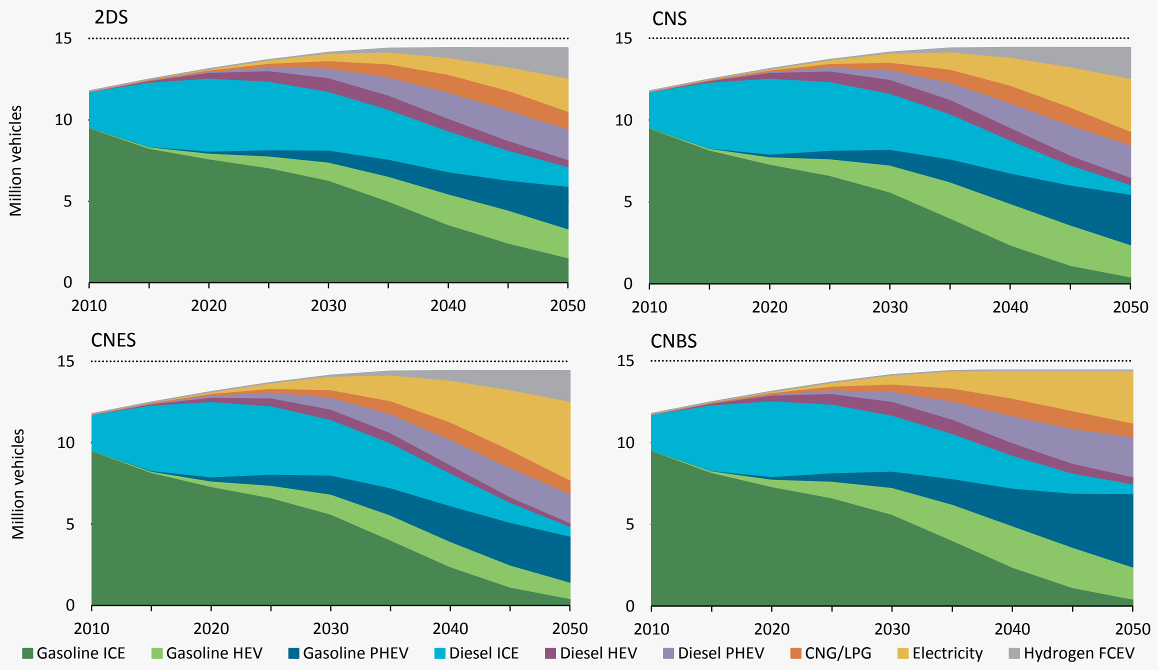


Notes: EJ = Exajoules. PLDVs = passenger light-duty vehicles. CNG = compressed natural gas. CTL = coal-to-liquid. GTL = gas-to-liquid. LPG = liquefied petroleum gas.

Key point *Total energy use for transport in the 4DS remains constant until 2050. After 2030, CNG, CTL and electricity increase market share, but the main development is conventional diesel replacing conventional gasoline.*

In order to achieve the significant reduction in energy consumption in the 2DS, modal shifts in transport must be supplemented by switching technologies. This is especially true for individual passenger transport, in which new technologies (BEV, PHEV, FCEV) account for 8% of sales by 2020 and more than 80% by 2050. The higher introduction rate is assumed to result in a more rapid technological development and thus PHEVs have a higher share of electricity-based driving. The introduction of fuel-cell technology starts around 2020 (CNS) to 2025 (2DS) and reaches significant shares on PLDV stock by the end of the first half of the century. By that time, the share of ICE-driven PLDVs (conventional and hybrids) of the total stock has been reduced to 36%, almost half of which is hybrid vehicles (Figure 5.10).

Figure 5.10 PLDV stock by technology



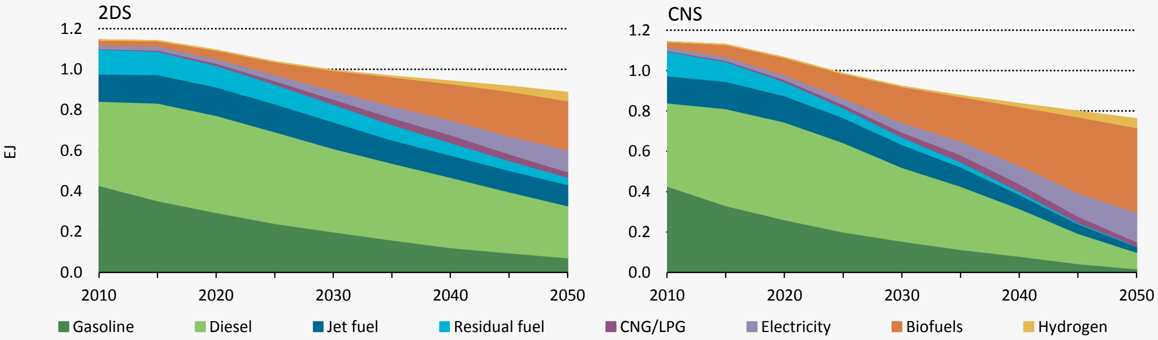
Notes: ICE = internal combustion engine. HEV = hybrid electric vehicle. FCEV = fuel-cell electric vehicle. The figures refer to technologies and not directly to the type of fuel used. Therefore, a conventional gasoline car can have more or less biofuels blended into the gasoline. In the CNBS, all fossil gasoline and diesel are fully replaced by biofuels in 2050; the CNS and CNES have a 75% blend of biofuels in gasoline and diesel ICE.

Key point *Market share for conventional diesel and gasoline cars declines more and faster in the CNS and CNES than in the 2DS. In CNBS, hydrogen fuel-cell vehicles do not enter the market at all because of availability of cheaper biofuels.*

The average fuel consumption of new PLDVs reaches 3.2 L/100km in 2DS by 2050 (without the effect of electrification). This represents more than a 50% reduction compared to current consumption per vehicle-kilometre. By 2020, the EU target of 95 gCO_2/km will be reached.

The long-haul road freight sector is particularly difficult to decarbonise as hybridisation does not deliver a high enough level of fuel savings over constant, long-distance driving to warrant the associated costs. Moreover, electrification is limited by the size, weight and recharge time for batteries. Therefore, even in a low-carbon future, high-energy-dense liquid fuels will remain important. To reach emissions targets, increased effort must be made to replace fossil fuels with sustainable low-carbon biofuels. In the 2DS, liquid petroleum fuels are blended in quantities of up to 35% with biofuels by 2050. Second-generation lignocellulosic ethanol is used to blend gasoline, and biomass-to-liquids (BTL) from wood and straw is used to blend diesel.

Figure 5.11 Energy use for transport by fuel in the 2DS and CNS



Note: CTL and GTL are not used in the scenario.

Key point *Total energy use drops slightly from 2010 to 2050 – mainly due to less energy use in PLDVs. Biofuels account for one-third of the transport energy in the 2DS and more than half in the CNS. In both cases, conventional gasoline is almost phased out by 2050.*

The CNS variants (CNES and CNBS) reveal two additional ways to reach a low-carbon future, although they do not deliver the same level of CO_2 emissions reduction. Focus is on different technology and fuel choices. The CNES shows a pathway with increased electrification, while the CNBS focuses on the increased use of biofuels. However, both scenarios depend on the same policies to achieve modal shifts and strategies to limit growth in demand for transport. The scenarios merely explore different technology pathways owing to the uncertain future of technological development in the transport sector. The CNBS is more optimistic about the potential for biofuels to replace totally gasoline and diesel by 2050, whereas the CNS and CNES have a maximum blending of biofuels in gasoline and diesel at 75%.

Envisaged penetration of improved technologies is at the upper margin of what is possible with regard to the pace of market introduction, taking into account the average vehicle retirement age of around 15 years.

In all carbon-neutral scenarios (CNS, CNES, CNBS), conventional ICE vehicles are almost phased out by 2050, which adds even more pressure to the pace at which vehicles with alternative technologies enter the market. For example, sales of EVs (PHEVs and BEVs) need to double every year between now and 2020, and then maintain significant two-digit annual growth rates at least until 2030. These rates of change are unprecedented and definitely challenge the feasibility of the CNS variants.

In the CNS, the average tested new PLDV fuel economy decreases to 2.8 L/100km, which represents more than 60% improvement of fuel economy. Achieving this target requires aggressive use of fuel economy measures such as downsizing, hybridisation, light weighting and decoupling of auxiliary aggregates from the engine, as well as rolling and air resistance reductions. Further improvements in technology are assumed within PHEV for which around 80% of driving is based on electricity; this will require larger batteries, thus driving up the vehicle price.

Freight transport requires major attention in the CNS variants as a significant modal shift to rail transport is assumed. By 2050, around 50% of the tonne-kilometres projected in the 4DS are shifted to rail transport in the CNS. This ambitious target requires a smart intermodal transport system.

In the CNS, penetration of alternative technologies follows an aggressive scheme. By 2050, conventional diesel and gasoline LCVs are no longer sold. More than half of the LCVs sold by that time are diesel hybrids, more than two-thirds of which are plug-in hybrids. The rest of the LCVs sold are either battery electric or fuel-cell vehicles (20%).

Heavy-duty vehicles (HDVs) still have a considerable share of ICE-powered new vehicles in the CNS. For example, about half of all new sales of HDVs are powered by either diesel or natural gas ICE. Approximately 20% are hybrids (for urban delivery) and around 30% of new sales of HDVs are FCEVs. Conventional diesel ICE HDVs are estimated to have a nearly 30% better fuel economy by 2030 compared with 2010, reaching around 20 L/100km without hybridisation.

In the CNS by 2050, gasoline and diesel are blended with 75% second-generation biofuels for all modes of transport, including air and shipping. This raises questions regarding the supply of biomass as both the power and transport sectors compete for raw biomass for energy consumption. Transportation of raw biomass is limited by economics due to its lower energy density and may prompt the need for import of secondary products.

The generation of electricity for electric vehicles and hydrogen for FCEVs is almost entirely decarbonised by 2050 and the batteries for electric vehicles, as well hydrogen used for transport, might serve as energy storage to capture excess electricity from renewable sources of energy. A more systemic approach is needed to estimate co-benefits of such an integrated system.

The CNS requires more effort to promote fuel shift in air transport, which is difficult to achieve for the Nordic countries, especially considering international air travel. In the CNS, CNES and CNBS, around 25% of total air travel is shifted to rail (*e.g.* domestic air travel) or avoided (international air travel), while fuel economy improves by 1.5% per year between 2010 and 2050. This improvement would be roughly in line with abatement costs of around USD 150 per tonne of carbon dioxide (tCO_2), leading to approximately 30% fuel economy improvement by 2030.[6] Further decarbonisation of air transport is difficult to achieve without breakthrough technologies such as hydrogen-fuelled aircrafts. Without technology options like this, aviation is likely to remain dependent on high-energy-dense liquid fuels. Low-carbon air travel is only possible with an aggressive uptake of low-carbon, sustainable biofuels.

The 2DS results in a 24% reduction in energy consumption for transport in 2050 compared with 2010. The greatest contribution to reduction comes from PLDVs (-50%) and road freight (-15%). To reach the targets for CNES and CNBS, more effort is needed to reduce significantly energy demand from transport technologies other than PLDVs (Figure 5.12).

Fuel use for road transport changes dramatically between the 4DS and the 2DS, and again between 2DS and the CNS variants. Road transport sees a switch to low-carbon fuels, and electrification gains a significant share in the in PLDV sector. Air and shipping still depend on fossil fuels to some extent in the CNS and the CNES; in the CNBS, biofuels completely replace fossil fuels (Figure 5.13).

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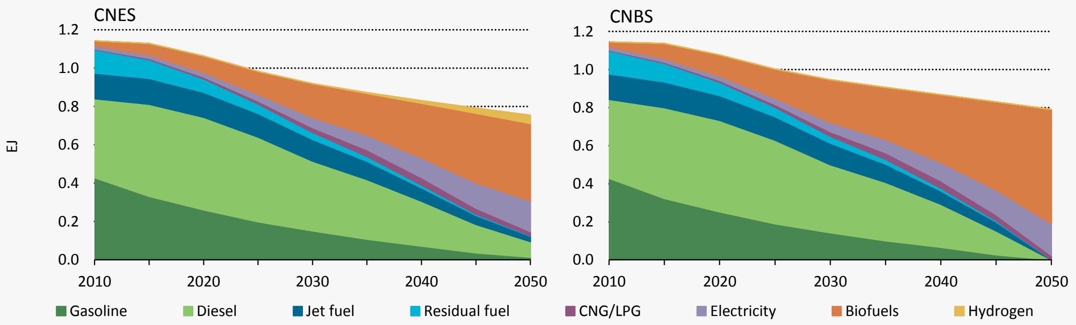
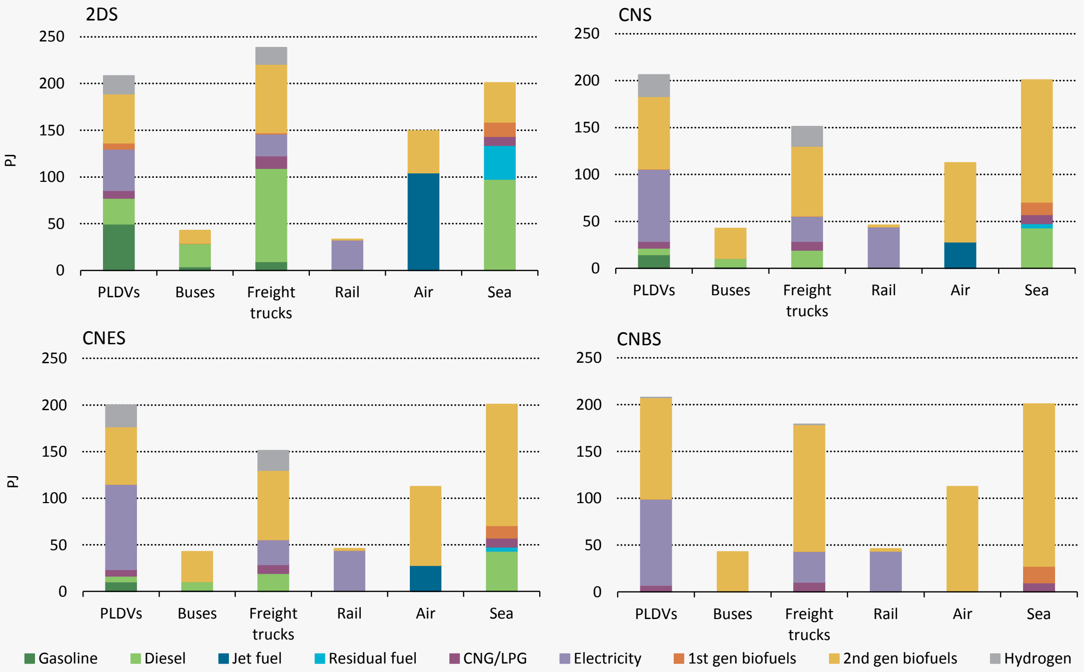
[6] Internal study.

Figure 5.12 Energy use for transport by fuel in the CNES and CNBS



Key point *Lower energy use by PLDVs helps to halve total energy use in transport by 2050. Biofuels cover around half of fuel supply in the CNES and more than 70% in the CNBS; electricity covers around one-quarter in both scenarios. In the CNBS, all fossil fuels are phased out by 2050, while some conventional diesel remains in the CNES.*

Figure 5.13 Fuel use by mode and fuel type in 2050



Key point *When compared with the 2DS, the CNS and CNES more than halve the use of fossil fuels for transport in 2050, while the CNBS totally replaces fossil fuels with non-fossils.*

Important developments up to 2030 and beyond

Some measures, such as avoidance of transport (through city planning, for example), will need to be introduced in the short term despite the fact that their impact will not be significant until after maybe 2030. Important developments should be achieved in all scenarios to enable the stabilisation of fuel use and CO_2 emissions up to 2030. Developments include:

- **Efficiency improvement of conventional technologies.** For the coming years, conventional technologies will continue to have the major share of new vehicles. Therefore, efficiency improvements of both passenger and commercial vehicles are important measures, regardless of the longer-term development and future technology breakthroughs.
- **Saturation of the development of transport demand.** In the short term, efforts to reduce transport demand will lead to lower fuel use and GHG emissions. In the longer term when transport is mainly delivered by low-carbon technologies, energy demand in transport is less a question of emissions and more a question of resources (*e.g.* biomass for biofuel production).

If the 2DS and CNS paths are to be followed, further policy measures need to be introduced in the short term. As conventional technologies also play an important role in the low carbon scenarios, efficiency improvements are of high importance and need to be accelerated compared with the 4DS.

Modal shift leads to a significant increase in passenger and freight transport by bus and rail, also in the short term. While a modal shift within passenger transport might not be imperative to achieve reductions in CO_2 emissions in the long term, it provides some hedging against the uncertainty of when and how alternative technologies, such as electric and hydrogen-fuelled vehicles, will make a breakthrough. Other advantages include a reduction of traffic congestion and lower local emissions.

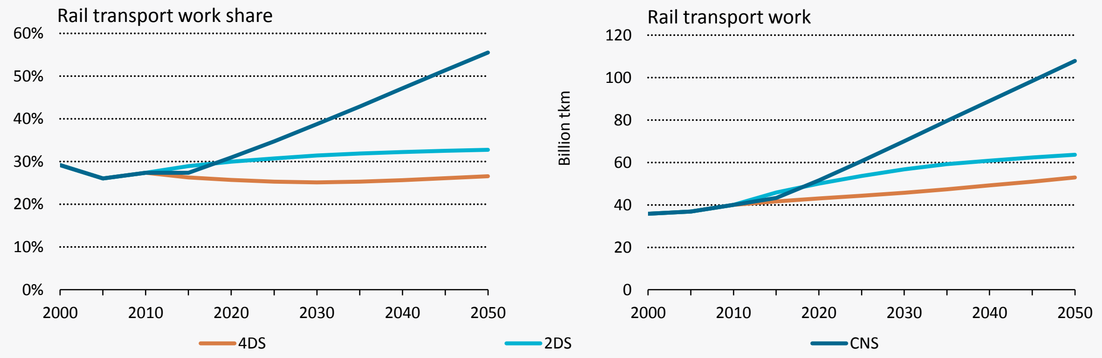
Diversification of PLDV stock has to take off before 2025. The timing will, however, depend on the possible market penetration rates, development of technology costs, consumer acceptance and infrastructure development (*e.g.* charging infrastructure).

Avoid measures and modal shifts

In the short term until 2030, measures to limit growth within passenger transport do not have an important impact in the 2DS compared with the 4DS. In contrast, infrastructure investments and planning have a long time horizon and, therefore, avoidance policies influencing infrastructure have to be discussed before 2030. All 2DS variants require significant modal shifts, with important changes compared with the 4DS also in the short term. In order to be able to reduce individual passenger transport, both rail and bus transport must increase. Already by 2015, passenger transport in rail and bus has to be 25% to 30% higher compared with the 4DS. By 2030, these figures increase and bus transport is almost 80% higher, while rail transport has to double. The share of rail and bus of total passenger transport increases from around 12% in 2010 to 20% in 2030. Part of this increase is due to a shift away from air transport, which decreases 12% by 2030 compared with the 4DS.

Within freight transport, modal shift is also essential. Until 2020, the 2DS and CNS variants show an increase in rail transport of around 20% compared with 2010, increasing rail transport to 30% of total rail and road transport. After 2020, rail transport has to increase significantly in the CNS, accounting for more than 40% of total rail and road transport by 2030 (increasing tkm by more than 50%) (Figure 5.14).

Figure 5.14 Rail transport share of total road and rail transport, and developement in rail transportation work



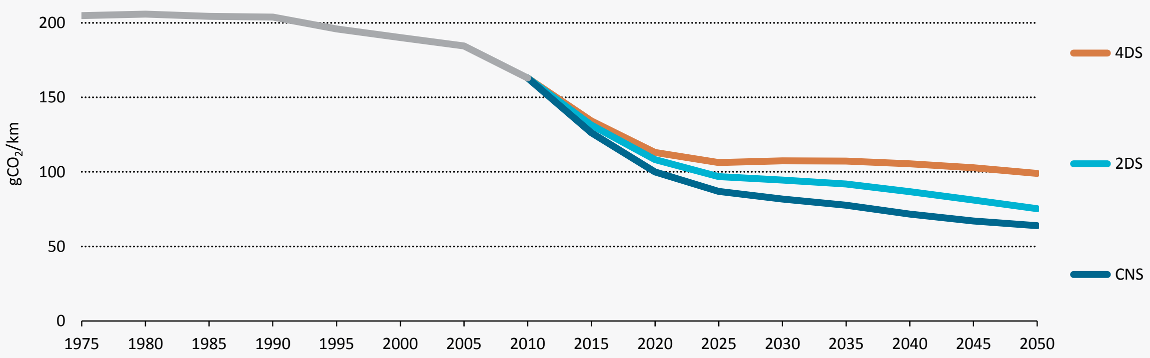
Note: Share of total rail transport (left graph) and development of rail transport in terms of billion tkm (right graph).

Key point *Strong measures are needed to prompt the significant modal shift from road to rail shown in the CNS and its variants, in which the share of rail transport more than doubles in 2050 compared with 2010.*

Important technology developments

All scenarios assume significant improvements in the energy efficiency of new PLDVs (Figure 5.15). Following the path of 2DS or CNS, however, requires improving efficiency from 12% to 20% compared with 4DS. One of the most important drivers behind PLDV efficiency is likely to be the EU requirements, which calls for emissions targets of 95 gCO_2/km by 2020. More stringent requirements must be implemented for the years after 2020 if the 2DS path is to be followed.

Figure 5.15 Development in PLDV fuel economy



Key point *All scenarios depend on significant improvement of PLDV fuel economy, driven largely by international regulations. In the long term, improvements of ICE or ICE hybrids will be limited; emissions are expected to stabilise at around 65 gCO_2/km.*

Stock developments (PLDV)

All scenarios assume a more diversified PLDV stock by 2050, including new and more efficient technologies. Within the 4DS, introduction of new technologies is limited until 2020: conventional and hybrid ICEs still account for 99% of total stock and more than 96% of total sales. Otherwise, only PHEVs gain some significance. Following the 2DS and CNS paths requires a share of around 10% PHEV and BEVs in total sales by 2020. Following the 2DS path requires that sales of PHEVs, BEVs and FCEVs reach around 75 000 in 2020, with stock increasing from 22 000 in 2015 to 230 000 in 2020 (Tables 5.4 and 5.5).

