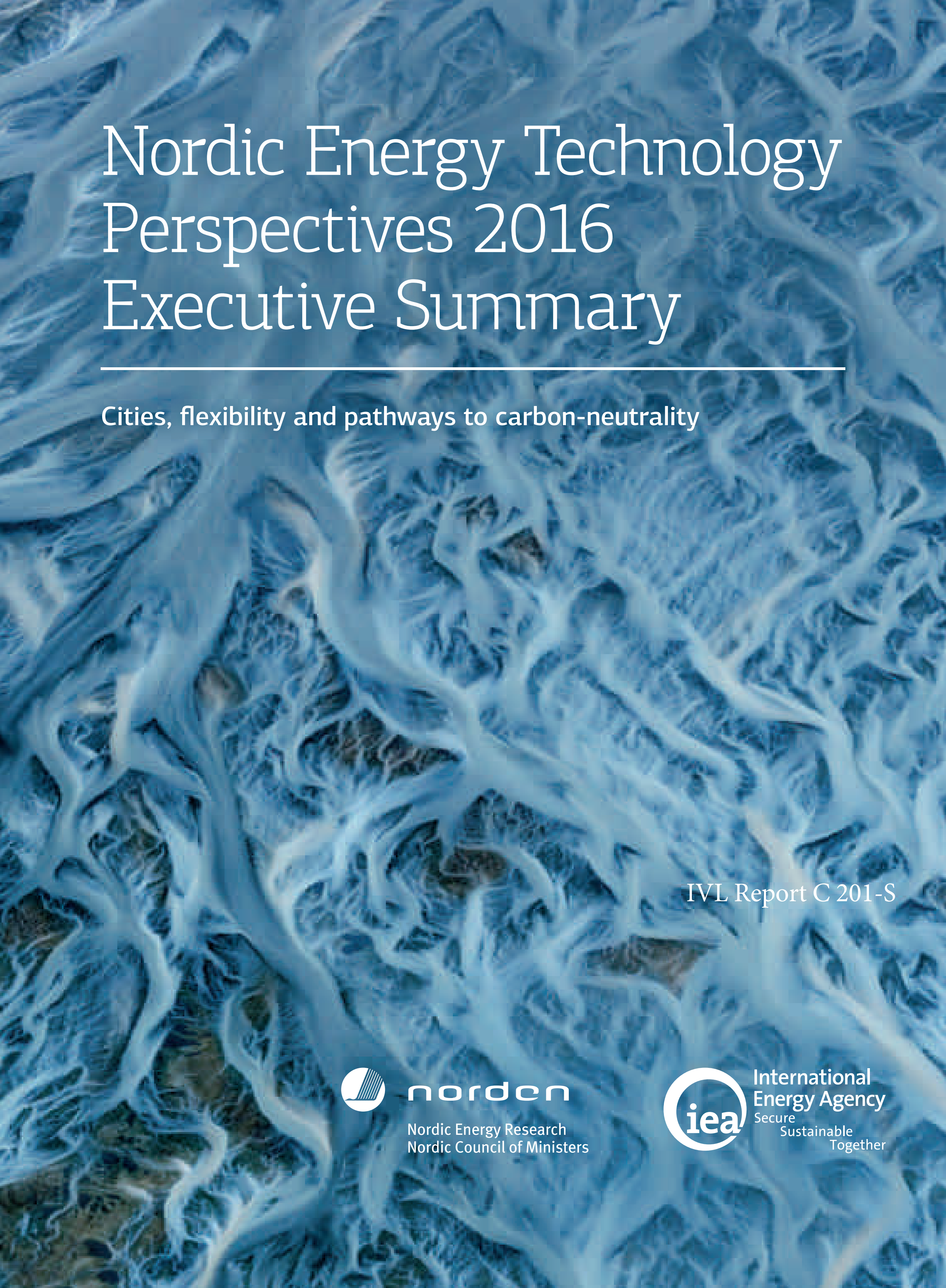

Nordic Energy Technology Perspectives 2016 Executive Summary

Cities, flexibility and pathways to carbon-neutrality

IVL Report C 201-S

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Nordic Energy Research
Nordic Council of Ministers

International Energy Agency
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Executive Summary

There is a clear technological and economical pathway for the Nordic region to push towards a near carbon-neutral energy system in 2050. Together, Nordic countries can send a strong signal to the global community that the ambitious aims of the Paris Climate Agreement are achievable.

Strategic actions

The Nordic Carbon-Neutral Scenario (CNS) central to this report sets out three macro-level strategic actions that will be key in achieving the climate targets of the Nordic countries in 2050. In the context of an overarching aim to achieve a near carbon-neutral energy system, governments, policy makers and private sector decision makers should:

1. ***Incentivise and plan for a Nordic electricity system that is significantly more distributed, interconnected and flexible than today's.***

This analysis demonstrates that if a carbon-neutral system is the target, it will likely cost less to transition to a more distributed electricity supply with a high share of wind than to maintain a system reliant on centralised nuclear and thermal generation. The utilisation of abundant Nordic wind resources, together with more active use of existing dispatchable hydropower, creates an opportunity for the Nordic region to play a stronger European role. The Nordic region can both export electricity and balance European variable renewables, generating large economic revenues and facilitating the transformation of the European energy system.