Table 5.4 Sales of PLDVs with electric trains (BEV, PHEV and FCEV) in 4DS and 2DS

			4DS		2DS	
	2011		2015	2020	2015	2020
Norway	3 600	1.6%	2 174	12 301	2 376	19 454
Denmark	450	0.3%	1 476	8 808	1 573	13 696
Sweden	180	0.0%	1 039	2 373	3 747	26 908
Finland	34	0.0%	1 221	7 901	1 126	11 793
Iceland	68	0.0%	185	1 356	202	2 172
OECD Nordic	4 332	0.0%	6 094	32 739	9 024	74 023

Note: These are approximate numbers calculated on total sales and the shares of each technology.
Sources: The 2011 data are from: Opplysningsrådet for Veitrafikken AS, 2012; Trafikanalys, 2012; Danmarks Statistik, 2012; TraFi, 2012.

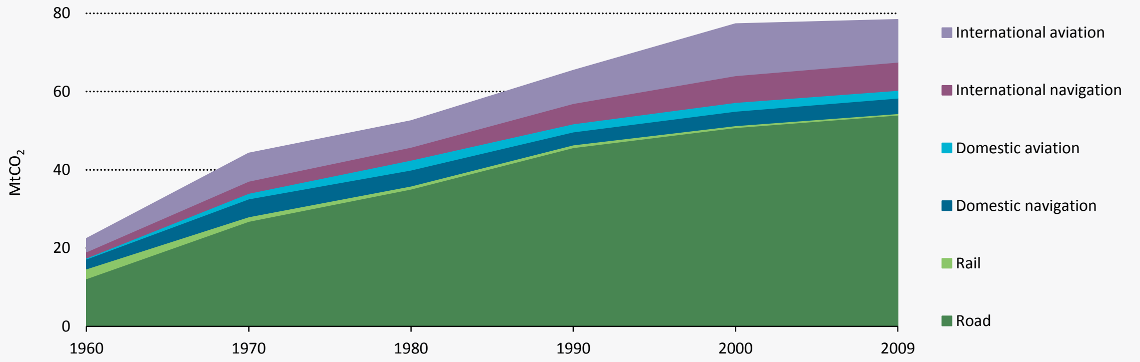
Table 5.5 Stock of PLDVs with electric trains (BEV, PHEV and FCEV) in 4DS and 2DS

			4DS		2DS	
	2011		2015	2020	2015	2020
Norway	4 000	0.3%	4 749	18 953	5 940	60 516
Denmark	750	0.0%	3 225	13 220	3 933	42 106
Sweden	370	0.0%	2 139	10 081	9 367	86 005
Finland	200	0.0%	2 667	11 407	2 814	35 110
Iceland	647	0.0%	405	1 851	506	6 442
OECD Nordic	5 967	0.0%	13 184	55 511	22 560	230 178

Source: The 2011 data are from: Opplysningsrådet for Veitrafikken AS, 2012; Trafikanalys, 2012; Danmarks Statistik, 2012; TraFi, 2012.

CO_2 emissions in transport

Figure 5.16 CO_2 emissions by transport mode



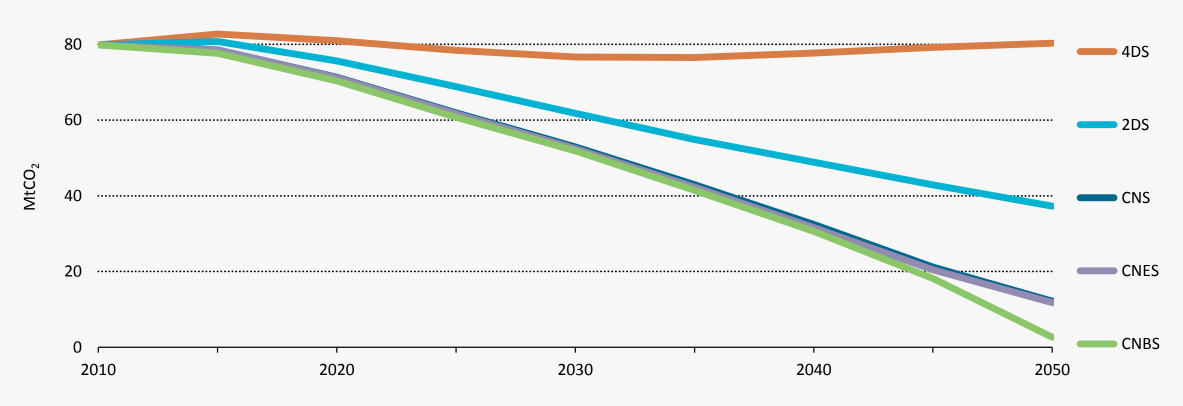
Key point *CO_2 emissions from transport in the Nordic countries have increased 3.5 times since 1960.*

Road transport is the main contributor to total transport CO_2 emissions in the Nordic countries, having risen from a share of 53% in 1960 to almost 70% in 2009. Total CO_2 emissions from transport has increased 3.5 times, with the main part of this growth taken up by road transport (Figure 5.16).

As road transport is the main emitter, this sector also offers the biggest potential for achieving emissions reductions. The deep cuts needed in the CNS also require serious reductions within shipping and aviation, which are the most difficult sectors to decarbonise. Aside from efficiency gains and the use of biofuels, breakthrough technologies are needed to overcome the barriers that limit the share of biofuels: namely, cost, availability or concerns about sustainability.

In the 2DS, overall emissions from the transport sector are reduced more than 50%, from around 80 $MtCO_2$ in the 4DS to nearly 37 $MtCO_2$ in the 2DS by 2050. In the CNS, emissions are reduced by nearly 80%, down to 12 $MtCO_2$ (Figure 5.17).

Figure 5.17 CO_2 emissions from transport in the Nordic countries for all scenarios



Key point *While the 2DS halves the emissions compared with the 4DS, the CNS and variants almost totally decarbonise the transport sector in the Nordic countries.*

Cost of decarbonising the Nordic transport sector

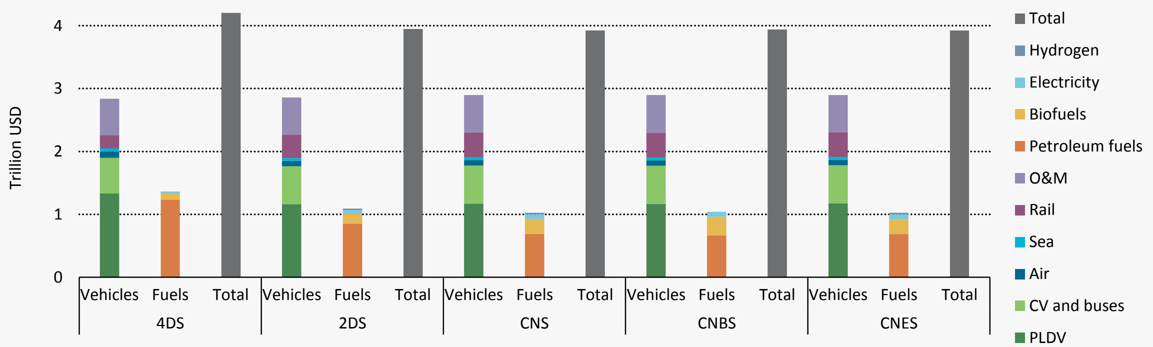
A striking outcome of analysis of the *NETP* transport scenarios relates to the associated costs. In fact, the differences are minimal: in all scenarios, around USD 4 000 billion is needed to develop, run and maintain the transport sector between 2010 and 2050 (Figure 5.18). Pursuing the carbon-neutral scenarios is actually slightly less costly than the 4DS.

The 2DS and carbon-neutral scenarios reflect a switch towards more efficient – but more expensive – technologies compared with the 4DS, which diverts costs from fuels to investments in technology. The total costs in the 2DS are reduced because of lower spending on fuels (as a result of higher efficiency), lower individual travel and lower fuel prices. Higher specific investment costs (*e.g.* for PLDVs) are offset due to lower stock that results from the "avoid and shift" strategy.

Between the 2DS and the CNS (and its variants), the vehicle stock is about constant; hence, there is less variation in investment costs. But by the time of large-scale vehicle technology deployment, the total costs of ownership (*e.g.* purchase costs, fuel costs, and operations and maintenance) among different vehicle types (PHEV, FCEV, BEV) are comparable, reflecting improved competitiveness as a result of economies of scale.

Infrastructure costs for roads, rail tracks, battery charging infrastructure etc. have not been included in this analysis, which means the full picture of total costs is not seen. But looking at the difference in cost of investing in and maintaining roads compared to rail tracks, or the cost of a charging infrastructure compared to a gasoline/diesel infrastructure, these differences will play a minor role relative to the costs of vehicles. Similar conclusions were presented in a recent Danish study on total costs for a fossil-fuel-free transport sector in Denmark by 2050 (Teknologirådet, 2012).

Figure 5.18 Undiscounted, cumulative costs for vehicles, fuels and O&M from 2010 to 2050



Note: PLDV = passenger light-duty vehicle. CV = commercial vehicle. O&M = operating and maintenance.

Key point *In the 2DS and the carbon-neutral scenarios (CNS, CNBS, CNES) cumulative spending on fuels is reduced compared to 4DS, while investments in vehicles are about equal.*

Technology spotlights

As seen from the scenarios, EVs and biofuels are expected to be the main – and most immediate – contributors in decarbonising the Nordic transport sector. In the longer term, other technologies such as hydrogen fuel-cell vehicles can become feasible solutions (see box 5.1). These technologies are likely to offer longer range and demand response possibilities, primarily by running electrolysers for production of hydrogen when wind power production is high. In the CNS and CNES, hydrogen accounts for 6.5% of the energy used for transport in 2050.

The following section on electric vehicles describes their advantages, possibilities, and existing policies and targets to support development of EVs already in place in the Nordic countries.

Electric vehicles

Achieving a long-term emissions reduction requires measures to improve fuel efficiency and alternative fuels, as well as new types of vehicles that can reach very low CO_2 emissions per kilometre including electric vehicles, hydrogen vehicles and plug-in hybrid electric vehicles.

Electric vehicles (EVs) are likely to become a cornerstone technology in transport systems. In addition to being independent of fossil fuels, EVs provide a number of advantages over conventional cars using combustion technologies, such as:

- Significantly reduced CO_2 emissions, especially when the car is charged using renewable energy. The amount by which CO_2 emissions are reduced depends on the marginal production (the last unit of electricity produced) of electricity at the time of charging, which depends on the flexibility of the charging and the surrounding energy system. For the next 10 to 15 years, marginal electricity production is likely to be supplied mainly by fossil fuels in Northern Europe. This will gradually change as the power sector is transformed into a purely renewable energy system.

- EVs reduce oil demand, thus improving the security of fuel supply and reducing the vulnerability to increasing or fluctuating crude oil prices.
- EVs improve the local environment significantly through less noise and no harmful atmospheric emissions (*e.g.* nitrogen oxides and particles), which is important especially in urban areas.
- EVs enable a high level of energy efficiency, depending on the source of power generation.
- EVs may contribute to the overall flexibility of the electricity system by providing a flexible electricity demand and EV batteries as storage. In practice, the amount to which EVs could contribute depends largely on the flexibility of the EV owners, the impact of smart metering schemes and the attrition on battery capacity.

In the next few years, it will be vital to build markets and promote customer acceptance of innovative technology, especially in regions that are heavily car-dependent (IEA, 2012). Even though battery costs have recently dropped, the cost of EVs on a “life-cycle” basis is still significantly higher than those of diesel or gasoline-based cars. The IEA expects that further reduction in the cost of batteries will allow EVs to become more competitive than conventional cars by 2020.

Considering the cost implication coupled with the limited driving range of existing EVs, it is apparent that dedicated policy measures are required in the short term to build markets for EVs.

The EU regulation concerning mandatory emissions-reduction targets for new cars provides additional incentives for manufacturers to produce vehicles with extremely low emissions (*i.e.* below 50 g/km) (EC, 2009). Each low-emitting car will be counted as: 3.5 vehicles in 2012 and 2013; 2.5 in 2014; 1.5 in 2015; and then one vehicle from 2016 onwards. These so-called “super credits” enable manufacturers to further reduce the average emissions of their new car fleet. Apart from that regulation, the European Union has not provided a policy framework to create a demand for EVs among European consumers.

The Nordic countries have all implemented various policy measures to promote electric vehicles, involving fiscal measures as well as funds to demonstrate and test various EV technologies.

Table 5.6 Existing instruments to promote EVs in the five Nordic countries

Denmark	EVs are exempt from registration tax and annual circulation tax; the exemption runs through 2015. It does not apply to hybrid vehicles. Free parking is available in some municipalities. Funds provided to support investments in recharging stations for EVs and to promote the infrastructure for hydrogen cars.
Norway	EVs are exempt from VAT, import duty and registration fees, and non-recurring tax for vehicles. They also have free parking and charging in public parking places, free drive-in lanes for public transport, and exemption from road tolls.
Finland	Car registration tax is based on CO_2 emissions: rates vary from 5% to 50%. EVs pay the minimum rate (5%) of the CO_2-based registration tax. As of 1 January 2013, EVs are exempt from the annual circulation tax, which is also based on CO_2 emissions. Rates for normal cars vary from USD 26 to USD 772.
Sweden	EVs with an energy consumption of 37 kilowatt hours (kWh) per 100 km or less and hybrid vehicles with CO_2 emissions of 120 g/km or less are exempt from the annual circulation tax (ownership tax) for a period of five years from the date of their first registration. For electric and plug-in hybrid vehicles, the taxable value (in Swedish “förmånsvärde”) of a company car under personal income tax is reduced by 40%, compared with the corresponding or comparable gasoline or diesel car. On 1 January 2012, the “super-green car premium” (Supermiljöbilspremie) of USD 5 970 was introduced for the purchase of all new cars with CO_2 emissions of maximum 50 g/km.
Iceland	EVs are exempt from VAT up to USD 12 870 while hydrogen cars and hybrids are exempt up to nearly USD 9 007. This is a temporary measure, set to expire at the end of 2013.

Note: These are measures taken at the national level in each country; local measures taken by municipalities may also exist, but have not been included here.

The sales figures for EVs have so far been rather moderate in all Nordic countries except Norway. At the end of 2011, some 370 EVs were in operation in Sweden, 750 in Denmark and just more than 200 in Finland. In Norway, the figure was about 3 900 and during the first nine months of 2012 close to 3 000 cars had been sold. In September 2012, EVs made up 5% of the total sales of passenger cars in Norway.

The possibility to avoid traffic congestion and easy access to parking and charging are likely to have had a significant impact on the willingness of consumers to buy an EV in Norway. Many Norwegian households have two cars and the share is even increasing slightly. Families with two cars have the opportunity to use an EV for daily driving for activities such as going to and from work, shopping, leisure, etc. The larger, fossil-fuelled cars can be used for longer distance travel.

There is strong political support for EVs in Norway. All political parties in the Norwegian Parliament, with the exception of one, recently signed a new climate agreement that implies a continuation to 2017 of tax advantages related to the purchase and use of zero-emission vehicles, up to a cap of 50 000 vehicles. This agreement provides a stable environment for consumers and car dealers. It also provides a framework that will enable the construction of the necessary recharging infrastructure. In addition, the goal of the climate agreement is that average emissions from new, privately owned cars will be 85 gCO_2/km by 2020, compared with around 135 gCO_2/km in May 2012. Parts of the vehicle stock must be zero-emissions vehicles such as EVs or conventional cars with significantly improved levels of energy efficiency.

In addition, the now-closed Norwegian car manufacturer Think Global fervently supported the development of policies to promote the deployment of EVs. As a result, such policies were in place when the larger international car manufacturers introduced their vehicles into the market.

Despite much lower EV sales than in Norway (between 260 and 320 cars per month in the first five months of 2012), several prominent EV concepts are being tested in Denmark, which may change the market in the years to come.

Several major private players developing EV technology have chosen Denmark as a test country for their concepts. The country provides favourable framework conditions for the early market introduction of factory-built EVs. Better Place, an electric vehicle firm active in Denmark, states that Denmark is a suitable test market due to its manageable size,[7] and topography that makes the infrastructure less complicated. Denmark is also considered a front runner in implementing renewable energy. Expertise in integrating wind power into the electricity system also makes Denmark a natural home to several major research and pilot projects for EVs and smart grids. The future potential for accessing smart grids and making use of excess wind power during low periods of consumption (*e.g.* during the night) is an advantage for investors of private EV technology concepts. Several competing charging systems are currently being installed and tested in Denmark.

Better Place works in partnership with the French car manufacturer Renault to provide the vehicles and the Japanese manufacturer Nissan to produce the lithium-ion batteries. Together with the national energy company, Dong Energy, Better Place has already installed eight battery-switching stations throughout the country and a national distribution of charging points. By January 2013, the expected number of functional battery-switching stations will be 15 and Better Place will establish an additional five during that year. In 2009, Dong Energy and Better Place initially envisioned that 500 000 electric vehicles would be driving on the Danish streets by 2020, a number that has since been revised downwards. Better Place currently has approximately 100 private customers and 300 business customers.

A competitor of Better Place is the Danish electric mobility operator (EMO) Clever, owned by energy companies Sydenergi and SEAS-NVE. Clever leases different EVs and provides charging

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[7] www.denmark.betterplace.com

stations, financial services, operational advice and environmental optimisation in relation to EVs and infrastructure. The company has also put in place 58 quick-charge and normal-charge stations. Clever uses the prevailing standard for quick-charging in Denmark, which was developed by Asian car manufacturers. This particular charging station can charge up to 80% capacity within 20 to 40 minutes, depending on the EV model and battery capacity. In addition, Clever has initiated a large EV testing project among private car drivers ("Test-an-EV") and is involved in the national demonstration project EDISON.[8] In total, 2 400 Danish citizens will test an electric vehicle for a period of three months. The project will run for two years, during which time Clever will collect data from the cars about battery technology, driving patterns, intelligent charging and the impact of EVs on the energy system.[9]

BYD, the Chinese car manufacturer, is yet another player on the Danish EV market. In March 2011, BYD Europe BV and Movia, the largest public transport company in Denmark, signed an agreement under which BYD is to provide two K9 pure electric buses for test run by Movia. The two electric buses will operate on a two-year trial run in Copenhagen on different passenger-carrying routes with different loads.[10]

In Finland, electric cars will be tested in a pilot scheme set up in Helsinki Metropolitan Area. According to plans, around 400 EVs will be in operation and the charging network will be expanded in the coming years. Employees of the municipality and private companies will drive the vehicles.

Fortum, the Finnish power company, has a charging concept for electric cars that provides charging services to companies and municipalities. The concept caters for different types of charging requirements, from overnight home charging to ultra-fast charging stations.

Icelandic law has exempted EVs from VAT: however, this is a temporary measure, set to expire at the end of 2013. Meanwhile, gains from the shift to EVs are large. Energy consumption of EVs already on the streets in 2010 was around 150 watt hours per kilometre (Wh/km) on average (Kristmundsson and Einarsdóttir, 2010). If, as a precaution, usage increases by 30% due to weather conditions, it would stand at 195 Wh/km. Based on general electricity prices in 2012, energy cost for using an EV in Iceland is USD 0.0183/km. With the current fuel price of around USD 1.93/L, owners of fossil-fuel-powered vehicles using only 5 L/100 km have an energy cost of USD 0.0966/km. Although their cars are energy efficient, they could still cut their fuel cost by more than 80% by switching to EVs.

Sigurðsson (2010) compares EVs and competing combustion engine cars with regard to Icelandic circumstances. Assuming a 6.36% interest rate, similar maintenance costs and fixed energy prices, this study concludes that a consumer driving an average distance per year would have to own and operate an EV for six to seven years before lower energy costs completely offset the initial price difference. The average age of cars in Iceland has been about nine years for the last two decades. With this relatively long period of ownership, rising fossil-fuel prices and declining EV prices could yield an outcome that is more favourable for EVs.

In the carbon-neutral scenarios investigated by *NETP*, electricity use for transport increases significantly in 2050 in all five Nordic countries combined – from the current 5 terawatt hour (TWh) (mainly railroads) up to around 40 TWh (some 7% of total net generation). A large share of that is assigned to EVs. Such a development will, of course, present new challenges to the electricity-supply system.

In many respects, a shift towards electric-powered transport is especially desirable and technically feasible in Iceland. The potential effects of a large expansion of electric vehicles on the Icelandic electricity system are discussed in Chapter 3.

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[8] www.edison-net.dk

[9] www.clever.dk

[10] www.byd-auto.net

Box 5.1 Hydrogen highway HyNor project

In 2003, interested parties from industry, government, environmental organisations and academia joined forces and initiated the HyNor project, which identified hydrogen as the energy that could provide clean transport for the future. Hydrogen was also highlighted as a key potential for Norway, a nation with a long history of exporting oil and gas, to play an important part in the use and production of future fuels. To demonstrate that technology for hydrogen stations is a viable alternative to the existing fossil-fuel-based infrastructure, participants decided to build a "hydrogen highway" from Stavanger in the west of Norway, along the southern coast, ending in Oslo in the east.

Along this road, which is 580 km, the project identified a certain number of sites (or nodes) as being important to enable driving a hydrogen vehicle comfortably without running out of access to fuel. Cities along the highway are home to more than half the population of Norway.

Separate private-public project groups were established for all the nodes, along with a steering committee for the project leaders who would co-ordinate efforts.

Phase I of the project (2003 to 2009) aimed to demonstrate the technology by enabling hydrogen vehicles to drive and refuel along this road.

The main points of focus for Phase II (2010 to 2012) were increasing the density of refuelling stations in the capital region and acquiring more vehicles. Other projects are worthy of note: H2-Moves Scandinavia has led to the introduction of 17 FCEVs on the road in Oslo, and CHIC (HyNor Oslo Bus) has resulted in five FC buses in Oslo.

Phase III (2013 to 2015) will focus on preparing for the introduction of FCEVs into the market. The project will work more closely with government agencies to ensure that the right codes and standards are in place. In addition, collaboration with neighbouring countries will be further strengthened, particularly through the Scandinavian Hydrogen Highway Partnership (SHHP). Potential pioneer customers will also be engaged to ensure a gradual build-up of the vehicle fleet in Norway, thereby giving car dealerships and maintenance crew some time to increase the practical experience related to FCEVs before the commercial introduction begins.

The focus on the infrastructure side will be to strengthen the station network in the Oslo region, making it permanent, with emphasis on the possibility to expand the capacity of the stations and to mobilise the adjoining corridors. The main priority will be the inter-city infrastructure, but some smaller, satellite stations will be important to release the full potential of the hydrogen vehicles.

Critical challenges

The technical potential to reduce GHG emissions in the transport sector are considerable and the Nordic countries have set out ambitious goals to reduce emissions to a minimum in the long term. Whether these targets can be met will depend on several factors, of which the following are likely to be the most important.

- **Growth in demand for transport must be slowed.** Recent statistics indicate that transport growth will be more moderate in the future, but there is a level of uncertainty about how demand will evolve in the long term.
- **The economics and performance of EVs need to be improved in order to make them competitive and attractive to consumers in the medium term.** In modelling exercises, EVs become a cornerstone technology due to their high efficiency and use of renewable energy sources that are not based on biomass. If they do not become more competitive in the real world, it will prove to be a big challenge for the long-term transformation of transport systems.
- **Modal shifts must be accelerated.** The 2DS assumes that a significant share of transport from cars and trucks will switch to train, bus and other modes of public transport. This transformation will require large investment in new infrastructure and may also necessitate strong policies, which may not be popular among consumers and companies.

Current policies of the Nordic countries are ambitious in the long term, but it is difficult to see that the policies now being implemented will enable development along the lines of either the 2DS or the CNS. A step forward would be to identify – within each of the generic measures of avoid, shift and improve – specific milestones and related policies with goals to be achieved by 2020 or 2025.

Chapter 6

Buildings

Direct carbon dioxide (CO_2) emissions per capita associated with the residential sector have fallen significantly and much faster in the Nordic countries than in other regions around the world. Greater energy efficiency and decarbonisation of the sector, however, could still lead to significant CO_2 emissions reductions.

Key findings

- ***The Nordic countries have progressively reduced the role of fossil fuels in the buildings sector as well as increased the energy efficiency of buildings.*** *This has been achieved by financial incentives, awareness campaigns, energy certificate systems, a system for certifying qualified experts and gradually introducing more stringent building codes.*
- ***Building codes are important policy devices for transitions to less energy intensive and low-carbon economies.*** *The Nordic countries have used this policy device progressively.*
- ***Direct emissions of CO_2 per capita in the buildings sector are now close to the world average,*** *despite a much greater energy use per household.*
- ***Electricity and commercial heat will dominate heating in both the residential and services sectors.*** *There is no great difference in terms of energy use shares between the two variants of the Carbon-Neutral Scenario (CNS) – the Carbon-Neutral high Bioenergy Scenario (CNBS) and the Carbon-Neutral high Electricity Scenario (CNES).*
- ***The similarities in energy use among the scenarios can be attributed to historical efforts in the Nordic countries to phase out the use of fossil fuels and promote other energy sources.***
- ***Carbon emissions associated with the buildings sector need to be reduced from 50 million tonnes of CO_2 ($MtCO_2$) in 2010 to less than 5 $MtCO_2$ in the 2°C Scenario (2DS)*** *and be even lower in the variants of the CNS.*
- ***Policies should focus on requiring retrofitted buildings to use best available technologies (BATs) for space heating.*** *Since building stock turnover is low (on the order of 1% per year), retrofits of the relatively old building stock will be more important for overall energy efficiency than new construction in the short term.*
- ***Some USD 100 billion[1] in additional investments will be required, primarily for building shell and appliances.*** *These are investment needs in the 2DS over and above those in the 4°C Scenario (4DS).*
- ***Low return on energy efficiency investments and, in some cases, social acceptance*** *are primary barriers to energy and CO_2 savings.*

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[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.

Recent trends

Buildings, both residential and service, use a variety of technologies and materials to provide the modern-day Nordic comforts. Energy is used for space heating and cooling, water heating, lighting, and various appliances, as well as business equipment in the service sector. The main factors influencing energy demand include population, income growth, number of people per household, appliance ownership, energy efficiency, existing technologies, efficiency of building shell (roofs, walls, windows), and climate. A complex interaction, therefore, exists among energy, material, economic, climate and demographic factors.

Most buildings last for decades, and some even for centuries. In the Nordic countries, buildings are more often refurbished than replaced, as they are rarely torn down and rebuilt. In order to save energy and reduce CO_2 emissions, taking into account the longevity of the building stock, it is important that best available technologies (BATs) are chosen when buildings are refurbished or built.

According to IEA estimates, 73% of existing building stock will still be in use in 2050 in Finland, Norway and Sweden. Energy efficiency measures during refurbishments, therefore, need to be addressed to a much greater extent than energy efficiency in new buildings in order to curb the overall energy demand in the buildings sector. However, the existing housing stock in the Nordic countries varies considerably among countries. Housing stock in Norway and Finland, for example, is relatively new and, therefore, refurbishment is more likely to take place to a greater extent than new construction. In Sweden, however, around one million apartments built in the 1960s will soon need to be refurbished, which provides a great opportunity but also a significant challenge to improve energy efficiency in the existing Swedish housing stock.

In Denmark, the housing stock is relatively old, with 79% of the buildings built before 1979 when tighter building codes were put in place. Furthermore, building turnover rate in Denmark has in the past been relatively slow and this further slows the rate of energy efficiency improvements. Old buildings are, therefore, more likely to be replaced by new energy efficient buildings rather than refurbished to a much greater extent in Denmark and Sweden than in Finland and Norway. As a result, it is likely that the average energy efficiency of buildings in Denmark and Sweden may increase faster in the near future when compared with Finland or Norway (Table 6.1).

Table 6.1 Share of residential building stock by age

Denmark	1919 and before	1920-45	1946-69	1970-79	1980-90	1991-2000	2001-09
	19.7%	16.1%	26.4%	16.6%	9.1%	5.4%	6.7%
Finland	1918 and before	1919-45	1946-70	1971-80	1981-90	1991-2000	2001-09
	1.5%	8.1%	27.6%	21.5%	18.5%	11.5%	9.8%
Norway	1921 and before	1921-40	1941-70	1971-80	1981-90	1991-2000	2001-10
	9.0%	6.8%	28.2%	17.1%	15.0%	10.6%	13.3%
Sweden	1918 and before	1919-45	1946-70	1971-80	1981-90	1991-2000	2001-08
	12.1%	14.7%	37.0%	16.8%	9.4%	5.5%	4.6%

Note: Residential buildings stock by age is not available for Iceland.
Source: Unless otherwise noted, all tables and figures in this report derive from IEA data and analysis.

The number of households and the number of people per household significantly affect energy consumption in the buildings sector. A population that is characterised by fewer people per household, but a larger total number of households, leads to a higher demand for energy. The average number of people per household in the European Union was 2.4 in 2010, while it was 2.0 in Denmark, Finland and Sweden, 2.1 in Norway, and 2.4 in Iceland. More households exist in the Nordic countries relative to the size of population. Types of residential dwellings also influence energy demand in the sector, as apartment buildings tend to have smaller residential dwellings per household compared with, for example, detached houses. Over half of building types in the Nordic countries are detached and semi-detached houses (Table 6.2). The lowest share of apartment buildings is in Norway at 23%, while it is around 40% to 50% for Denmark, Finland and Iceland.

Table 6.2 Share of dwelling type in the residential sector

2010	Denmark	Finland	Iceland	Norway	Sweden
Detached (one dwelling) houses, farmhouses	44%	41%	50%	52%	56%
Semi-detached (two dwelling) houses	14%	14%		9%	
Row (attached, linked, terraced) houses				12%	44%
Multi-dwelling buildings (apartment buildings)	39%	44%	49%	23%	
Other dwellings	3%	2%	1%	4%	N/A
Total	100%	100%	100%	100%	100%

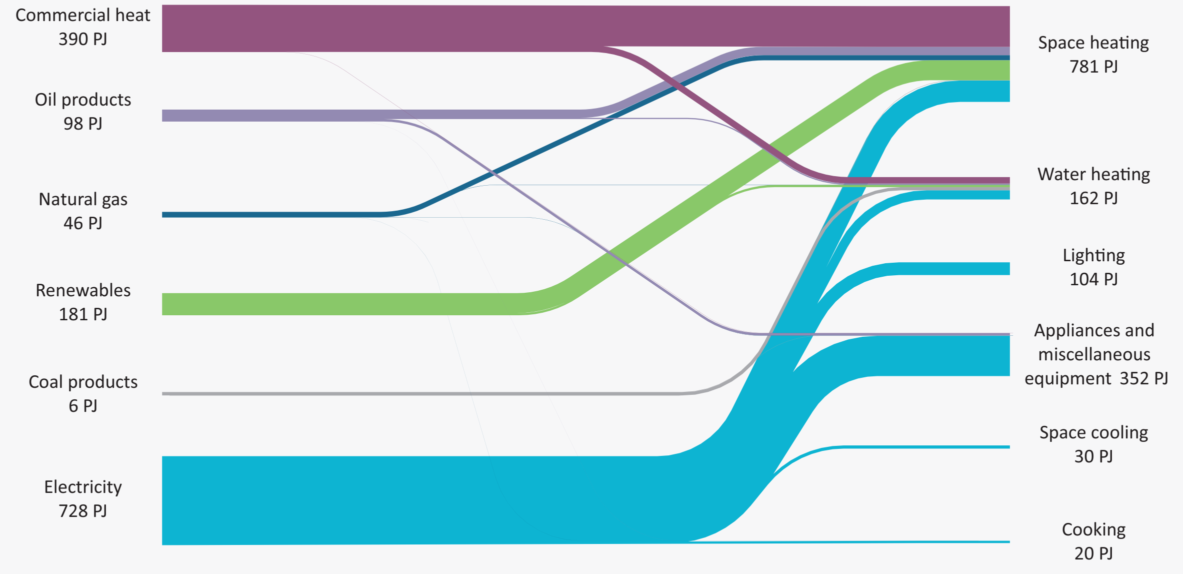
Sources: Statistics Sweden, 2012; Statistics Norway, 2012; Statistics Denmark, 2012; Statistics Finland, 2012; Sigurdardottir, 2012.

Energy use in the Nordic buildings sector

The buildings sector used 1 527 petajoules (PJ) of energy in 2010, or about 33% of total energy use in the Nordic countries. The share of energy used in the Nordic buildings sector is similar to the worldwide share of energy use. About two-thirds of all energy used in the buildings sector, amounting to 965 PJ in 2010, was used in the residential sector. The remaining energy, 562 PJ, was used in the service sector in 2010.

Electricity is the most used source of energy in the Nordic countries, followed by commercial heat. Renewables account for about 12% of total energy use, while fossil-fuel use is 10%. The greatest share of the energy is used for space heating, followed by appliances and miscellaneous equipment (Figure 6.1).

Figure 6.1 Nordic energy flows in the buildings sector, 2010



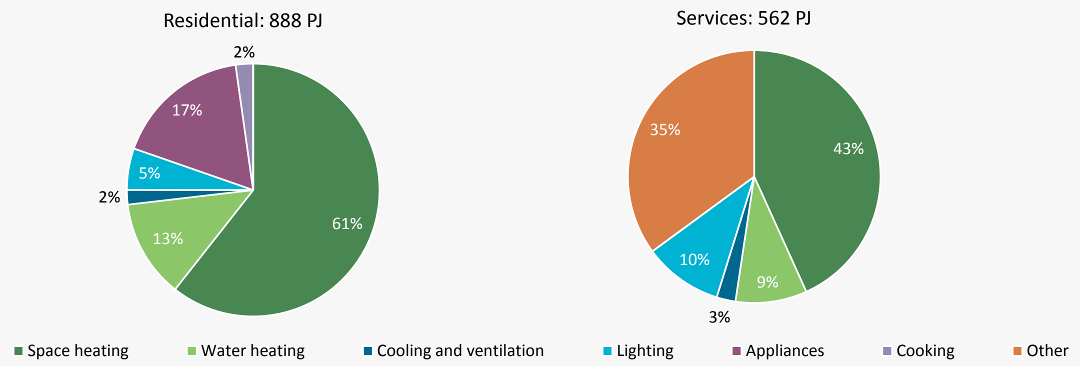
Notes: Figures and data that appear in this report can be downloaded from www.iea.org/etp/nordic.
The numbers for energy use in this figure have been heating degree-days corrected.

Key point *Electricity and commercial heat are the most used energy sources.*

Nearly 60% of all energy used in Nordic households is used for space heating and 13% is used for water heating (Figure 6.2). The relatively cold climate, as well as prosperity in the Nordic countries characterised by the high number of smaller households compared with other regions, most likely contributes to the greater total energy use compared with other groups of countries.

The Nordic countries are relatively prosperous, as they have the highest gross domestic product (GDP) per capita of all the groups of countries. The energy use per household is also high, 73 gigajoules (GJ) per household, and only OECD Americas has greater use of energy per household (Figure 6.3). The ratio of GDP per capita and energy use per household is an indication of the energy efficiency of household prosperity and is 0.44 (GDP per capita/GJ per household) for the Nordic countries and second only to OECD Asia-Oceania, which has a ratio of 0.62. Nordic countries have a slightly higher ratio than OECD Europe of 0.41 but much higher than, for example, Latin America, 0.32 ; China, 0.25; and India, 0.13 (GDP per capita/GJ per household).

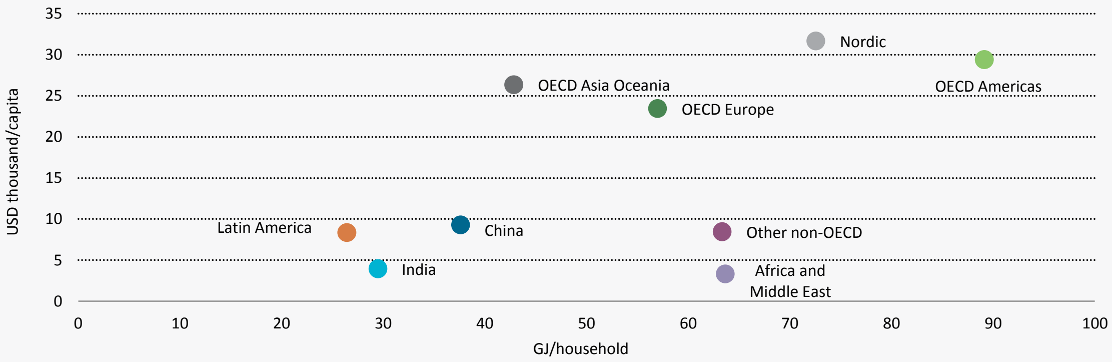
Figure 6.2 Nordic share of energy use by type, residential and services, 2010



Note: The numbers for energy use in this figure have been heating degree-days corrected.

Key point *Space and water heating require the most energy in Nordic households.*

Figure 6.3 GDP per capita and GJ per household in the residential sector, 2009



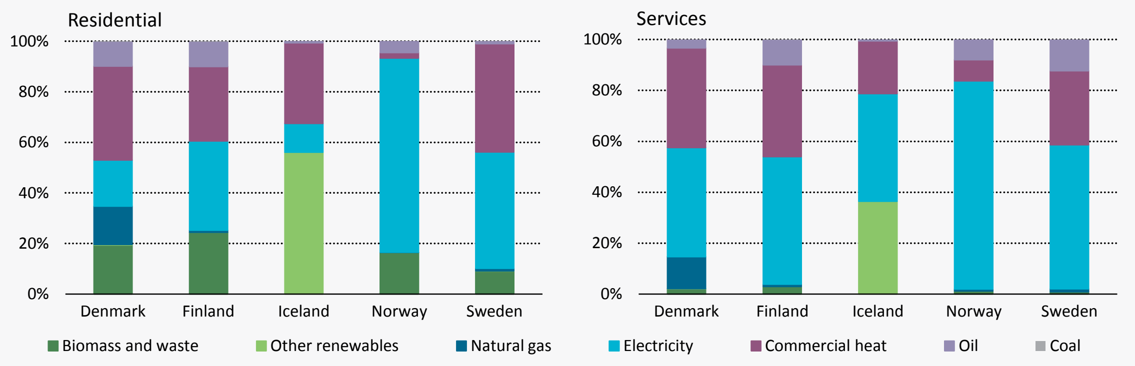
Notes: GDP = gross domestic product. GJ = gigajoule.

Key point *The Nordic countries are prosperous and use more energy per household than other world regions.*

Use of different energy sources

In this analysis, buildings are divided into two categories: residential and services. The use of energy sources differs the most for Iceland and Norway compared with other Nordic countries (Figure 6.4). Geothermal energy is used in Iceland for space heating while electricity is used in Norway. Geothermal energy in Iceland is a relatively cheap energy source and became the dominant source for space heating soon after the oil crisis mainly due to government policies. Currently, approximately 90% of all Icelandic households use geothermal energy for space heating. Moreover, the Icelandic government has implemented policies to increase even further the use of geothermal energy.

Figure 6.4 Energy use by type in the building sector in 2010



Key point *Energy sources in the Nordic countries differ significantly among countries.*

Norway´s use of electricity in the residential sector is much greater than in the other Nordic countries as electricity is commonly used for space heating. The abundance of hydropower for electricity production and low electricity prices has led to this trend. Consequently, the share of electricity used in the buildings sector is much greater in Norway compared to the other Nordic countries. The Norwegian government implemented a policy in 2007 where 40% of energy for space and water heating in new and refurbished houses must come from energy sources other than electricity or fossil fuels.

District heating has been increasing in all Nordic countries for decades and has reached maturity in all countries except Norway. The growth potential in district heating is, therefore, limited in the other four Nordic countries while growth opportunities still exist in Norway (Nordic Energy Perspectives, 2009).

All the Nordic countries use relatively few fossil fuels in the residential sector. Therefore the starting point for fossil-fuel use is low when it comes to analysing different scenarios. Oil is close to 10% of energy use in both Denmark and Finland, while it is around 5% in Norway and only 1% in Sweden. The share of oil usage in the residential sector in Iceland is negligible, as is the use of coal in all Nordic countries. Denmark is the only country that uses a significant amount of gas in the residential sector, accounting for 14% of total buildings energyuse. All Nordic countries, except Iceland, use between 9% and 24% of biomass and waste as an energy source in the residential sector.

Generally, the service sector uses more electricity than the residential sector due to lighting, air conditioning and business equipment, and this is no different in the Nordic region. The lowest share of electricity in the service sector is found in Iceland at 42%. (Figure 6.4). Again, Iceland is the only country using significant quantities of geothermal energy. Finland uses the greatest share at 80%.

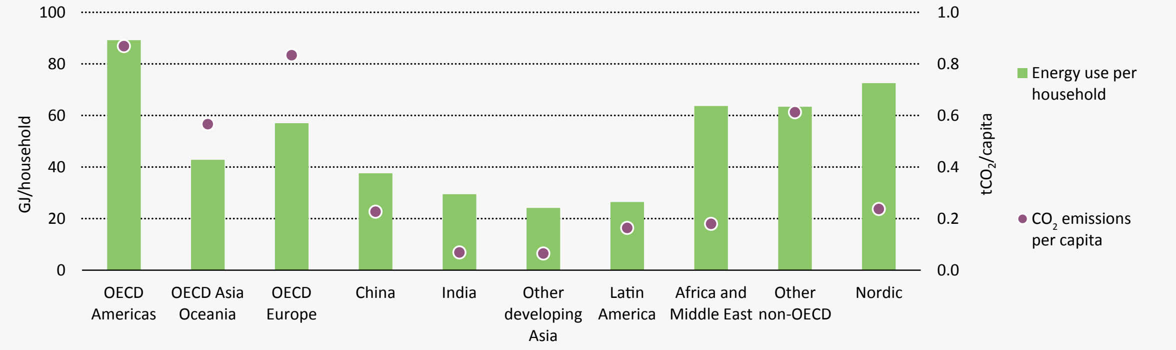
In general, more fossil fuels are used in the service sector compared with the residential sector. However, the share is still relatively low. Denmark uses the greatest share of fossil fuels at 16% and is the only country to use a significant amount of gas, which accounts for 13% of total energy in the country's service sector. The share of fossil fuels used stands at 12% in Finland, 10% in Sweden and 8% in Norway, and in all of these countries oil is the main fossil fuel used. Iceland uses the least amount of fossil fuels at 1%, with oil being the only fossil fuel used.

The share of biomass and waste is much lower in the service sector compared with the residential sector. The share of biomass is only between 0% and 3% in the service sector compared with between 9% and 24% in the residential sector. These figures do not include Iceland because the country does not use biomass and waste as a source of energy.

CO_2 emissions from the buildings sector

Given their level of energy use, Nordic countries emit significantly less CO_2 per capita in the residential sector compared with other groups of OECD countries. Direct emissions in 2009 amounted to 0.24 tonnes of CO_2 (tCO_2) per capita in the Nordic countries, while OECD countries in the Americas and Europe revealed a level of direct emissions greater than 0.8 tCO_2 per capita (Figure 6.5).