The potential for significant net economic and climate benefits associated with greater grid interconnection and wind build-out need to be balanced against the energy security concerns of industry and the need for public acceptance of new infrastructure. Higher shares of wind will require enhanced system integration across sectors and technologies, and among the Nordic countries. In addition, it will necessitate complementing existing dispatchable hydropower with other sources of flexibility to minimise integration costs. The current challenging economic outlook for nuclear power in the face of competition from wind leads to a decrease in stable base load (especially in Sweden), further increasing the need for system flexibility. The transition to greater electricity trade and interdependence among Nordic countries must allay concerns from energy-intensive industries over security of supply. Despite low average generation costs in the Nordic region, prices to consumers vary between countries, partly as a result of different tax regimes. Greater integration with the European electricity system will likely push Nordic electricity prices for consumers and industry towards the higher prices characteristic of the continent. Higher shares of wind are also likely to lead to greater price variations. This signifies a substantial change from the low and stable prices that have long been a key competitive advantage for Nordic industry, necessitating clever policies to guide the transition.

2. *Ramp up technology development to advance decarbonisation of long-distance transport and the industrial sector.*

Despite a broad electrification of short-distance transport, long-distance modes are unlikely to be decarbonised without utilising large volumes of biofuels. If Nordic biomass continues to be transformed into higher-value products (e.g. within the pulp and paper industry), 16% of total Nordic biomass demand across all sectors will need to be met by imports in 2050 (including for refuelling at Nordic ports). Sustainable and politically acceptable sourcing of those resources will be crucial. Decarbonising transport through local advanced biofuel production would likely be more costly than participating in global biofuel markets. Although research, development, demonstration and deployment (RDD&D) efforts in advanced biofuels could lower costs, using Nordic biomass resources to cover the entire demand for bioenergy would mean diverting them from higher value products in industry. Competing low-carbon fuels, such as hydrogen or highway electrification, bear higher investment risks and costs, both for vehicles and distribution infrastructure. Pilot projects to improve understanding of the technical feasibility and cost profile of these solutions should be pursued.

Emissions from industry are the most challenging to reduce, requiring rapid advances in the demonstration and deployment of carbon capture and storage (CCS) and other innovative low-carbon process technologies. With substantial activity in iron and steel, cement, chemicals and aluminium sectors, Nordic industry has a relatively large share of process-related emissions that cannot be mitigated through energy efficiency or switching to lower-carbon energy mixes. If wide application of innovative low-carbon technologies, such as industrial CCS, does not materialise as envisioned in the CNS, the development and demonstration of breakthrough process technologies will need to be dramatically accelerated to reduce these emissions. Alternatively, other sectors of the economy would need to reduce emissions even further. Greater Nordic cooperation will be needed on RDD&D, policies and infrastructure planning for CCS.

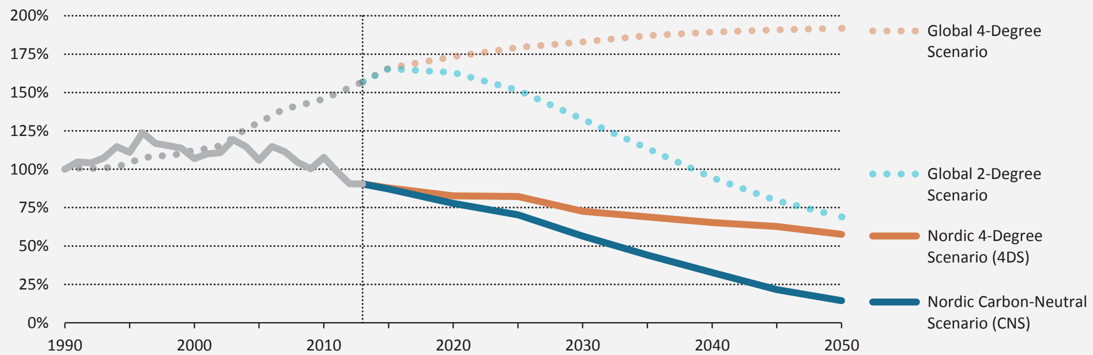
3. *Tap into the positive momentum of cities to strengthen national decarbonisation and energy efficiency efforts in transport and buildings.*

Several Nordic capitals and smaller cities have adopted climate targets that are more aggressive than national aims. Better alignment and co-operation across national and local policy allows national efforts to leverage this urban leadership. With Nordic urban areas expected to grow at twice the rate of previous decades, an opportunity exists to transition to low-carbon, highly integrated and efficient urban energy systems. Accelerated renovation to improve the efficiency of existing buildings is critical, and areas of high population density facilitate the use of district heating and cooling in buildings – in some cases through the use of excess heat. Electric vehicles (EVs), public transport and cycling are best suited to cities and offer enhanced mobility services, improved local air quality and reductions in congestion, in addition to lower energy use and emissions. Shifting the policy focus to improving energy services (rather than just delivering energy) is the most effective way to capture such non-energy benefits of a low-carbon energy system.