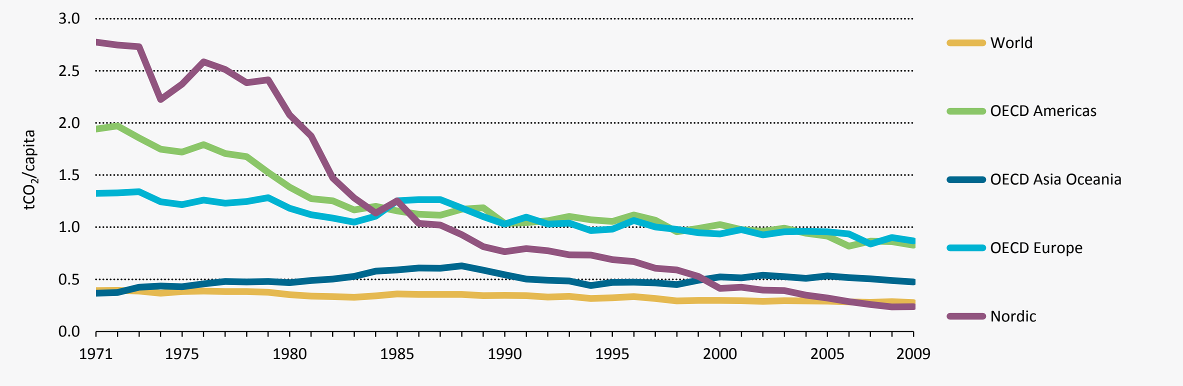
Figure 6.5 Energy use per household and direct CO_2 emissions per capita in the residential sector, 2009



Key point *Direct CO_2 emissions per capita are much lower in the Nordic countries compared with other groups of countries.*

Direct carbon dioxide emissions per capita have been decreasing ever since they reached a peak in 1970 at 2.92 tCO_2 (Figure 6.6). Nordic countries placed particular emphasis on phasing out the direct use of fossil fuels in the residential sector (see Technology Spotlight), which has helped to significantly reduce the direct emissions per capita.

Figure 6.6 Direct CO_2 emissions per capita in the residential sector



Key point *Direct CO_2 emissions per capita have fallen much faster in the Nordic countries compared with other regions.*

Scenario assumptions

Energy consumption in the buildings sector is driven by a number of factors including population, income, number and size of households, geographic region, climatic conditions, energy prices, services sector value added, and floor area of service sector. These factors have an impact on the heating and cooling load, the number and types of appliances owned, and their patterns of use. Those key parameters are used in all the scenarios analysed in this section.

Table 6.3 Key activity in the buildings sector

	2010	2030	2050	Average annual growth rate 2010–50
Population (thousands)	25 498	27 848	28 941	0.3%
GDP (million, 2010 USD at PPP)	1 009	1 645	2 349	2.1%
GDP/capita (thousand, 2010 USD at PPP)	39 586	59 058	81 175	1.8%
Total households (thousands)	10 379	10 712	11 005	0.1%
Residential floor area (million m^2)	1 176	1 325	1 493	0.6%
Household occupancy (people per house)	2.5	2.6	2.6	0.2%
Average floor area per household (m^2)	113	124	136	0.4%
Services floor area (million m^2)	486	550	589	0.5%

Note: PPP = purchasing power parity.

The different scenarios and variants use different assumptions for technology penetration, fuel shares, adoption of BATs and implementation of energy efficiency measures. The specific assumptions can be found in Annex C.

Scenario results

Energy consumption

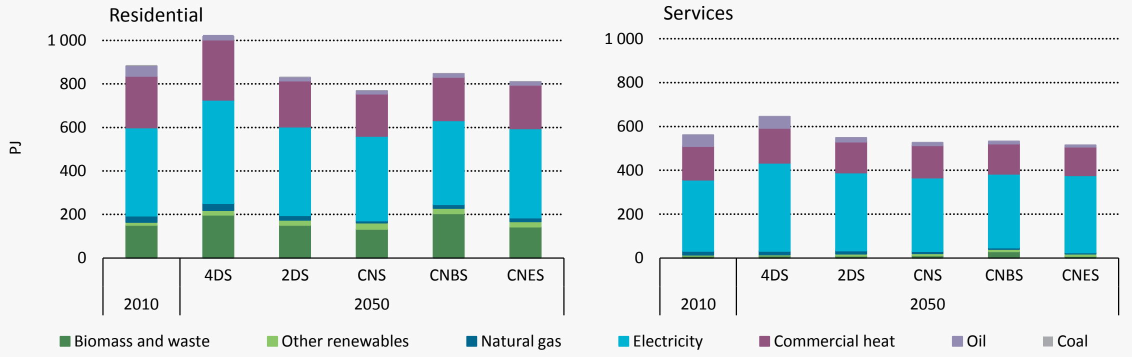
The total amount of energy used in residential buildings increases from 965 PJ in 2010 to 1 031 PJ in 2050 in the 4DS, or about 7%. The increased energy use will come from electricity, biofuels and waste, while the use of fossil fuels will decrease significantly.

In the 2DS, total energy consumption decreases 8%, from 965 PJ in 2010 to 846 PJ in 2050 in the residential sector. The energy use in the CNS and its two variants is, in general, similar to the 2DS. The use of fossil fuels has decreased further compared to the 4DS, and the main difference is the increased use of biofuels and waste in the CNBS.

Energy use in service buildings is expected to increase from 562 PJ in 2010 to 645 PJ in 2050 in the 4DS, or 15%. Energy use is lower in the four other scenarios. Moreover, the use of fossil fuels has decreased whereas the use of biofuels and waste has increased. Electricity and commercial heat continue to be the dominant energy sources in the service sector through to 2050.

Overall, the differences in energy shares among the scenarios are not significant. In all scenarios, for both the residential and service sector, electricity and commercial heat will continue to be the main sources of energy (Figure 6.7). The use of biofuels and waste will also be significant and will increase substantially. The use of fossil fuels will decrease, and in some scenarios will be negligible, while the use of renewables will increase but not by significant amounts.

Figure 6.7 Energy consumption in the buildings sector

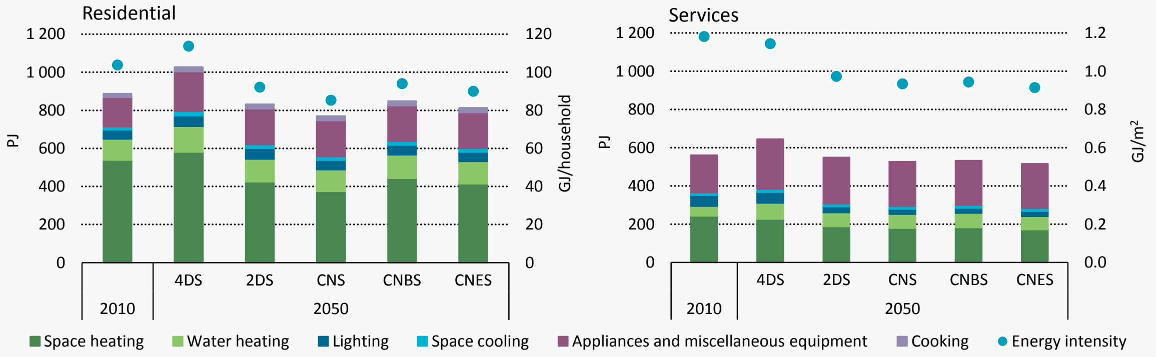


Notes: Other renewables include solar and geothermal. The numbers for energy use in 2010 in this figure have been heating degree-days corrected.

Key point *Energy use in the residential sector increases by 7% in the 4DS.*

The similarities in energy use among the scenarios can be attributed to the historical efforts in the Nordic countries to phase out the use of fossil fuels and promote other energy sources. The outcomes from the two variants of the CNS (the CNBS and CNES) are not drastically different from the CNS although special emphasis has been placed on either biofuels and waste, or electricity and its infrastructure. Energy use per household is only greater in the 4DS compared with current levels while it is lower in the other four scenarios (Figure 6.8). The lower energy intensity levels include improvements such as in space heating, lighting and appliances as described in Annex C. Space and water heating continue to be the main uses of energy in the Nordic households in 2050. Space heating, appliances and lighting will also continue to be the main use of energy in the service sector.

Figure 6.8 Energy consumption and intensity in the buildings sector



Notes: GJ/m^2 = gigajoules per square metre. The numbers for energy use in 2010 in this figure have been heating degree-days corrected.

Key point *Demand for water and space heating remains dominant in 2050.*

Overall, the scenarios in the buildings sector portray electricity and commercial heat as the main future energy sources regardless of whether it is the 4DS, 2DS, CNS or its variants. The main uses of energy will continue to be space and water heating. The main growth in all scenarios is projected to be in other renewables, and biofuels and waste. Although the share of renewables increases fast, their use does not alter future energy shares significantly. The use of fossil fuels in all scenarios is reduced from 12% in the service sector and 10% in the residential sector in 2010 to 8% in the 4DS and between 3% and 6% in the 2DS and its variants. This inevitably leads to a reduction in CO_2 emissions.

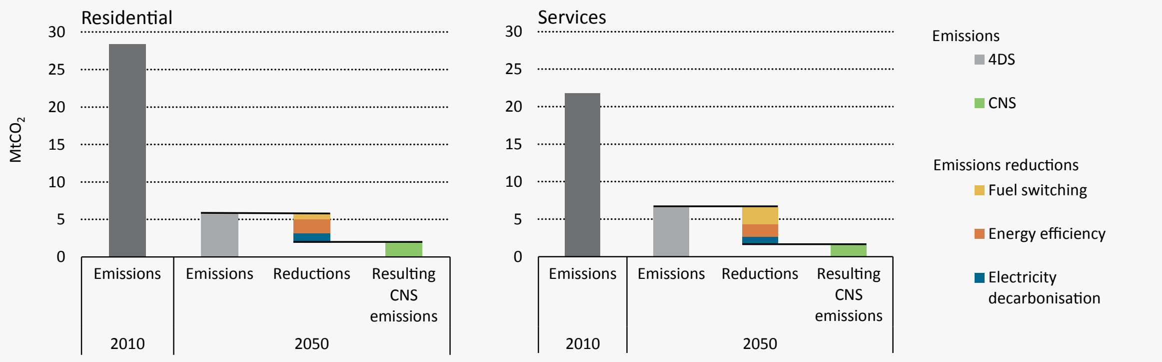
Emissions from the buildings sector

By 2050, direct CO_2 emissions in the buildings sector need to decrease about 20% compared with 2010 levels in the 4DS and nearly 60% in the 2DS. The greatest emissions savings will come from increased energy efficiency, fuel switching as well as decarbonization of electricity (Figure 6.9).

The share of emissions directly from the buildings sector in 2050 will be 6% of total emissions in the 4DS and 7% in the 2DS, compared with 5% in 2010 and 12% in 1990. The reason for the increased share of emissions from this sector, compared with total emissions, can be attributed to the fact that a great reduction in direct emissions has already taken place. The reduction was achieved by the introduction of various policies that had the goal of phasing out fossil fuels. These past efforts have, therefore, already greatly reduced the amount of emissions within the buildings sector.

Given the projected population of 28.9 million in the Nordic countries in 2050, the direct emissions of CO_2 per capita in the residential sector are expected to be around 0.08 tCO_2 in the 4DS and 0.06 tCO_2 in the 2DS. Both of these amounts are considerably lower than the 2010 levels of 0.24 tCO_2. The share of fossil fuels in the energy mix decreases considerably in all scenarios and accounts for a mere 3% to 6% in the 2DS, CNS and its variants. Given the low share of fossil fuels, it is quite possible that the buildings sector will be CO_2-neutral in the future as remaining fossil fuels are replaced by other energy sources.

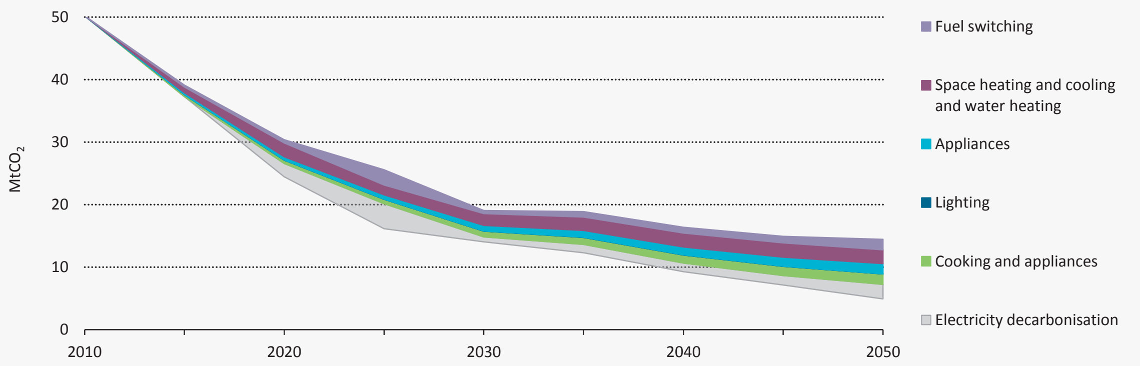
Figure 6.9 CO_2 emissions and reductions in the buildings sector



Key point *Emissions in the buildings sector will continue to decrease in both the 4DS and the 2DS.*

From now until 2020, emissions savings will mainly be due to greater energy efficiency. After 2020, however, decarbonisation must take place and then provide the greatest share of indirect emissions savings until 2050 (Figure 6.10).

Figure 6.10 Options contributing to CO_2 emissions reduction in the 2DS and CNS compared to the 4DS

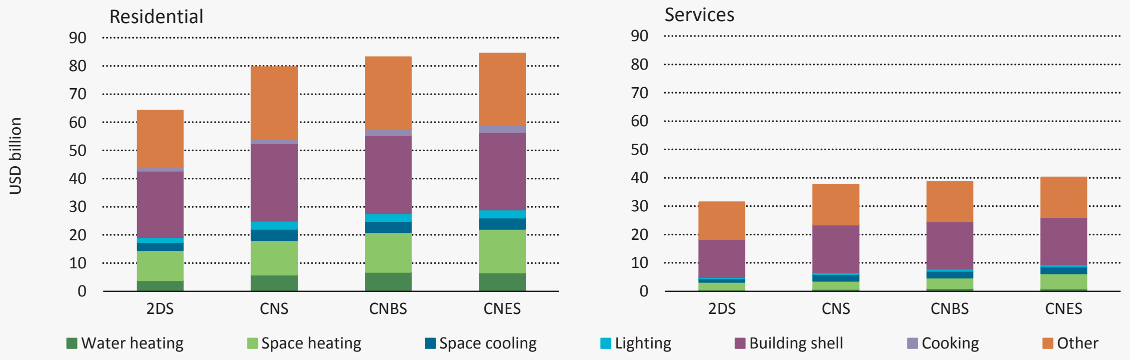


Key point *Decarbonising electricity will be necessary in the long term to avoid CO_2 emissions.*

Additional investments required in the buildings sector

The total additional investment in end-use technology needed to achieve the 2DS, CNS, CNBS and CNES compared to the 4DS is estimated to be between USD 96 billion and USD 124 billion (2012 USD). Most of the additional investment is needed in the residential sector, which will require between USD 64 billion and USD 84 billion in investment (Figure 6.11).

Figure 6.11 Additional investment needs in the buildings sector 2010 to 2050 (2012 USD)



Key point *Additional investments need to take place in the building shell and appliances.*

The greatest share of additional investment is in the building shell and appliances (other), which accounts for about 60% to 70% of all additional investment in the residential sector and around 80% in the service sector. This additional investment is needed to ensure that the buildings sector adopts the more stringent assumptions as laid out in Annex C.

Technology spotlights

Current policies for phasing out fossil fuels in the buildings sector

Nordic countries are implementing various measures to phase out fossil fuels as sources of energy for space heating. The European Performance of Buildings Directive (EPBD),[2] with its energy performance certificate system; the Boiler Efficiency Directive;[3] and the directive on the energy labelling of household appliances have all been implemented.[4] Out of the three directives though, Iceland has implemented only the one on energy labelling of household appliances.

Although measures adopted differ widely among the Nordic countries, they fall into three distinct categories. Categories include: measures aimed at reducing the use of fossil fuels by increasing energy efficiency; those aimed at preventing use completely by switching to renewables; and others used to raise awareness about efficient technologies.

All Nordic countries address the high initial investment costs associated with switching to renewables through a number of different measures. For example, all countries financially endorse the scrapping of oil-fired boilers and electrical heating. In Norway, as a general rule, 40% of heat demand in new buildings has to be supplied by sources other than grid electricity or fossil fuels (exemptions are possible). A ban on electrical and oil heating in new buildings also exists. Grants are awarded to those who install heat pumps or wood-pellet stoves and in February 2009, around 31 000 people applied for such grants. Grants can be up to 20% of the investment cost, with a maximum of USD 1 700 granted for heat pumps. Denmark subsidises the scrapping of oil-fired boilers only to replace them with district heating when possible, but elsewhere with heat pumps and solar energy. In 2010, USD 68 million was earmarked for this purpose. A ban on electric heating also exists and conversion to electric heating is encouraged in existing buildings in areas where district heating or natural gas networks are available.

Sweden has given tax refunds amounting to 30% of costs when converting from oil boilers to renewables. The state covers the material and labour costs of accessing district heating and provides investment grants for photovoltaic (PV) installations. By 2010, USD 9.6 million had been granted in solar heating investments. The Central Finland Energy Agency promotes wood-pellet heating and since 2011 a subsidy has covered 20% of costs incurred when residential buildings switch from oil or electric heating to either wood-pellet heating or heat pumps. In 2010 alone, 112 000 tonnes of wood pellets were used for heating in Finland, avoiding an estimated 85 000 tCO_2 emissions. The Icelandic Energy Authority subsidises a switch from fossil-fuel or electrical heating to heat pumps when geothermal district heating is not available by providing lump-sum grants according to the cost and estimated energy savings. The authority also subsidises connections to district-heating systems when available as well as the construction of new district-heating systems.

Lack of awareness about efficient technologies also inhibits market solutions. The Nordic countries have addressed that by campaigning for energy efficiency and renewable energy, and by implementing energy labels and certificates. The Nordic environment label, The Swan, takes energy efficiency and greenhouse-gas (GHG) emissions into account. More than 6 000 trademarks in over 70 categories of products and services currently carry the label. Each country has its own measures as well. The Norwegian Research Council, Enova, runs an energy information helpline and energy guidance label. There have been

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[2] Directive 2002/91/EC of the European Parliament and of the Council of 16 December 2002 on the energy performance of buildings

[3] Directive 92/42/EEC of 21 May 1992 on efficiency requirements for new hot-water boilers fired with liquids or gaseous fuels.

[4] Directive 2010/30/EU of 19 May 2010 on the indication by labelling and standard product information of the consumption of energy and other resources by energy-related products.

information campaigns and regional energy efficiency centres run by utilities, providing information to consumers. The Danish Energy Fund has campaigned with printed guides, TV programmes and advertisements, for instance informing people on the savings from low-energy products despite their higher initial costs. The Electricity Savings Trust provides consumers with updated information on their energy consumption and has campaigned for the use of electricity-saving sockets. In Finland, there have been campaigns promoting heat pumps and energy conservation in oil-heated buildings. Consumers can also obtain co-ordinated energy advice and information on energy conservation on the web, by e-mail and via a telephone helpline. The Icelandic Energy Agency also provides information on energy, creates educational materials for schools and consumers, and helps small and medium-sized companies and municipalities to plan strategies to improve energy efficiency. Online calculators are also available for homeowners to calculate their possible energy savings, energy costs and payback time for the investment. Reykjavik Energy also offers information and education on energy use and ways to reduce it.

Building codes stipulate minimum requirements for housing insulation to limit energy demand, which have gradually been tightened (see Technology Spotlight on building codes). Nordic countries also help homeowners to meet, and even exceed, these requirements. Norway defines two levels of energy efficient residential buildings (low energy buildings, LEBs) and one level of passive houses. The government provides financial support to those wanting to meet these standards, as well as others who just want to improve energy efficiency. The city of Oslo also has a local energy efficiency fund, which allocates grants of at least USD 260 or 20% to 50% of the project costs for improving energy efficiency in all permanent residences. However, the fund has only led to 1 TWh of saved energy since 1982. According to Enova’s 2011 annual report, the company’s various research and development (R&D) or building and energy improvement grants and projects have amounted to USD 2 billion in the past decade, and yielded total energy savings of 16.56 TWh. Denmark also defines classes of LEBs, although definitions are not the same in all Nordic countries. For such houses, the ban on electric heating and obligations to connect to district heating or natural gas networks do not apply. Thus, although radically reducing the usage, LEBs don’t necessarily mean the abolition of fossil fuels for space heating. Denmark, for example, has a grant scheme supporting the development, production and marketing of energy-saving products. Thereby it encourages technicians and innovators on the market to turn their focus to energy efficiency. Annual maintenance and supervision of heating equipment has also helped to reduce use.

Sweden offered subsidies to households in LEBs and tax concessions to those renovating houses with regard to energy efficiency. Current policies are not directly aiming for energy efficiency measures as households get tax deductions for general building improvements. In Finland, subsidies and grants are also awarded for improving insulation, and buying more efficient boilers and electrical appliances. Tax deductions of up to USD 3 800 per person also apply for those employing technicians for energy efficiency improvements. A policy also exists to have energy meters fitted in all homes and individual apartments in apartment buildings. Regular energy audits have also helped to reduce energy consumption. The Icelandic Energy Agency provides insulation grants to those living in areas without geothermal district heating.

Building codes in the Nordic countries

Being the northernmost region in Europe, the Nordic countries are exposed to some of the coldest and most extreme winter temperatures. Good insulation in buildings has, therefore, long been a matter of interest for their inhabitants. Climate is quite variable though, both among and within these countries. The Scandinavian peninsula reaches far north and is dominated by a mainland climate where temperatures can plummet to extremely low levels or rise to extremely high ones as well, for extended periods. Iceland, with its more tempered but windier oceanic climate, is somewhat an outlier in this respect.

Building codes are important policy devices for transitions to a less energy-intensive and low-carbon economy. Such codes are also a central factor in reducing CO_2 emissions to levels outlined in the *NETP* scenarios as well as help to advance energy efficiency in the region's building stock. Building codes are also important for sustainable development, technical advances and innovation, as well as protecting public health, property and the environment. According to Laustsen (2008), the first real building codes emerged in Scandinavia around 1960. National requirements have existed in Sweden since the early 1950s and in Denmark since 1961. By stating requirements such as U-values (a coefficient for thermal transmittance) of insulation, air tightness, energy use for airing and total energy requirements, the codes encourage and require the buildings sector to plan for the long term.[5] Lower U-values indicate less thermal transmittance in the building shell. Nordic policy considers the initial building cost and the total lifetime cost of owning and running buildings, while also weighing the impact of reducing dependency on fossil fuels and increasing energy security on the environment and society as a whole. The codes are tailored to different climates, usage, energy sources and size of buildings.

The European Energy Performance of Buildings Directive (EPBD) has been implemented in all Nordic countries except Iceland. Abundant renewable energy at very low prices makes energy efficiency in buildings a less pressing issue in Iceland. Icelandic authorities have, therefore, considered that the EPBD is not beneficial enough for either consumers or the environment to warrant its adoption. However, energy efficiency requirements for both new buildings and the renovation of older ones in the Icelandic building code, last revised in 2012, have been tightened considerably in the past two decades. Despite being less stringent than elsewhere, the code is believed by Icelandic specialists to require more energy efficiency than cost-minimisation would determine optimal, and profitability is low because of low energy prices. This is unusual, since according to Laustsen (2008), efficiency standards appearing in building codes are rarely stringent enough to prove economical.

In all Nordic countries, allowed U-values have contracted dramatically since around 1990, by which time all their building codes defined U-values (Figure 6.12). In 2008, a comparison of building codes from the Nordic counties, excluding Iceland, with those of other IEA member countries revealed the four highest-ranking countries to be Nordic (IEA, 2008). The overall value has more than halved in both Finland and Sweden in the past twenty years, dropping 53% to 0.62 watt per degree

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[5] The U-value is a thermal transmittance coefficient, *i.e.* how much energy passes through one square metre of a material by a difference of one degree in temperature. It is measured in watt (W) per degree Kelvin (K) per m^2.

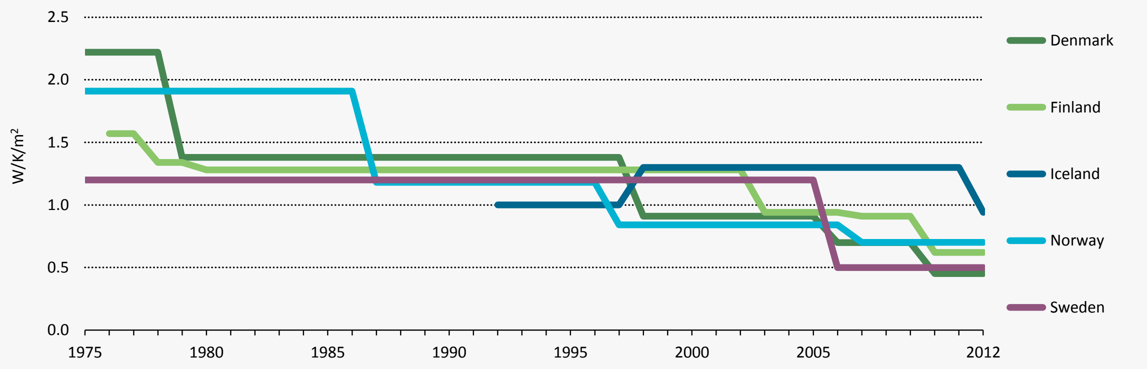
Table 6.4 Maximum allowed U-values in the Nordic countries

	Wall	Roof	Window	Door	Floor	Overall
Denmark	0.30	0.20	1.80	1.80	0.20	1.06
Finland	0.17	0.09	1.00	1.00	0.16	0.62
Iceland	0.25	0.15	1.70	1.70	0.20	0.94
Norway	0.18	0.15	1.20	1.60	0.15	0.70
Sweden	0.18	0.13	1.20	1.20	0.15	0.50

Note: Overall value is defined as Uwall + Uroof + Ufloor + 0.2*Uwindow.
Sources: Danish Energy Agency, 2012; Ministry of Local Government and Regional Development, 2012; National Board of Housing, Building and Planning, 2012; Ministry of the Environment, 2012; Iceland Construction Authority, 2012.

Kelvin (K) per square metre (W/m^{2}K) in Finland and dropping 58% to 0.50 W/m^{2}K in Sweden. From 1992 to 2012, maximum allowed overall U-value for houses in Iceland has gone from 1.00 W/m^{2}K to 0.94 W/m^{2}K despite a hike in window value, which was previously very low and not economically optimum. Maximum values for walls, roofs and floors have all been lowered significantly instead. The average for walls, windows and doors has stayed unchanged. The change in building-component U-values has not only been a matter of tightening requirements but can also be attributed to increasing freedom of choice for building owners to insulate in a way they believe reduces the costs. Since 1987, the overall U-value has dropped around 30% in Norway, to 0.90 W/m^{2}K.

Figure 6.12 Maximum allowed overall U-values in the Nordic countries



Note: For calculation methodology of overall U-values, please see Annex D.
Source: Nordic building regulations.

Key point *Thermal insulation requirements have been tightened considerably.*

Recently, Nordic building codes have also started to restrict total energy demand per residence in kilowatt hours per square metre of heated living space per year. In Denmark and Norway, this value is defined by a simple formula involving the size of each residence. In Finland, four different formulas of similar form pertain to different categories for the size of residences (Anet in Table 6.5). Builders choose to meet either the maximum component U-values or a comprehensive building shell standard. In Sweden, a single amount depending on the energy source and climate zone defines maximum allowed energy demand. The allowance is greater if heating is supplied by energy sources other than electricity and if the zone is more northerly. In 2006, the total energy demand restriction replaced the maximum U-values on specific building components as the main requirement. No maximum total energy need is defined in the Icelandic building code, as reliable information on residence size is lacking and gathering it is not believed to yield large enough savings.

Table 6.5 Maximum total energy needs per m^2 of heated living space per year

Denmark	(52.5 + 1650/(m^2 warmed living space)) kWh					
Finland	Warm living space (A_{net}) size in sq.m.					
	$A_{net} < 120$	$120 < A_{net} < 150$		$150 < A_{net} < 600$		$600 < A_{net}$
	204 kWh	$372 – 1.4*A_{net}$ kWh		$173 – 0.07*A_{net}$ kWh		130 kWh
Iceland	No defined maximum per sq.m.					
Norway	(120 + 1600/(m^2 warmed living space)) kWh					
Sweden	Electrical heating			Heating other than electric		
	Climate zone I	Climate zone II	Climate zone III	Climate zone I	Climate zone II	Climate zone III
	95 kWh	75 kWh	55 kWh	130 kWh	110 kWh	90 kWh

Note: Overall value is defined as Uwall + Uroof + Ufloor + 0.2*Uwindow.
Sources: Danish Energy Agency, 2012; Ministry of Local Government and Regional Development, 2012; National Board of Housing, Building and Planning, 2012; Ministry of the Environment, 2012; Iceland Construction Authority, 2012.

Buildings account for a large part of energy usage in Nordic societies, due to both a high living standard and a cold climate. According to the Norwegian Directorate for Building Quality, around 40% of energy consumption in Norway takes place in buildings. The Nordic authorities are aiming to update their building codes to a passive house standard by 2015 and a nearly zero-energy standard by 2020, in compliance with the EPBD policy. Work on defining concepts and writing national standards is ongoing in Scandinavia and Finland. Construction of passive houses is becoming more common, most noticeably in Norway and Sweden, as the building industry prepares to meet those standards for all buildings. At the same time, passive and nearly zero-energy buildings are almost unheard of in Iceland, and open window ventilation is still common in new buildings, with no restrictions on design. Many Icelanders even prefer to open windows when the inside temperature is too high instead of turning down the heat. Novelty provisions in the Icelandic 2012 building code, however, introduce energy efficiency policies on ventilation and air tightness in line with those of the other Nordic building codes.

Critical challenges

Emissions associated with the buildings sector need to be reduced from 50 $MtCO_2$ to below 5 $MtCO_2$ in the 2DS in 2050, and be even lower in the CNS. The main emissions reduction needs to come from both decarbonisation and greater energy efficiency of the sector. The energy efficiency improvements are required to take place throughout the time period, while decarbonisation needs to start contributing to emissions reduction after 2020. The shares of different energy sources will not be altered significantly in the different scenarios, and electricity and commercial heat continue to dominate and the role of fossil fuels will be minor In order to achieve the emissions reduction; additional investments are required mainly in building shells and appliances.

In order to reach the potential energy savings, it is important to overcome investment barriers in the buildings sector, and action by the governments in the Nordic countries have already begun to guide developments in the right direction. Successful policies have been implemented in the past and are also important for future development.

Decarbonising electricity is vital in order to achieve long-term CO_2 emissions savings in the Nordic buildings sector. Firm action is required as well as continued support for phasing out fossil fuels. Within the Nordic countries the main barrier to continued improvement in energy efficiency is the slow rate of turnover of the building stock, as well as the difficulty in improving energy efficiency (space heating and cooling) of older buildings. For example, the turnover rate of building stock has been slow in Denmark, which has, in turn, slowed down the improvements in energy efficiency. Because new buildings are in general much more energy efficient than older buildings, more emphasis should be given to retrofitting older buildings.

The Swedish Million Programme offers a summary of the possible difficulties in improving the energy efficiency of buildings. Initially, the programme was set up by the Swedish Parliament with the goal of building 100 000 dwellings per year between 1965 and 1974. These buildings need to be retrofitted due to their age and could provide an opportunity for further energy savings. However, various barriers exist preventing this from happening. Energy efficiency improvements do not reduce the operating costs of these buildings and, therefore, rents must be raised. These apartments are in low-income areas and the residents might not be able to pay the higher rent. It is, therefore, very hard for the housing companies to reduce the energy consumption in their buildings, while at the same time maintain the bottom line (Swedish Association of Public Housing Companies, 2011). Therefore both financial and social factors can sometimes prevent energy savings.

Another barrier is the lack of awareness about efficient technologies. Homeowners and firms may simply not be aware of energy efficient technologies nor the financial or environmental benefits they can bring. Governments can increase awareness through campaigns and by publishing reliable information.

Nordic countries are similar in many ways, but differ particularly in terms of access to energy sources. Iceland, for example, has access to geothermal energy and Norway has historically used a higher share of electricity than other countries in the region due to its abundant hydropower resources and low electricity prices. The buildings stock is also quite different among the five countries. Consequently, critical challenges differ depending on the different resources available and characteristics of the building stock.

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

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[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.

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[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.

Annexes

A. Analytical Approach

The *Nordic Energy Technology Perspectives* (*NETP*) follows the same analytical approach as *Energy Technology Perspectives 2012* (*ETP 2012*) (www.iea.org/etp). It applies a combination of backcasting and forecasting. Backcasting lays out plausible pathways to a desired end state. It makes it easier to identify milestones that need to be reached, or trends that need to change promptly, in order for the end goal to be achieved. The advantage of forecasting, where the end state is a result of the analysis, is that it allows greater considerations of short-term constraints.

Achieving the *NETP* scenarios does not depend on the appearance of breakthrough technologies. All technology options introduced in the analysis are already commercially available or at a stage of development that makes commercial-scale deployment possible within the scenario period. Costs for many of these technologies are expected to fall over time, making a low-carbon future financially viable.

The analysis and modelling aim to identify the most economic way for society to reach the desired outcome, but for a variety of reasons the scenario results do not necessarily reflect the least-cost ideal. Many subtleties are difficult to capture in a cost optimisation framework, such as political preferences, feasible ramp-up rates, capital constraints and public acceptance. For the end-use sectors (buildings, transport and industry), carrying out least-cost analysis is difficult and not always suitable. Long-term projections inevitably contain significant uncertainties and many of the assumptions underlying the analysis will likely turn out to be inaccurate. Another important caveat to the analysis is that it does not account for secondary effects resulting from climate change, such as adaptation costs.

The *NETP* analysis acknowledges those policies that are already implemented or committed. In the short term, this means that deployment pathways may differ from what would be most cost-effective. In the longer term, the analysis emphasises a normative approach and fewer constraints governed by current political objectives apply in the modelling. The objective of this methodology is to provide a model for a cost-effective transition to a sustainable energy system.

To make the results more robust, the analysis pursues a portfolio of technologies within a framework of cost minimisation. This offers a hedge against the real risks associated with the pathways: if one technology or fuel fails to fulfil its expected potential, it can more easily be compensated by another if its share in the overall energy mix is low. The tendency of the energy system to comprise a portfolio of technologies becomes more pronounced as carbon emissions are reduced. This has implications for energy security as well as for the uncertainties embodied in the scenarios.

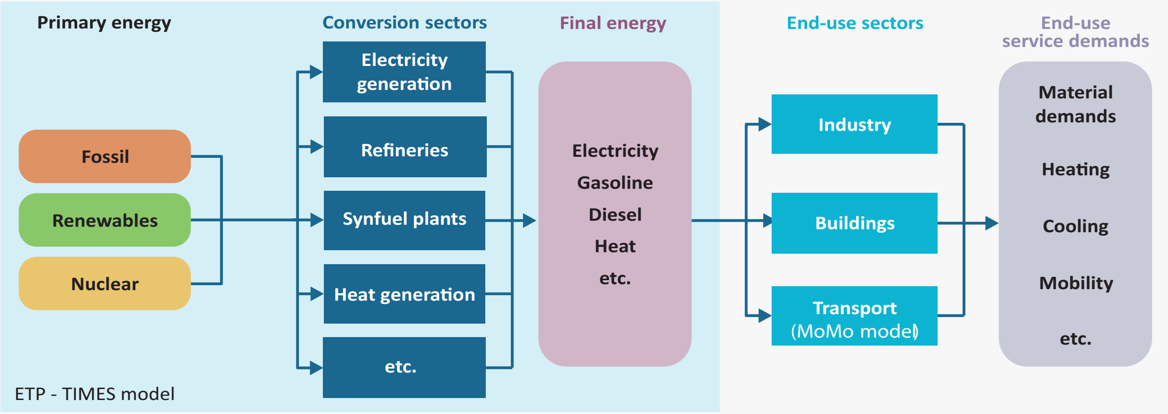
The ETP model

The ETP model, which is the primary analytical tool used in *NETP*, combines analysis of energy supply and demand. The model supports the integration and manipulation of data from four soft-linked models:

- energy conversion;
- industry;
- transport; and
- buildings (residential and commercial/services).

Using the energy conversion model, it is possible to explore outcomes that reflect variables in energy supply in the three sectors with the largest demand, and hence the largest emissions (models for industry, transport and buildings [residential and commercial]). The following schematic illustrates the interplay of these elements in the processes by which primary energy is converted into the final energy that is useful to these demand-side sectors (Figure A.1).

Figure A.1 The ETP model



The energy conversion module is a least-cost optimisation model. The demand-side modules are stock accounting simulation models. Consistency of supply, demand and price is ensured through an iterative process, as there is no hard link between the sector models. The *ETP* model works in five-year time steps.

The conversion sector (*i.e.* transformation of power and fuel) in *NETP 2013* is analysed using the ETP-TIMES[1] model, which covers the five Nordic countries (Denmark, Finland, Iceland, Norway and Sweden) and depicts, in a technology-rich fashion, the supply side of the Nordic energy system. The model spans the spectrum from primary energy supply and conversion to final energy demand up to 2050. Starting from the current situation in the conversion sectors (*e.g.* existing capacity stock, operating costs and conversion efficiencies), the model integrates the technical and economic characteristics of existing technologies

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[1] The ETP model is based on *The Integrated MARKAL-EFOM system (TIMES)* model generator, which has been developed and is continuously enhanced by the Energy Technology Systems Analysis Programme (ETSAP), one of the IEA Implementing Agreements (Loulou *et al.*, 2005).

that can be added to the energy system. The model can then determine the least-cost technology mix needed to meet the final energy demand calculated in the *ETP* end-use sector models for industry, transport and buildings. Technologies are described by their technical and economic parameters, such as conversion efficiencies or specific investment costs. Learning curves are used for new technologies to link future cost developments with cumulative capacity deployment.

To capture the impact of variations in electricity and heat demand, as well as in the generation from some renewable technologies on investment decisions, a year is divided into four seasons, with each season represented by a typical day with 12 daily load segments. The ETP-TIMES model also takes into account additional constraints in the energy system (*e.g.* fossil-fuel resource constraints or emissions reduction goals) and provides detailed information on future energy flows, as well as their related emissions impacts, required technology additions and the overall costs of the supply-side sector.

Industry is modelled using a stock accounting spreadsheet that covers (in detail) five energy-intensive sectors: iron and steel, cement, chemicals and petrochemicals, pulp and paper, and aluminium. Demand is estimated based on country- or regional-level data for gross domestic product (GDP), disposable income, short-term industry capacity, current materials consumption, demand saturation rates and resource endowments. Total production is simulated by factors such as process, age structure (vintage) of plants and stock turnover rates. Overall production is similar across scenarios, but means of production differ considerably. For example, the same level of crude steel production is expected in both the 4°C Scenario (4DS) and 2°C Scenario (2DS), but the 2DS reflects a much higher use of scrap, which is less energy-intensive than production from raw materials. Each industry sub-model is designed to account for sector-specific production routes.

Changes in the technology mix and efficiency improvements are driven by exogenous assumptions on penetration of best available technologies (BATs) at each given time. The analysis incorporates the projected relative cost of those technologies, as well as how marginal abatement costs in industry compare to those in other sectors at the given time period. Thus, the results are sensitive to assumptions on how quickly physical capital is turned over and how effective incentives are for using BATs in new construction.

Transport is modelled with a Nordic variant of the mobility model (MoMo), a global transport spreadsheet model that allows projections and policy analysis to 2050, with considerable regional and technological detail. The mobility model encompasses most vehicle and technology types (*e.g.* 2- and 3-wheelers, passenger cars, light trucks, medium and heavy freight trucks, buses) and all modes of transport (*e.g.* non-road modes such as rail, air and shipping). Since the model integrates assumptions on the availability of technology and cost at different points in the future, it reveals, for example, how costs could drop if technologies were deployed at a commercial rate. The model also comprises fairly detailed bottom-up "what-if" modelling, especially for passenger light-duty vehicles (PLDVs) and trucks (Fulton, *et al.*, 2009).

Energy use is estimated based on stocks, use (travel per vehicle), consumption (energy use per vehicle, *i.e.* fuel economy) and emissions (via fuel emission factors for carbon dioxide [CO_2] and pollutants on a vehicle and well-to-wheel basis). For each scenario, this model supports a comparison of marginal costs of technologies and aggregates to total cost across all modes and regions.

The primary drivers of technological change in transport are assumptions on the cost evolution of the technology and the policy framework providing the incentives to adopt the technology. Oil prices and the set of policies assumed can significantly alter technology penetration patterns.

The buildings sector is modelled using a simulation stock accounting model, split into residential and commercial sub-sectors for the countries in the Nordic region. For both subsectors, the model uses income, population, urbanisation data and services value added to project floor space per capita as well as activity levels such as cooking, appliance ownership and energy efficiency. Based on this set of drivers, demand for individual energy services and the share of each energy technology needed to meet this demand are projected to 2050. Space heating demand is calculated using detailed data on building stock (including energy efficiency of different periods). For lighting and appliances, the model recognises that equipment penetration is driven by income per capita and historical regressions. Space cooling is projected using regional climatic conditions and income per capita. Simulating (from the bottom up) all energy uses traditionally associated with buildings, the buildings model is suited to analyse scenarios for energy efficiency in buildings and end-use technology penetration.

B. Framework Assumptions

Economic activity (Table B.1) and population (Table B.2) are the two fundamental drivers of demand for energy services in the *NETP* scenarios. These two drivers are kept constant across all scenarios as a means of providing a starting point for the analysis and facilitating the interpretation of the results. Under the *NETP* assumptions, gross domestic product (GDP) of the five Nordic countries combined will nearly quadruple by 2050. Uncertainty around GDP growth across the scenarios is, however, significant. The climate change rate, even in the 4DS, is likely to have a negative impact on the potential for economic growth. This impact is not captured by the *NETP* analysis. Moreover, the structure of the economy is likely to have non-marginal differences across scenarios, suggesting that GDP growth is unlikely to be identical even without considering impacts of climate change. The redistribution of financial, human and physical capital will affect the growth potential, both globally and on a regional scale. While the *NETP* analysis provides important insights into the cost of CO_2 reductions for consumers and for the global economy, the analysis does not assess the full impact on GDP. Other studies have attempted to do this by analysing, for example, the impact on GDP from climate change mitigation.

Table B.1 GDP assumptions

[USD 2010]	2009	2020	2030	2040	2050	CAAGR (%) 2009-2050
Denmark	198	251	315	384	451	2.0%
Finland	180	236	297	362	425	2.1%
Iceland	12	16	20	24	28	2.0%
Norway	254	329	415	503	591	2.1%
Sweden	336	475	598	727	855	2.3%
Nordic 5	980	1 307	1 645	1 998	2 350	2.2%

Note: CAAGR = compounded average annual growth rate.

Integrating a high level of technological detail in a macroeconomic model could, in theory, resolve some of the discrepancies among the findings based on different modelling approaches. Because such integration is extremely challenging, however, different modelling approaches should be used instead to highlight different perspectives of a problem. Energy prices, including those of fossil fuels, are a central variable in the *ETP* analysis (Table B.3). The continuous increase in global energy demand is translated into higher prices on energy and fuels. Unless current demand trends are broken, rising prices are a likely consequence. However, the technologies and policies to reduce CO_2 emissions in the N*ETP* scenarios will have a considerable impact on energy demand, particularly for fossil fuels. Lower demand for oil in the 4DS and the 2DS means there is less need to produce oil from costly fields higher up the supply curve, particularly in non-OPEC countries. As a result, the oil price is projected to stay under USD 100 (US dollars) per barrel throughout the projection period and could even to drop during the last decades before 2050.

Prices for natural gas will also be affected as demand decreases and indirectly through the link to oil prices that often exists in long-term gas supply contracts. Finally, coal prices are also substantially lower owing to the large shift away from coal in the low-carbon scenarios.

Table B.2 Population projection

[Million]	2010	2020	2030	2040	2050
Denmark	5.55	5.74	5.89	5.94	5.92
Finland	5.37	5.53	5.62	5.62	5.61
Iceland	0.32	0.36	0.39	0.41	0.43
Norway	4.88	5.23	5.57	5.84	6.06
Sweden	9.38	9.92	10.38	10.66	10.92
Nordic 5	25.50	26.77	27.85	28.47	28.94

Source: UN, 2011.

Table B.3 Energy prices for external imports and exports

[USD 2010/GJ]		2009	2020	2030	2040	2050
4DS	Hard coal	3.4	3.6	3.7	3.7	3.7
	Natural gas	7.1	9.8	11.1	11.4	11.3
	Crude oil	13.8	19.2	20.7	21.0	20.9
	Electricity	18.1	22.0	30.9	35.5	37.8
	Liquid biofuels	23-30	23-30	23-31	24-32	24-34
2DS, CNS	Hard coal	3.4	3.2	2.5	2.2	2.1
	Natural gas	7.1	9.3	9.2	8.5	8.0
	Crude oil	13.8	17.1	17.1	16.3	15.3
	Electricity	18.1	24.9	35.1	39.2	41.4
2DS, CNS, CNES	Liquid biofuels	23-30	23-30	21-28	22-28	22-29
CNBS	Liquid biofuels	23-30	23-30	20-26	20-25	20-23

Notes: GJ = gigajoules. CNS = Carbon-Neutral Scenario. CNBS = Carbon-Neutral high Bioenergy Scenario. CNES = Carbon-Neutral high Electricity Scenario.

C. Central Assumptions for Sector Modelling

Power and district heating

Table C.1 Marginal abatement costs in the electricity sector in the 4DS and 2DS

[2010 USD/tCO_2]	2020	2030	2040	2050
4DS	30	40	50	65
2DS	40	90	120	160

Note: tCO_2 = tonnes of CO_2.

Table C.2 Main scenario assumptions in the electricity sector

	4DS	2DS	CNS	CNBS	CNES
Renewables	NREAP targets in 2020 for Denmark, Finland Sweden; +26.4 TWh for Norway and Sweden in common electricity certificate market by 2020; Denmark: min. target of 17.8 TWh wind generation in 2020; Hydropower expansion limited to +5 TWh in Sweden and +30 TWh in Norway.	as in 4DS	as in 4DS	as in 4DS	as in 4DS
Nuclear	Finland: max. 6.4 GW of new reactors possible; Sweden: replacement of existing reactors possible, but no expansion beyond current capacity levels.	as in 4DS	as in 4DS	as in 4DS	as in 4DS
Coal	Norway: No coal use in Norway; Denmark: Phase-out of coal plants without CCS by 2030; Denmark, Sweden: No new coal-fired power plants, neither with nor without CCS.	as in 4DS	as in 4DS	as in 4DS	as in 4DS
Electricity export prices to Continental Europe	Increase from USD 65/MWh in 2009 to USD/MWh 136 in 2050.	USD 150/MWh in 2050	USD 150/MWh in 2050	USD 150/MWh in 2050	USD 150/MWh in 2050
Carbon price	USD 65/tCO_2 in 2050	USD 160/tCO_2 in 2050	USD 160/tCO_2 in 2050	USD 160/tCO_2 in 2050	USD 160/tCO_2 in 2050

Notes: NREAP = National Renewable Energy Action Plan. TWh = terawatt hours. GW = gigawatts. CCS = carbon capture and storage. MWh = megawatt hours. USD 65/tCO_2 = United States dollar per tonne of carbon dioxide.

Table C.3 Technical and economic assumptions for selected power technologies

	Overnight investment costs (2010 USD/kW)			Fixed operating and maintenance costs (2010 USD per kW/yr)			Net conversion efficiency (lower heating value) %			Technical life-time (years)	Construction time (years)	Capacity factor (%)			LCOE (2010 USD/MWh)		
	2010	2030	2050	2010	2030	2050	2010	2030	2050			2010	2030	2050	2010	2030	2050
USC	2 300	2 300	2 300	46	46	46	47	50	52	35	4	85	85	85	64	118	151
USC + oxy-fuel	n.a.	3 450	2 950	n.a.	104	89	n.a.	42	44	35	4	n.a.	85	85	n.a.	91	82
Gas turbine	500	500	500	10	10	10	38	40	42	30	1	15	15	15	133	194	207
NGCC	1 000	1 000	1 000	20	20	20	57	61	63	30	3	60	60	60	63	100	109
NGCC + postcomb.	n.a.	1 600	1 500	n.a.	48	45	n.a.	54	56	30	3	n.a.	85	85	n.a.	87	78
Wind, onshore	1632-2266	1415-1966	1318-1919	33-45	28-39	28-38	100	100	100	25	1	30-22	33-25	35-26	71-134	56-104	51-95
Wind, offshore	3200-4200	2576-3209	2411-2988	99-126	77-96	72-90	100	100	100	25	2	45-41	47-42	47-42	113-162	85-118	79-110
PV, utility scale	4 000	1 440	1 050	40	14	11	100	100	100	25	1	11	12	13	430	142	98
PV, rooftop	4 900	1 750	1 300	49	18	13	100	100	100	25	0	9	11	12	644	190	130
Biomass, CHP (50 MW)	4 025	4 025	4 025	81	81	81	30 (85)	32 (91)	32 (91)	35	3	60	60	60	69	71	71
Biomass, CHP (10 MW)	5 700	5 700	5 700	200	200	200	28 (83)	30 (89)	30 (89)	35	2	60	60	60	118	120	120
Hydro, large (300 MW)	2 500	2 500	2 500	50	50	50	100	100	100	80	4	46	46	46	72	72	72
Hydro, small (10 MW)	5 200	5 200	5 200	104	104	104	100	100	100	80	3	46	46	46	146	146	146
Nuclear, LWR	4 000	4 000	4 000	80	80	80	36	37	37	50	5	90	90	90	69	69	69

Notes: LCOE = Levelised cost of electricity. kW = kilowatt. USC = ultra-super-critical. NGCC = natural gas combined cycle. Postcomb. = postcombustion. PV = photovoltaic. CHP = combined heat and power. LWR = light water reactors. LCOE are based on fuel and CO_2 prices of the 2DS (see Table B.3 and Table C.1). For biomass CHP plants, first efficiency numbers refer to the electric efficiency, whereas the number in brackets represents the overall efficiency. LCOE of biomass CHP plants are based on fuel costs of USD 5/GJ and a heat credit of USD 45/MW_{heat}

Table C.4 Cross-border transmission capacities (GW)

	Existing capacities and under construction		Options for additional new capacity	
	All scenarios		4DS, 2DS, CNS, CNBS	CNES
[GW]	2010	2020	2020 or later	2020 or later
Denmark <-> EU	2.3	2.3	0.7	2.3
Denmark <-> Sweden	2.4	2.4		unbounded
Finland<-> EU	0.35	1.0		0.3
Finland <-> Sweden	1.85	2.65		unbounded
Norway <-> Denmark	1.0	1.7		unbounded
Norway <-> EU	0.7	1.4	4.0	6.0
Norway <-> Finland	0.1	0.1		unbounded
Norway <-> Sweden	3.7	3.7	1.4	unbounded
Sweden <-> EU	1.2	1.9		2.0
Russia -> Finland	1.56	1.56		unbounded
Russia -> Norway	0.05	0.05		unbounded

Transport

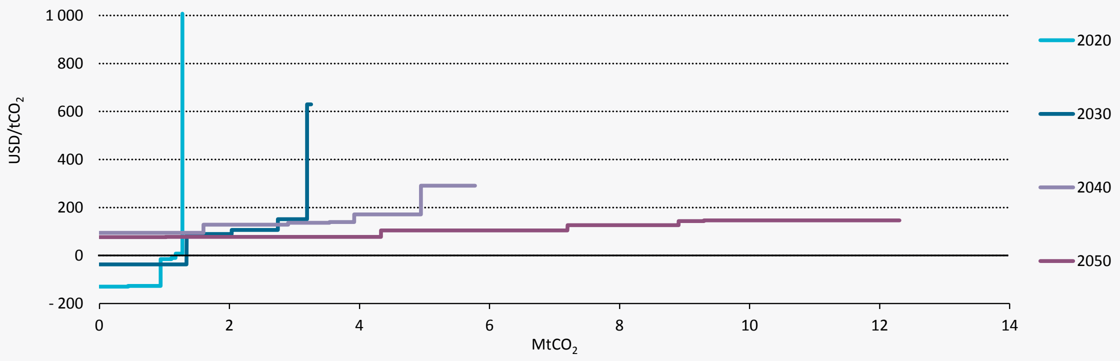
For transport, *NETP* considers a range of efficiency and technology options. Costs are estimated for improving gasoline vehicle fuel economy, shifts to advanced diesel vehicles, hybrid vehicles, plug-in hybrids, battery electric vehicles and fuel-cell vehicles.

Figure C.1 shows how the total tonnes of reduction (horizontal axis) can be achieved at a given abatement cost per tonne (vertical axis) and how this changes over time. The potential reductions rise over time mainly because it takes time to roll out the improvements and increase the use of specific technologies over the entire stock of vehicles. Reductions related to fuel-cell vehicles, for example, only begin to show up in 2040.

The other important effect of time is abatement cost reduction. The base 2DS results show fairly strong cost reductions for key technologies such as batteries and fuel-cell systems. Abatement cost reductions also result from rising fuel prices, such that fuel savings become more valuable over time. The net effects reflect the fact that the cost per tonne of avoided CO_2 is highly sensitive to relatively modest changes in technology and fuel costs.

Overall, most of the cost reductions in 2020 (mainly fuel economy improvements) can be achieved at less than USD 0 per tonne. Above zero, the costs quickly become very high but the amount of CO_2 reduction achieved is quite low. This reflects the period required to reduce the costs of electric vehicles and plug-in hybrids through policy support. Such support would not be of interest (from a societal perspective) were it not for the fact that the costs will decrease over time as cumulative production provides learning effects. Since these are societal cost calculations, even costs below zero might not be taken up by the market. This could be the case if, for example, personal discount rates are much higher than societal ones and the payback time for investments is longer than people are willing to tolerate.

Figure C.1 Transport PLDV marginal abatement cost curves by projection year



Notes: MtCO$_2$ = million tonnes of CO$_2$. PLDV = passenger light-duty vehicle

Key point *Marginal abatement costs evolve over time, and in transport there is a clear lowering of these costs as a result of learning outpacing the move up the cost curve.*

Buildings sector

Table C.5 Key assumptions for space heating in the residential sector

Energy Efficiency	New Build	Retrofit
4DS	Drop in average kWh/m² to Passivhaus standard in 2075	1% annual retrofit rate to 65-80 MJ/m²
2DS	Drop in average kWh/m² to Passivhaus standard in 2050	1% annual retrofit rate to Passivhaus (54 MJ/m² for space heating)
CNS	Drop in average kWh/m² to Passivhaus standard in 2025	1.25% annual retrofit rate to Passivhaus
CNES	Drop in average kWh/m² to Passivhaus standard in 2025	1.25% annual retrofit rate to Passivhaus
CNBS	Drop in average kWh/m² to Passivhaus standard in 2025	1.25% annual retrofit rate to Passivhaus
Fuel Mix		
4DS	Broadly constant fuel shares, slight increase in biomass and heat pumps for space and water heating	
2DS	Heat pump penetration increases to between 20% and 25% by 2050; growth in DH share (10% growth in DK, SE, IS all geothermal).	
CNS	Heat pump penetration increases to between 30% and 35% by 2050; DH 15% growth in DK, SE, FI. IS all geothermal.	
CNES	Heat pump penetration higher than in CNS (varies by country)	
CNBS	Increase in biomass boiler fuel share compared to CNS (varies by country); Increase in the DH demand	

Note: DK = Denmark. FI = Finland. IS = Iceland. SE = Sweden.

Table C.6 Key assumptions for appliances and lighting in the residential sector

All scenarios	Same appliance growth for all scenarios, based on saturation curves for ownership and number of households
4DS	4% appliance replacement rate, with 60% of new and replaced BPT; between 34% and 38% CFL
2DS	4% appliance replacement rate, with 70% BPT (BPT is 5% more efficient in this scenario); between 34% and 38% CFL or LED by 2050
CNS	4% appliance replacement rate, with 70% BPT (BPT is 10% more efficient in this scenario); between 55% and 58% CFL or LED by 2050
CNES	4% appliance replacement rate, with 70% BPT (BPT is 10% more efficient in this scenario); between 55% and 58% CFL or LED by 2050
CNBS	4% appliance replacement rate, with 70% BPT (BPT is 10% more efficient in this scenario); between 55% and 58% CFL or LED by 2050

Notes: BPT = best practice technology. CFL = compact fluorescent lamp. LED = light emitting diode

Table C.7 Key assumptions for cooking and water heating in the residential sector

4DS	No intensity improvement. Broadly constant fuel shares, with complete phase-out of fossil fuels by 2050.
2DS	Small intensity improvement in water heating (0.2% annual). Strong increases in biomass use and electricity, *e.g.* 80% increase by 2050 in biomass share in SE; 50% in FI. Biomass water heating and cooking in NO grows to 6% from near-zero today.
CNS	Small intensity improvement in water heating (0.2% annual). Small increase in solar water heating (between 8% and 9% of the mix in 2050). Increased HP penetration, reaching 14% HP penetration in SE; 17% in FI; 17% in NO; 12% in DK by 2050. Geothermal only in IS in 2050.
CNES	Small intensity improvement in water heating (0.2% annual). Higher penetration of heat pumps than in the 85% scenario (between 80% and 100% increase compared to standard 85% by 2050, except for IS where all geothermal).
CNBS	Small intensity improvement in water heating (0.2% annual). Strong increase in local biomass boilers and heat exchangers (share of water heating met by DH).

Notes: CNBS and CNES share all assumptions with CNS except where highlighted. HP= heat pump, DH= district heating. NO = Norway.

Table C.8 Key assumptions for the services sector

End use	4DS status in 2050	2DS status in 2050	CNS status in 2050	CNBS status in 2050	CNES status in 2050
Space heating	Most fuels are not changed from 2010. Heat pumps share increases.	Phasing out of fossil fuels, especially oil and coal.	Phasing out of all fossil-fuel-fired heating equipment with more biomass, district heating and heat pumps.	Strong increase in local biomass boilers and heat exchangers compared with CNS in 2050.	Higher penetration of heat pumps compared to CNS in 2050.
Water heating	Most fuels are not changed from 2010. Heat pumps share increases.	Increase of solar, heat pumps and district heating.	Phasing out of all fossil-fuel-fired heating equipment with more biomass, district heating and heat pumps.	Strong increase in local biomass boilers and heat exchangers compared with CNS in 2050.	Higher penetration of heat pumps compared to CNS in 2050.
Lighting	50% of existing light bulbs are replaced by efficient ones.	All existing light bulbs are replaced by efficient ones.	All existing light bulbs are replaced by efficient ones, and 10% lower intensity than the 2DS.	Same as the CNS	Same as the CNS
Cooling	Slight improvement of average UEC in 2050.	Average UEC is 10% lower than the 4DS in 2050.	Average UEC is 10% lower than the 2DS in 2050.	Same as the CNS	Same as the CNS
Appliances and miscellaneous equipment	0.3% increase of intensity per year from 2010 to 2050.	Intensity is 10% lower than the 4DS in 2050.	Intensity is 10% lower than the 2DS in 2050.	Same as the CNS	Same as the CNS
Building envelope	25-35% improvement of energy intensity compared with 2010 (varies by country).	25-35% improvement of energy intensity compared with 2010 (varies by country).	Around 10% lower energy intensity than the 2DS in 2050.	Same as the CNS	Same as the CNS

Note: UEC = unit energy consumption.

Industry

The Tables C.9–C.21 summarise the material production assumptions for the Nordic region in the scenarios.

Table C.9 Nordic aluminium production in the 4DS (megatonnes)

	2010	2015	2020	2025	2030	2035	2040	2045	2050
Primary Aluminium	2.4	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3
Recycled Aluminium	3.6	3.8	4.1	4.3	4.5	4.6	4.7	4.7	4.7

Note: Recycled aluminium includes recovered and recycled aluminium within the industry

Table C.10 Nordic aluminium production in the 2DS (megatonnes)

	2010	2015	2020	2025	2030	2035	2040	2045	2050
Primary aluminium	2.4	2.4	2.3	2.3	2.4	2.4	2.4	2.4	2.4
Recycled aluminium	3.6	4.1	4.3	4.5	4.7	4.8	4.8	4.8	4.8

Note: Recycled aluminium includes recovered and recycled aluminium within the industry.

Table C.11 Nordic aluminium production in the CNS (megatonnes)

	2010	2015	2020	2025	2030	2035	2040	2045	2050
Primary aluminium	2.4	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2
Recycled aluminium	3.6	3.8	4.1	4.3	4.5	4.7	4.7	4.8	4.8

Note: Recycled aluminium includes recovered and recycled aluminium within the industry.

Table C.12 Nordic cement and clinker production in the 4DS (megatonnes)

	2010	2015	2020	2025	2030	2035	2040	2045	2050
Cement	8.4	8.6	8.8	9.0	9.2	9.2	9.3	9.3	9.3
Clinker production	6.8	7.0	7.1	7.2	7.3	7.3	7.3	7.3	7.2
Clinker to cement ratio	0.81	0.81	0.81	0.80	0.80	0.79	0.79	0.78	0.77

Table C.13 Nordic cement and clinker production in the 2DS (megatonnes)

	2010	2015	2020	2025	2030	2035	2040	2045	2050
Cement	8.4	8.6	8.8	9.0	9.2	9.2	9.3	9.3	9.3
Clinker production	6.8	7.0	7.1	7.2	7.2	7.1	7.0	6.9	6.8
Clinker to cement ratio	0.81	0.81	0.80	0.79	0.78	0.77	0.76	0.74	0.73

Table C.14 Nordic cement and clinker production in the CNS (megatonnes)

	2010	2015	2020	2025	2030	2035	2040	2045	2050
Cement	8.4	8.6	8.8	9.0	9.2	9.2	9.3	9.3	9.3
Clinker production	6.8	7.0	7.0	7.0	6.9	6.7	6.4	6.1	5.9
Clinker to cement ratio	0.81	0.81	0.80	0.78	0.75	0.72	0.69	0.66	0.63

Table C.15 Nordic chemicals and petrochemicals production in the 4DS (megatonnes)

	2010	2015	2020	2025	2030	2035	2040	2045	2050
Ethylene	1.23	1.26	1.28	1.30	1.31	1.33	1.33	1.33	1.33
Propylene	0.42	0.44	0.46	0.47	0.48	0.50	0.51	0.51	0.52
BTX	0.11	0.14	0.16	0.18	0.20	0.24	0.26	0.27	0.29
Ammonia	0.50	0.48	0.50	0.53	0.55	0.58	0.60	0.62	0.64
MeOH	0.91	0.94	0.97	1.01	1.04	1.07	1.09	1.11	1.13

Notes: BTX = benzene, toluene and mixed-xylene. MeOH = methanol.

Table C.16 Nordic chemicals and petrochemicals production in the 2DS and CNS (megatonnes)

	2010	2015	2020	2025	2030	2035	2040	2045	2050
Ethylene	1.23	1.25	1.26	1.26	1.26	1.27	1.25	1.24	1.22
Propylene	0.44	0.44	0.45	0.46	0.46	0.47	0.47	0.47	0.47
BTX	0.11	0.14	0.16	0.18	0.20	0.23	0.25	0.26	0.27
Ammonia	0.50	0.48	0.50	0.53	0.55	0.58	0.60	0.62	0.64
MeOH	0.91	0.94	0.97	1.01	1.04	1.07	1.09	1.11	1.13

Notes: BTX = benzene, toluene and mixed-xylene. MeOH = methanol.

Table C.17 Nordic iron and steel production in the 4DS (megatonnes)

	2010	2015	2020	2025	2030	2035	2040	2045	2050
EF steel	4.8	3.9	4.5	4.9	5.3	5.7	6.1	6.4	6.7
BF/BOF steel	4.6	6.1	6.1	5.9	5.6	5.4	5.2	5.0	4.8
Total crude steel production	9.4	10.0	10.6	10.8	10.9	11.1	11.3	11.4	11.5

Notes: EF= electric furnace. BF = blast furnace. BOF = basic oxygen furnace.

Table C.18 Nordic iron and steel production in the 2DS (megatonnes)

	2010	2015	2020	2025	2030	2035	2040	2045	2050
EF steel	4.8	3.9	4.5	4.9	5.3	5.6	5.9	6.1	6.4
BF/BOF steel	4.6	6.1	6.1	5.9	5.7	5.5	5.4	5.3	5.2
Total crude steel production	9.4	10.0	10.6	10.8	10.9	11.1	11.3	11.4	11.5

Notes: EF= electric furnace. BF = blast furnace. BOF = basic oxygen furnace.

Table C.19 Nordic iron and steel production in the CNS (megatonnes)

	2010	2015	2020	2025	2030	2035	2040	2045	2050
EF steel	4.8	4.2	5.1	5.8	6.4	7.0	7.5	8.0	8.6
BF/BOF steel	4.6	5.8	5.5	5.0	4.6	4.1	3.7	3.3	2.9
Total crude steel production	9.4	10.0	10.6	10.8	10.9	11.1	11.3	11.4	11.5

Notes: EF= electric furnace. BF = blast furnace. BOF = basic oxygen furnace.

Table C.20 Nordic pulp, paper and paperboard production in the 4DS (megatonnes)

	2010	2015	2020	2025	2030	2035	2040	2045	2050
Chemical wood pulp	15.5	16.3	16.9	17.4	17.8	18.2	18.6	18.9	19.2
Mechanical wood pulp	8.8	8.7	8.7	8.4	8.5	8.6	8.6	8.6	8.6
Other fiber pulp	0.6	0.6	0.6	0.6	0.7	0.7	0.7	0.7	0.7
Household and sanitary paper	0.5	0.6	0.6	0.6	0.7	0.7	0.7	0.7	0.7
Newsprint	2.9	2.9	2.9	2.8	2.8	2.7	2.7	2.6	2.6
Paper and paperboard	0.5	0.5	0.6	0.6	0.7	0.7	0.7	0.7	0.8
Printing and writing paper	11.5	11.1	11.1	10.9	10.8	10.8	10.8	10.8	10.7
Wrapping, packaging paper and board	9.6	9.9	10.1	10.4	10.6	10.8	10.9	11.0	11.1
Recovered paper	3.0	3.4	3.7	3.9	4.2	4.4	4.5	4.7	4.9

Table C.21 Nordic pulp, paper and paperboard production in the 2DS and CNS (megatonnes)

	2010	2015	2020	2025	2030	2035	2040	2045	2050
Chemical wood pulp	15.5	16.4	17.0	17.6	18.1	18.7	19.1	19.5	19.8
Mechanical wood pulp	8.8	8.9	9.0	8.5	8.5	8.4	8.4	8.3	8.1
Other fiber pulp	0.6	0.5	0.4	0.1	0.0	0.0	0.0	0.0	0.1
Household and sanitary paper	0.5	0.6	0.6	0.6	0.7	0.7	0.7	0.7	0.7
Newsprint	2.9	2.9	2.9	2.6	2.6	2.5	2.5	2.4	2.4
Paper and paperboard	0.5	0.5	0.6	0.6	0.7	0.7	0.7	0.7	0.8
Printing and writing paper	11.5	11.1	11.1	10.9	10.8	10.8	10.8	10.8	10.7
Wrapping, packaging paper and board	9.6	9.9	10.1	10.4	10.6	10.8	10.9	11.0	11.1
Recovered paper	3.0	3.5	3.7	4.0	4.3	4.5	4.7	4.9	5.1

Price Sensitivity Analyses

The scenario analyses in *NETP* depend on various input assumptions, ranging from the techno-economic characterisation of future technologies in the energy system over energy prices to GDP and population projections (influencing the useful energy service demand or material demand of the industry sector). Although great care has been spent deriving these input assumptions, *e.g.* price assumptions in the 4DS and 2DS are based on analysis in *ETP 2012* (IEA, 2012), it is clear that considerable uncertainty exists in the actual development of these factors, especially over a time horizon reaching out to 2050. Prices for energy carriers being imported into or exported out of the Nordic region are critical input factors in this context. For the *NETP* scenarios, this is in particular true for the export prices for electricity, influencing the electricity exports from the Nordic region to Continental Europe and thereby also the capacity development in the Nordic power sector, as well as for the biofuel import prices, influencing the extent to which biofuel imports are used to reach the ambitious reduction targets in the CNS and its variants. To illustrate the impact of these prices, two sensitivity analyses have been considered: one for the electricity price in the CNES, and one for the biofuel import price in the CNS.

Electricity export prices in the CNES

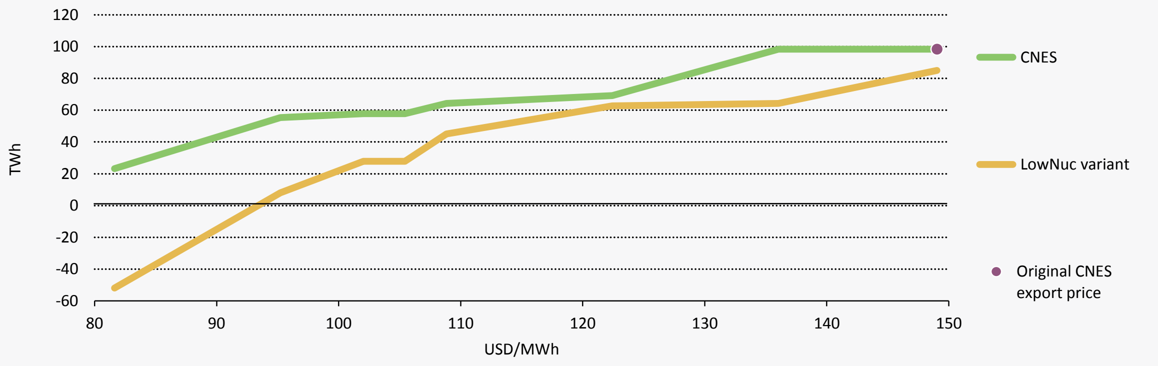
In the CNES (and also the CNS), the electricity export prices have been assumed to be the same as in the 2DS. The impacts of different export price pathways in the CNES on the net electricity exports of the Nordic region have been analysed. Besides electricity prices, sufficient generation capacity for low-cost electricity is a further factor. Therefore, also a variant of the CNES has been considered, which assumes a lower nuclear deployment (LowNuc variant) with no build of new nuclear plants in Sweden as well as a slower deployment of nuclear in Finland (resulting in 3.2 GW in 2050 in Finland compared to 6.4 GW in the CNES).

Figure C.2 shows the resulting relationship between the electricity export price in 2050 and the exports. Starting from the export price level in the CNES of USD 150/MWh, exports start to decline for prices below USD 135/MWh in both variants. Lower nuclear capacity in the LowNuc variant results, however, in a more rapid decline in exports, as the reduced availability of nuclear as low-cost generation option in this variant results in higher electricity prices.

In the CNES, the expansion of export transmission capacities stops when reaching an export price level below USD 100/MWh. A further decline of the export price in 2050 results in a reduced utilisation of the existing transmission capacities built before 2015. On the generation side, the decline in exports is largely accompanied by reduced on- and offshore wind generation in the Nordic region.

In the LowNuc variant, the drop in electricity exports relative to the CNES is initially significantly lower than the difference in nuclear generation of 90 TWh in 2050 may suggest, since part of the reduced nuclear generation is offset by increased generation from wind. But the difference between the LowNuc variant and the CNES increases with declining electricity export prices. At a price slightly above USD 90/MWh in the variant, the Nordic region switches from a net exporter to a net importer of electricity.

Figure C.2 Impact of electricity export prices on net exports in 2050 in the CNES and its low nuclear variant

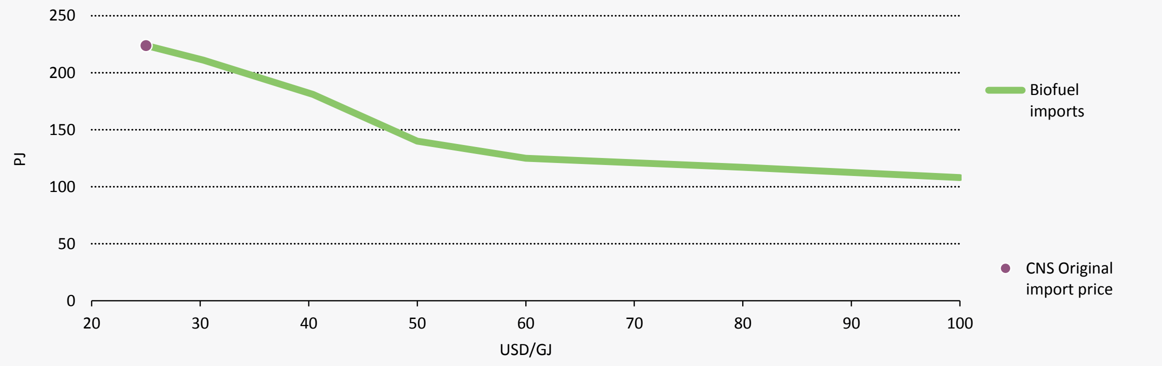


Key point *Electricity export prices are a critical factor influencing the net exports and generation capacity in the Nordic region.*

Biofuel Import Prices in the CNS

Increasing the import prices for liquid biofuels in the CNS results in reduced imports (Figure C.3). Since liquid biofuels are crucial to decarbonise the transport sector, especially for shipping and aviation, the reduced biofuel imports are compensated mainly by a reduced biomass use in other sectors, largely power and heat generation, where alternative generation options exist, so that the saved biomass can be used for biofuels production for the transport sector. The potential for saving or substituting biomass in the power, buildings and industry sectors is, however, limited, so that with increasing prices the impact on biofuel imports diminishes. Even assuming extremely huge biofuel import prices of more than USD 50/GJ (USD 280 per barrel [bbl]) imports of more than 100 petajoules (PJ) remain in 2050. In other words, biofuel imports are essential to decarbonise the transport sector and reach the overall 85% reduction target in 2050, since domestic biomass resources of around 1 600 PJ are not sufficient to cover the required demand for biomass-based energy carriers.

Figure C.3 Impact of biofuel import prices on biofuel imports in the CNS in 2050



Key point *Biofuel imports initially decline with increasing import prices, but domestic resources within the Nordic region are not sufficient, so that even under extremely high biofuel import prices imports are required, mainly for the transport sector, to reach the 85% reduction target in 2050.*

D. Notes on Electricity Prices

Denmark

Table D.1 General Tax (VAT)

From	To	%
01.01.78	01.10.78	18
02.10.78	30.06.80	20
01.07.80	31.12.91	22
01.01.92	now	25

Notes: VAT = value added tax. VAT is not included in prices and taxes shown for industry, because it is refunded.

Special taxes

Labour market tax: From 1 February 1989 to 31 December 1991, this compulsory labour market tax, fixed at 2.5% of the basis of calculation of VAT, was imposed upon enterprises.

CO_2 tax: From January 2008 onwards, a CO_2 tax of Danish Krones (DKK) 150/tonne CO_2 is levied on VAT-registered enterprises. From January 1996 to December 2007, the CO_2 tax was DKK 90/tonne. From January 1993 to December 1995, the tax was DKK 50/tonne.

Energy tax: The energy tax is differentiated even more than the CO_2 tax, different tax rates applying both for different energy products and for different uses of the same product. Fuels for electricity generation are exempt from the tax, as it applies as an output tax on electricity.

Sulphur tax: From 1996 to 2000, in an effort to encourage a further shift from sulphur-rich to sulphur-poor fuels in combustion processes, *e.g.* from high-sulphur to low-sulphur coal or to natural gas, a sulphur tax of DKK 10/kg SO_2 was phased in. The tax is differentiated only according to the sulphur content of fuels (not on energy use). Prior to the end of 1999, fuels used for electricity generation were exempt from the tax, but the tax rate for electricity was calculated according to individual power plants' sulphur quotas. As a special concession, the 1996 rate will apply to coal used in certain high energy-consuming boilers and furnaces for a maximum transition period of 20 years.

Table D.2 Excise tax

From	To	DKK/MWh
15.05.92	31.12.93	270
01.01.94	31.12.94	300
01.01.95	31.12.95	330
01.01.96	31.12.96	360
01.01.97	31.12.97	400
01.01.98	31.12.98	466
01.01.99	31.12.99	481
01.01.00	31.12.00	490
01.01.01	31.12.01	505
01.01.02	31.12.04	520
01.01.05	31.12.07	530
01.01.08	31.12.08	541
01.01.09	31.12.09	550
01.01.10	now	613

Note: This tax is not included in the prices for industry, because it is refunded.

Special taxes

Table D.3 Payments to energy savings

From	To	DKK/MWh
01.01.00	now	6

Table D.4 Distribution tariff (DKK/MWh)

From	To	Tariff	Refunded to industry
01.01.00	now	40	30

Table D.5 Environment tax (and portion refunded to industry)

From	To	DKK/MWh	% Refunded to industry
15.05.92	31.12.92	100	100
01.01.93	31.12.96	100	50
01.01.97	31.12.97	100	40
01.01.98	31.12.98	100	30
01.01.99	31.12.99	100	20
01.01.00	31.12.02	100	10
01.01.03	31.12.04	100	40
01.01.05	31.12.07	90	26
01.01.08	31.12.08	88	25
01.01.09	31.12.09	89	25
01.01.10	now	62	25

Table D.6 Sulphur tax

From	To	DKK/MWh
01.01.96	31.12.98	9
01.01.99	31.12.99	13
01.01.00	now	0

Note: The price and tax shown are those actually paid (after rebates).

Industry

From the first quarter of 2005 (1Q05) onwards, prices refer to the industrial consumers with the average consumption 50 GWh/year. Prior to 1Q05, prices shown are the national average price for consumption equivalent to 1 000 MWh/year, including standing charges, and represent the average electricity price to all industrial sectors.

Sources: From 1Q05 onwards, Energitilsynet. Prior to 1Q07, Statistics Denmark.

Households

Prices correspond to consumption of 3 MWh/year, including standing charges.

Source: Statistics Denmark.

Finland

Table D.7 General Tax (VAT)

From	To	% Applied	% Total price
01.08.86	31.05.89	19.05	16.00
01.06.89	30.11.89	19.76	16.50
01.12.89	31.12.90	20.48	17.00
01.01.91	30.09.91	21.21	17.50
01.10.91	30.06.10	22.00	18.03
01.07.10	now	23.00	18.70

Note: VAT is not included in prices and taxes shown for industry because it is refunded.

Special taxes: From 1 January 1997 onwards, the energy/CO_2 tax is 100% carbon tax. In addition, fuels used in producing electricity are free of the energy/CO_2 tax and precautionary stock fee. Prior to 31 December 1996, the energy/CO_2 tax was approximately 75% carbon tax and 25% energy tax.

The peat tax and the tax subsidies on electricity produced in peat-fired power plants have been abolished. Earlier, small power plants (under 40 MVA) had been receiving tax subsidies. The decree to amend the law concerning the excise tax on electricity and certain fuels became effective on 1 July 2005.

Source: Ministry of Trade and Industry, Energy Statistics

Table D.8 Excise tax

From	To	EUR/MWh	FIM/MWh
Prior to	31.12.96		see tax column
01.01.97	31.03.97	4.0	24.0
01.04.97	31.12.97	2.4	14.5
01.01.98	31.08.98	3.4	20.2
01.09.98	31.12.02	4.2	25.0
01.01.03	31.12.06	4.4	
01.01.07	31.12.07	2.2	
01.01.08	31.12.10	2.5	
01.01.11	Now	6.9	

Note: FIM = Finnish Marks.

Industry

Table D.9 Precautionary stock fee

From	To	EUR/MWh	FIM/MWh
01.01.97	Now	0.1	0.75

Fiscal charges and fees

From January 2007 onwards, prices refer to the national average for a consumption of 2 000 to 19 999 MWh/year in a medium-scale industry; data collection for industrial electricity prices now follows the new methodology of Eurostat. Prices prior to September 2006 refer to the national average for a consumption of 2 000 MWh/year of high voltage over at least 4 000 hours/year in a medium-scale industry.

Table D.10 Excise tax

From	To	EUR/MWh	FIM/MWh
Prior to	31.12.96	See tax column	
01.01.97	31.03.97	4.0	24
01.04.97	31.08.98	5.6	33
01.09.98	31.12.02	6.9	41
01.01.03	31.12.07	7.3	
01.01.08	31.12.10	8.7	
01.01.11	now	16.9	

Households

Table D.11 Precautionary stock fee

From	To	EUR/MWh	FIM/MWh
01.01.97	Now	0.1	0.75

Fiscal charges and fees

Price shown refers to electricity used for non-heating purposes in a single house (120 m^2) at a rate of 5.0 MWh/year with 3x25A.

Norway

Table D.12 General tax (VAT)

From	To	%
01.01.70	31.12.92	20
01.01.93	31.12.94	22
01.01.95	31.12.00	23
01.01.01	31.12.04	24
01.01.05	now	25

Note: VAT is not included in prices and taxes shown for industry because it is refunded.

Special taxes

Table D.13 Consumption Tax

From	To	NOK/MWh
01.05.74	30.06.78	10.0
01.07.78	31.12.80	20.0
01.01.81	31.12.82	22.0
01.01.83	31.12.83	25.0
01.01.84	31.12.84	27.0
01.01.85	31.12.85	29.0
01.01.86	30.06.86	31.0
01.07.86	31.12.86	32.0
01.01.87	31.12.87	34.0
01.01.88	31.12.88	36.0
01.01.89	31.12.89	37.0
01.01.90	31.12.90	38.5
01.01.91	31.12.91	40.0
01.01.92	31.12.92	41.5
01.01.93	31.12.93	46.0
01.01.94	31.12.94	51.0
01.01.95	31.12.95	52.0
01.01.96	31.12.96	53.0
01.01.97	31.12.97	56.2
01.01.98	31.12.98	57.5
01.01.99	31.12.99	59.4
01.01.00	31.12.00	85.6
01.01.01	31.12.01	113.0

01.01.02	31.12.02	93.0
01.01.03	31.12.03	95.0
01.01.04	31.12.04	96.7
01.01.05	31.12.05	98.8
01.01.06	31.12.06	100.5
01.01.07	31.12.07	102.3
01.01.08	31.12.08	105.0
01.01.09	31.12.09	108.2
01.01.10	31.12.10	110.1
01.01.11	31.12.11	112.1
01.01.12	now	113.9

Note: NOK = Norwegian Krone.

Taxes refer to average annual revenues per MWh that utilities receive from industry and households. They are converted to quarterly tax rates using the electricity sub-indices from the monthly Consumer Price Index (for households) and in the monthly Wholesale Price Index (for industry).

Source: Ministry of Industry and Energy; questionnaire survey of all power plants including those owned by industry.

Industry

Table D.14 Excise tax (applies to power-intensive industry and paper and pulp industry)

From	To	NOK/MWh
01.01.87	31.12.87	31
01.01.88	31.12.88	34
01.01.89	31.12.89	37

From 1 January 1990 onwards, the power-intensive and paper and pulp industries are paying the same tax as the other sectors. Prices refer to the average of the prices for the energy-intensive sectors such as manufacturing, paper and products, mining, quarrying, other manufacturing, transport, construction site power, private and public services. Prices for industry do not include grid rent.

Households

Note: From 2008 onwards, prices represent average spot contract prices; before 2008, average variable price contacts.

General taxes (VAT): Rates vary between regions and over time. The national average rate is close to 20%.

Prices shown also include agriculture.

Sweden

Table D.15 General tax (VAT)

From	To	%
01.03.90	30.06.90	23.46
01.07.90	now	25.00

Note: VAT is not included in prices and taxes shown for industry because it is refunded.

Special tax

NO_x Levy: From 1 January 1992 onwards, a levy of Swedish Krona (SEK) 40/kg of nitrogen oxide emissions from certain combustion plants is applied. The tax is levied on plants liable to pay it according to the amount of energy produced. The levy is not included in estimated tax component shown in this context.

From 2007, prices refer to the Eurostat consumption band DD for households and ID for industry (see specifications). No information was available from 1998 to 2006. Prior to 1998, prices refer to annual average ex-tax revenues per MWh received by all public utilities from total deliveries to manufacturing industry, mining, and quarrying (industry), and from low-voltage deliveries to households and commerce (households). Latest data are derived from the most actual annual statistics on revenues by using producer price index on electricity (industry) and consumer price index on electricity (households).

Special taxes

Energy tax (SEK/MWh): The lower value under category “Household and Commercial” is valid for some municipalities in the north of Sweden, while the higher tax is valid for the rest of the country. Approximately 9% of the households are subject to the lower tax while the rest, 91%, are subject to the higher rate.

Table D.16 Energy tax (SEK/MWh)

From	To	Industry		Household and Commercial
		< 40 MWh/year	Add. consumption	
20.03.77	20.12.79	30	20	30
21.12.79	30.06.81	40	30	40
01.07.81	31.12.83	40	30	30-40
01.01.84	30.11.84	52	30	42-52
01.12.84	31.12.86	72	50	62-72
01.01.87	30.06.89	50	50	62-72
01.07.89	28.02.90	70	70	82-92
01.03.90	31.12.92	50	50	22-72
01.01.93	31.12.93	0	0	35-85
01.01.94	31.12.94	0	0	36-88
01.01.95	31.12.95	0	0	37-90
01.01.96	31.08.96	0	0	43-97
01.09.96	30.06.97	0	0	58-113
01.07.97	31.12.97	0	0	82-138
01.01.98	31.12.98	0	0	96-152
01.01.99	31.12.99	0	0	95-151
01.01.00	31.12.00	0	0	106-162
01.01.01	31.12.01	0	0	125-181
01.01.02	31.12.02	0	0	140-198
01.01.03	31.12.03	0	0	168-227
01.01.04	31.12.04	5	5	181-241
01.01.05	31.12.05	5	5	194-254
01.01.06	31.12.06	5	5	201-261
01.01.07	31.12.07	5	5	204-265
01.01.08	31.12.08	5	5	178-270
01.01.09	31.12.09	5	5	186-282
01.01.10	now	5	5	185-280

Specifications

Consumption band DD: annual consumption of 5 000 to 15 000 kWh.

Consumption band ID: annual consumption of 2 000 to 20 000 MWh.

Source: From 2007, Eurostat, Energy Statistics: gas and electricity prices - new methodology from 2007 onwards. Prior to 1998, Statistics Sweden.

E. Notes on Primary Energy Conventions

When constructing an energy balance, it is necessary to adopt conventions for primary energy from several sources, such as nuclear, geothermal, solar, hydro, wind, etc. The two types of assumptions that have to be made are described below.

Choice of the primary energy form

For each of these sources, there is a need to define the form of primary energy to be considered; for instance, in the case of hydro energy, a choice must be made between the kinetic energy of falling water and the electricity produced. For nuclear energy, the choice is between the energy content of the nuclear fuel, the heat generated in the reactors and the electricity produced. For photovoltaic (PV) electricity, the choice is between the solar radiation received and the electricity produced.

The principle adopted by the IEA is that the primary energy form should be the first energy form downstream in the production process for which multiple energy uses are practical. The application of this principle leads to the choice of the following primary energy forms:

- Heat for nuclear, geothermal and solar thermal;
- Electricity for hydro, wind, tide/wave/ocean and solar photovoltaic.

Calculation of the primary energy equivalent

There are essentially two methods that can be used to calculate the primary energy equivalent of the above energy sources: the partial substitution method and the physical energy content method.

The partial substitution method: In this method, the primary energy equivalent of the above sources of electricity generation represents the amount of energy that would be necessary to generate an identical amount of electricity in conventional thermal power plants. The primary energy equivalent is calculated using an average generating efficiency of these plants. This method has several shortcomings, including the difficulty of choosing an appropriate generating efficiency and the fact that the partial substitution method is not relevant for countries with a high share of hydro electricity. For these reasons, the IEA, as most international organisations, has now stopped using this method and adopted the physical energy content method.

The physical energy content method: This method uses the physical energy content of the primary energy source as the primary energy equivalent. As a consequence, there is an obvious link between the principles adopted in defining the primary energy forms of energy sources and the primary energy equivalent of these sources.

For instance, in the case of nuclear electricity production, as heat is the primary energy form selected by the IEA, the primary energy equivalent is the quantity of heat generated in the reactors. However, as the amount of heat produced is not always known, the IEA estimates the primary energy equivalent from the electricity generation by assuming an efficiency of 33%, which is the average of nuclear power plants in Europe.

In the case of hydro, wind and solar PV, as electricity is the primary energy form selected, the primary energy equivalent is the physical energy content of the electricity generated in the plant, which amounts to assuming an efficiency of 100%. For geothermal, if no country-specific information is reported, the primary energy equivalent is calculated as follows:

- 10% for geothermal electricity;
- 50% for geothermal heat.

Since these two types of energy balances differ significantly in the treatment of electricity from solar, hydro, wind, etc., the share of renewables in total energy supply will appear to be very different depending on the method used. As a result, when looking at the percentages of various energy sources in total supply, it is important to understand the underlying conventions that were used to calculate the primary energy balances.

F. Definitions

This annex provides definitions and units used throughout this publication.

Definitions

	2-, 3- and 4-wheelers	This vehicle category includes motorised vehicles having two, three or four wheels. 4-wheelers are not homologated to drive on motorways, such as all terrain vehicles.
A	Advanced biofuels	Advanced biofuels comprise different emerging and novel conversion technologies that are currently in the research and development, pilot or demonstration phase. This definition differs from the one used for "Advanced Biofuels" in United States legislation, which is based on a minimum 50% lifecycle greenhouse-gas (GHG) reduction and which, therefore, includes sugar cane ethanol.
	Aquifer	A porous, water saturated body of rock or unconsolidated sediments, the permeability of which allows water to be produced (or fluids injected). If the water contains a high concentration of salts, it is a saline aquifer.
B	Bayer process	Process for the production of alumina from bauxite ore.
	Biodiesel	Biodiesel is a diesel-equivalent, processed fuel made from the transesterification (a chemical process that removes the glycerine from the oil) of both vegetable oils and animal fats.
	Biofuels	Biofuels are fuels derived from biomass or waste feedstocks and include ethanol and biodiesel. They can be classified as conventional and advanced biofuels according to the technologies used to produce them and their respective maturity.
	Biogas	Biogas is a mixture of methane and CO_2 produced by bacterial degradation of organic matter and used as a fuel.
	Biomass	Biomass is a biological material that can be used as fuel or for industrial production. Includes solid biomass such as wood, plant and animal products, gases and liquids derived from biomass, industrial waste and municipal waste.
	Biomass and waste	Biomass and waste includes solid biomass, gas and liquids derived from biomass, industrial waste and the renewable part of municipal waste. Includes both traditional and modern biomass.

Biomass-to-liquids	Biomass-to-liquids (BTL) refers to a process that features biomass gasification into syngas (a mixture of hydrogen and carbon monoxide) followed by synthesis, of liquid products (such as diesel, naphtha or gasoline) from the syngas, using Fischer-Tropsch catalytic synthesis or a methanol-to-gasoline reaction path. The process is similar to those used in coal-to-liquids or gas-to-liquids.
Bio-SNG	Bio-synthetic natural gas (BIO-SNG) is biomethane derived from biomass via thermal processes.
Black liquor	A by-product from chemical pulping processes, which consists of lignin residue combined with water and the chemicals used for the extraction of the lignin.
Buses and minibuses	Passenger motorised vehicles with more than nine seats.

C

Capacity credit	Capacity credit refers to the proportion of capacity that can be reliably expected to generate electricity during times of peak demand in the grid to which it is connected.
Capacity (electricity)	Measured in megawatts (MW) capacity (electricity), is the instantaneous amount of power produced, transmitted, distributed or used at a given instant.
Carbon Capture and Storage (CCS)	An integrated process in which CO_2 is separated from a mixture of gases (*e.g.* the flue gases from a power station or a stream of CO_2-rich natural gas), compressed to a liquid or liquid-like state, then transported to a suitable storage site and injected into a deep geologic formation.
Clean coal technologies (CCTs)	CCTs are designed to enhance the efficiency and the environmental acceptability of coal extraction, preparation and use.
Clinker	Clinker is a core component of cement made by heating ground limestone and clay at a temperature of about 1 400°C to 1 500°C.
Coal	Coal includes both primary coal (including hard coal and brown coal) and derived fuels (including patent fuel, brown-coal briquettes, coke-oven coke, gas coke, gas-works gas, coke-oven gas, blast-furnace gas and oxygen steel furnace gas). Peat is also included.
Coefficient of performance	Coefficient of performance is the ratio of heat output to work supplied, generally applied to heat pumps as a measure of their efficiency.
Co-generation	Co-generation refers to the combined production of heat and power.
Coal-to-liquids	Coal-to-liquids (CTL) refers to the transformation of coal into liquid hydrocarbons. It can be achieved through either coal gasification into syngas (a mixture of hydrogen and carbon monoxide), combined with Fischer-Tropsch or methanol-to-gasoline synthesis o produce liquid fuels, or through the less developed direct-coal liquefaction technologies in which coal is directly reacted with hydrogen.

	Conventional biofuels	Conventional biofuels include well-established technologies that are producing biofuels on a commercial scale today. These biofuels are commonly referred to as first-generation and include sugar cane ethanol, starch-based ethanol, biodiesel, Fatty Acid Methyl Esther (FAME) and Straight Vegetable Oil (SVO). Typical feedstocks used in these mature processes include sugar cane and sugar beet, starch bearing grains, like corn and wheat, and oil crops, like canola and palm, and in some cases animal fats.
	Corex	A smelting-reduction process developed by Siemens VAI for manufacture of hot metal from iron ore and coal in which the iron ore is pre-reduced in a reduction shaft using offgas from the melter-gasifier before being introduced into the melter-gasifier.
D	Demand response	Demand response is a mechanism by which the demand side of the electricity system shifts electricity demand over given time periods in response to price changes or other incentives, but does not necessarily reduce overall electrical energy consumption. This can be used to reduce peak demand and provide electricity system flexibility.
	Distribution	Electricity distribution systems transport electricity from the transmission system to end users.
E	Electrical energy	Measured in megawatt hours (MWh) or kilowatt hours (kWh), indicates the net amount of electricity generated, transmitted, distributed or used over a given time period.
	Electricity generation	Electricity generation is defined as the total amount of electricity generated by power only, or combined heat and power plants, including generation required for own use. This is also referred to as gross generation.
	Energy intensity	A measure where energy is divided by a physical or economic denominator, *e.g.* energy use per unit value added or energy use per tonne of cement.
	Enhanced oil recovery (EOR)	EOR is a process that modifies the properties of oil in a reservoir to increase recovery of oil, examples of which include: surfactant injection, steam injection, hydrocarbon injection, and CO_2 flooding. These processes are typically used following primary recovery (oil produced by the natural pressure in the reservoir) and secondary recovery (using water injection), but can be used at other times during the life of an oilfield.
	Ethanol	Although ethanol can be produced from a variety of fuels, in this book, ethanol refers to bio-ethanol only. Ethanol is produced from fermenting any biomass high in carbohydrates. Today, ethanol is made from starches and sugars, but second generation technologies will allow it to be made from cellulose and hemicellulose, the fibrous material that makes up the bulk of most plant matter.
F	FINEX	A smelting-reduction process developed by Pohang Iron and Steel Company (POSCO) in collaboration with Siemens VAI, where iron ore fines are pre-reduced in a series of fluidised bed reactors before being introduced to the melter-gasifier.
	Fischer-Tropsch (FT) synthesis	Catalytic production process for the production of synthetic fuels. Natural gas, coal and biomass feedstocks can be used.

Flexibility	Power system flexibility expresses the extent to which a power system can modify electricity production or consumption in response to variability, expected or otherwise. In other words, it expresses the capability of a power system to maintain reliable supply in the face of rapid and large imbalances, whatever the cause. It is measured in terms of the MW available for ramping up and down, over time (±MW/time).
Fuel cell	A device that can be used to convert hydrogen or natural gas into electricity. Various types exist that can be operated at temperatures ranging from 80°C to 1 000°C. Their efficiency ranges from 40% to 60%. For the time being, their application is limited to niche markets and demonstration projects due to their high cost and the immature status of the technology, but their use is growing fast.

G

Gas	Gas includes natural gas, both associated and non-associated with petroleum deposits, but excludes natural gas liquids.
Gas-to-liquids (GTL)	GTL refers to a process featuring reaction of methane with oxygen or steam to produce syngas (a mixture of hydrogen and carbon monoxide) followed by synthesis of liquid products (such as diesel and naphtha) from the syngas using Fischer-Tropsch catalytic synthesis. The process is similar to those used in coal-to-liquids or biomass-to-liquids.

H

Heat	Heat is obtained from the combustion of fuels, nuclear reactors, geothermal reservoirs, capture of sunlight, exothermic chemical processes and heat pumps which can extract it from ambient air and liquids. It may be used for domestic hot water, space heating or cooling, or industrial process heat. In IEA statistics, heat refers to heat produced for sale only. Most heat included in this category comes from the combustion of fuels in co-generation installations, although some small amounts are produced from geothermal sources, electrically powered heat pumps and boilers. Heat produced for own use, for example in buildings and industry processes, is not included in IEA statistics, although frequently discussed in this book.
HIsmelt	A direct smelting process, licensed by HIsmelt Corporation, where iron ore is reduced in a molten metal bath.
HIsarna	A smelting reduction process being developed by the European Ultra-Low Carbon Dioxide Steelmaking (ULCOS) programme, which combines the HIsmelt process with an advanced Corus cyclone converter furnace. All process steps are directly hot-coupled, avoiding energy losses from intermediate treatment of materials and process gases.
Hydropower	Hydropower refers the energy content of the electricity produced in hydropower plants, assuming 100% efficiency. It excludes output from pumped storage and marine (tide and wave) plants.
Integrated gasification combined cycle	Integrated gasification combined-cycle (IGCC) is a technology in which a solid or liquid fuel (coal, heavy oil or biomass) is gasified, followed by use for electricity generation in a combined-cycle power plant. It is considered a promising electricity generation technology, due to its potential to achieve high efficiencies and low emissions.

I	Isarna	The former name for the HIsarna process, which is a smelting reduction process being developed by the European Ultra-Low Carbon Dioxide Steelmaking (ULCOS) programme, which combines the HIsmelt process with an advanced Corus cyclone converter furnace. All process steps are directly hot-coupled, avoiding energy losses from intermediate treatment of materials and process gases.
L	Low-carbon energy technologies	Lower CO_2 emissions, higher-efficiency energy technologies from all sectors (buildings, industry, power and transport) that are being pursued in an effort to mitigate climate change.
M	Markets	Markets are structures which allow buyers and sellers to exchange any type of goods, services and information.
	Middle distillates	Middle distillates include jet fuel, diesel and heating oil.
	Modern biomass	Modern biomass includes all biomass with the exception of traditional biomass.
N	Non-energy use	Non-energy use refers to fuels used for chemical feedstocks and non-energy products. Examples of non-energy products include lubricants, paraffin waxes, coal tars and oils as timber preservatives.
	Nuclear	Nuclear refers to the primary heat equivalent of the electricity produced by a nuclear plant with an average thermal efficiency of 33%.
O	Oil	Oil includes crude oil, condensates, natural gas liquids, refinery feedstocks and additives, other hydrocarbons (including emulsified oils, synthetic crude oil, mineral oils extracted from bituminous minerals such as oil shale, bituminous sand and oils from coal liquefaction) and petroleum products (refinery gas, ethane, LPG, aviation gasoline, motor gasoline, jet fuels, kerosene, gas/diesel oil, heavy fuel oil, naphtha, white spirit, lubricants, bitumen, paraffin waxes and petroleum coke).
P	Passenger light duty vehicles	This vehicle category includes all four-wheels vehicle aimed at the mobility of persons on all types of roads, up to nine persons per vehicle and 3.5t of gross vehicle weight.
	Purchasing power parity (PPP)	PPP is the rate of currency conversion that equalises the purchasing power of different currencies. It makes allowance for the differences in price levels and spending patterns between different countries.
R	Renewables	Renewable includes biomass and waste, geothermal, hydropower, solar photovoltaic, concentrating solar power, wind and marine (tide and wave) energy for electricity and heat generation.
	Road mass transport	See buses and minibuses.
S	Smart grids	A smart grid is an electricity network that uses digital and other advanced technologies to monitor and manage the transport of electricity from all generation sources to meet the varying electricity demands of end-users. Smart grids co-ordinate the needs and capabilities of all generators, grid operators, end-users and electricity market stakeholders to operate all parts of the system as efficiently as possible, minimising costs and environmental impacts while maximising system reliability, resilience and stability.

	Steam coal	All other hard coal that is not classified as coking coal. Also included are recovered slurries, middlings and other low-grade coal products not further classified by type. Coal of this quality is also commonly known as thermal coal.
	Synthetic fuels	Synthetic fuel or synfuel is any liquid fuel obtained from coal, natural gas or biomass. The best known process is the Fischer-Tropsch synthesis. An intermediate step in the production of synthetic fuel is often syngas, a mixture of carbon monoxide and hydrogen produced from coal which is sometimes directly used as an industrial fuel.
T	Total final consumption (TFC)	TFC is the sum of consumption by the different end-use sectors, it excludes conversion losses from the transformation sector (power plants, oil refineries, etc.), energy industry own energy use and other losses. TFC is broken down into energy demand in the following sectors: industry (including manufacturing and mining), transport, buildings (including residential and services) and other (including agriculture and nonenergy use). The final consumption of the transport sector includes international marine and aviation bunkers..
	Total primary energy demand (TPED)	TPED represents domestic demand only and is broken down into power generation, other energy sector and total final consumption.
	Total primary energy supply (TPES)	TPES is the total amount of energy supplied to the energy system, at the domestic level it is equivalent to total primary energy demand. Total primary energy supply is made up of primary energy production + imports - exports ± stock changes. Stock changes reflect the difference between opening stock levels on the first day of the year and closing levels on the last day of the year of stocks on national territory. A stock build is a negative number, a stock draw a positive number.
	Traditional biomass	Traditional biomass refers to the use of fuel wood, charcoal, animal dung and agricultural residues in stoves with very low efficiencies.
	Transmission	Electricity transmission systems transfer electricity from generation (from all types, such as variable and large-scale centralised generation, and large-scale hydro with storage) to distribution systems (including small and large consumers) or to other electricity systems.

Sector Definitions

Buildings	Buildings includes energy used in residential, commercial and institutional buildings. Building energy use includes space heating and cooling, water heating, lighting, appliances, cooking and miscellaneous equipment (such as office equipments and other small plug loads in the residential and service sectors).
Energy industry own use	Energy industry own use covers energy used in coal mines, in oil and gas extraction and in electricity and heat production. Transfers and statistical differences as well as pipeline transport are also included in this category.
Fuel transformation	Fuel transformation covers the use of energy by transformation industries and the energy losses in converting primary energy into a form that can be used in the final consuming sectors. It includes losses by gas works, petroleum refineries, coal and gas transformation and liquefaction as well as biofuel production. Energy use in blast furnaces, coke ovens and petrochemical plants is not included, but accounted for in Industry.
Industry	Industry includes fuel used within the manufacturing and construction industries. Fuel used as petrochemical feedstock and in coke ovens and blast furnaces is also included. Key industry sectors include iron and steel, chemical and petrochemical, non-metallic minerals, and pulp and paper. Use by industries for the transformation of energy into another form or for the production of fuels is excluded and reported separately under fuel transformation. Consumption of fuels for the transport of goods is reported as part of the transport sector.
Other end-uses	Other end-uses refer to final energy used in agriculture, forestry and fishing as well as other non-specified consumption.
Power generation	Power generation refers to fuel use in electricity plants, heat plants and co-generation plants. Both main activity producer plants and small plants that produce fuel for their own use (autoproducers) are included. Energy use and emissions for pipeline transport are also included.
Transport	Transport includes all the energy used once transformed (tank to wheel); international marine and aviation bunkers is shared among countries based on the statistics available. Energy use and emissions related to pipeline transport are accounted for under Energy industry own use.

Units

Unit prefix	E	exa (10^{18}, quintillion)
	P	peta (10^{15}, quadrillion)
	T	tera (10^{12}, trillion)
	G	giga (10^{9}, billion)
	M	mega (10^{6}, million)
	k	kilo (10^{3}, thousand)
	c	centi (10^{-2}, hundredth)
	m	milli (10^{-3}, thousandth)
	μ	micro (10^{-6}, millionth)
Area	Ha	hectare
	m^2	square metre
Emissions	CO_2-eq	carbon-dioxide equivalent
	g CO_2/km	gramme of carbon dioxide per kilometre
	g CO_2/kWh	gramme of carbon dioxide per kilowatt-hour
	g CO_2-eq	gramme of carbon-dioxide equivalent (using 100-year global warming potentials for different greenhouse gases)
	g/Nm^3	gramme per normal cubic metre
	ppm	parts per million (by volume)
	t CO_2-eq	tonne of carbon-dioxide equivalent (using 100-year global warming potentials for different greenhouse gases)
Energy	bbl	barrel
	J	joule
	tce	tonne of coal equivalent (equals 0.7 toe)
	toe	tonne of oil equivalent
	Wh	watt-hour
Mass	g	gramme
	kg	kilogramme
	t	tonne
Monetary	USD million	1 US dollar x 10^{6}
	USD billion	1 US dollar x 10^{9}
	USD trillion	1 US dollar x 10^{12}
Pressure	bar	bar
	Pa	pascal
Temperature	°C	degree Celsius

Volume	m^3	cubic metre
Sector-specific units	bcm	billion cubic metres
Gas	tcm	trillion cubic metres
	bbl	barrel
Oil	mb/d	million barrels per day
Power	g CO_2/kWh	gramme of carbon dioxide per kilowatt-hour
	W	watt (1 joule per second)
	W_e	watt electrical
	Wh	watt-hour
	W_{th}	watt thermal
	g CO_2/km	gramme of carbon dioxide per kilometre
Transport	km	kilometre
	km/hr	kilometre per hour
	lge	litre gasoline equivalent
	pkm	passenger kilometre
	tkm	tonne kilometre
	vkm	vehicle kilometre

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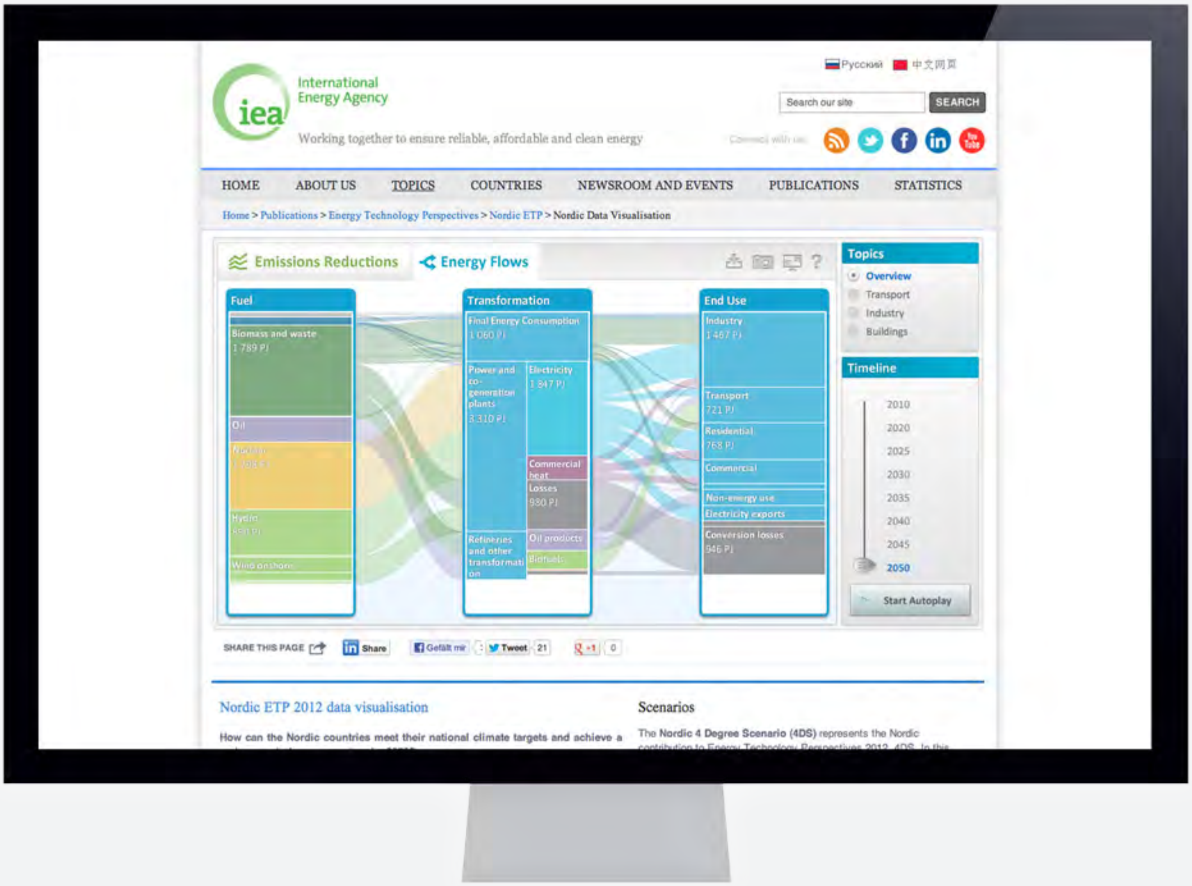

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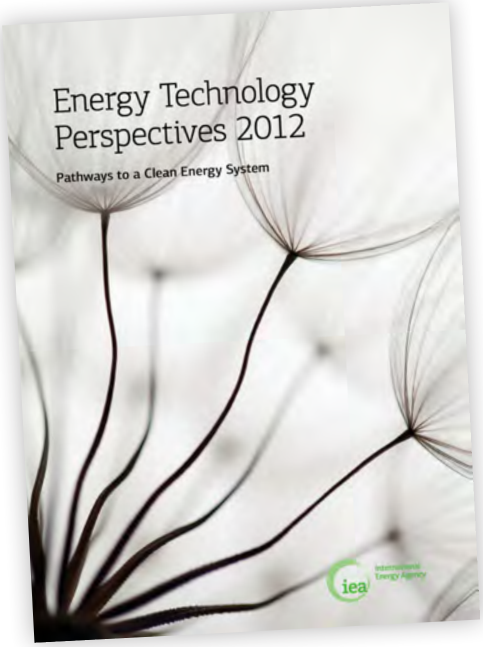

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