Nordic Energy Technology Perspectives 2016 (NETP 2016) presents technology pathways towards a near-zero emission Nordic energy system, in direct response to the ambitious national climate targets for 2050 across the region. It is the result of a joint project involving the International Energy Agency (IEA), Nordic Energy Research and leading research institutions from all five Nordic countries. While the analytical framework (including technology assumptions and global fuel prices) is common to the IEA's *Energy Technology Perspectives*

2016, *NETP 2016* presents in-depth Nordic scenarios tailored to inform the decisions of Nordic policy makers. The analysis is presented around the Nordic Carbon-Neutral Scenario (CNS), which results in an 85% reduction in emissions by 2050 (from 1990 levels). The Nordic 4°C Scenario (4DS) entails a 42% reduction and serves as the baseline.

Figure ES.1 Nordic and global CO_2 emissions



Figures and data in this report can be downloaded at www.iea.org/etp/nordic.

Key point *The CNS can be viewed as a test of the Paris Climate Agreement: Nordic CO_2 emissions[1] drop by 85% by 2050 (compared with 1990 levels), surpassing the 70% decline projected in the global 2°C Scenario[2] set out in ETP 2016.*

NETP 2016 updates and strengthens the scenarios presented in *NETP 2013*. In addition, it examines the central challenges that the 2013 edition identified, using a broader portfolio of specialised energy system models. New analysis examines how urban energy systems can stimulate decarbonisation of transport and buildings, and how increasing the flexibility of the Nordic electricity system can support integration of high shares of variable renewable electricity. *NETP 2016* calculates the investments required and identifies opportunities for policy action and international cooperation that enable the CNS.

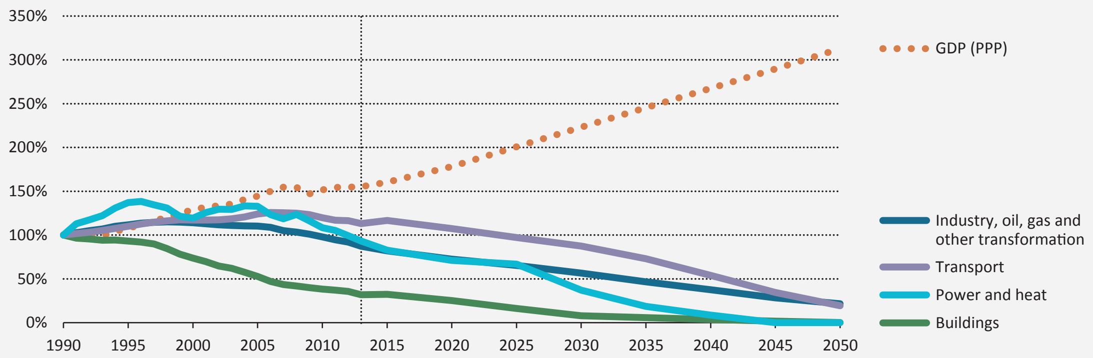
1 Unless otherwise noted, CO_2 emissions are energy-related, including process- and feedstock-related emissions from industry as well as emissions from international shipping and aviation refuelling in Nordic countries.

2 The global 4°C Scenario represents a future in which strategic action limits global average temperature increase to 4°C. The Nordic 4°C Scenario (4DS) is the Nordic contribution to the global 4°C Scenario and functions as the baseline scenario for this study. The global 2°C Scenario reflects more aggressive approaches to limit the rise to 2°C. The Nordic Carbon-Neutral Scenario (CNS) aims for even greater emissions reduction within the Nordic region (as the rest of the world pursues the global 2°C Scenario). Broadly in line with statements from Nordic governments, the CNS assumes a 15% share of emissions reduction is achieved through offsets.

Achieving a carbon-neutral Nordic energy system

The Nordic countries have already decarbonised aspects of their energy systems, having decoupled CO_2 emissions from GDP growth more than two decades ago. Mitigation of direct emissions from buildings is most advanced, thanks to the expansion of district heating networks and the phasing-out of oil-fired boilers. Emissions from power and district heat were the next to decline (after peaking in the mid-1990s) through an expansion of renewables. Stable and ambitious carbon taxation and renewable energy incentives have stimulated a growing share of renewable energy, primarily in the forms of bioenergy and wind. The common Nordic electricity grid has facilitated decarbonisation by allowing wind power in Denmark to be partially balanced by hydropower in Norway and Sweden. The carbon intensity of Nordic electricity supply was around 59 grammes of CO_2 per kilowatt-hour (gCO_2/kWh) in 2013, already at the level the world must reach in 2045 to realise the global 2°C Scenario.

Figure ES.2 Nordic CO_2 emissions and economic growth in the CNS, by sector

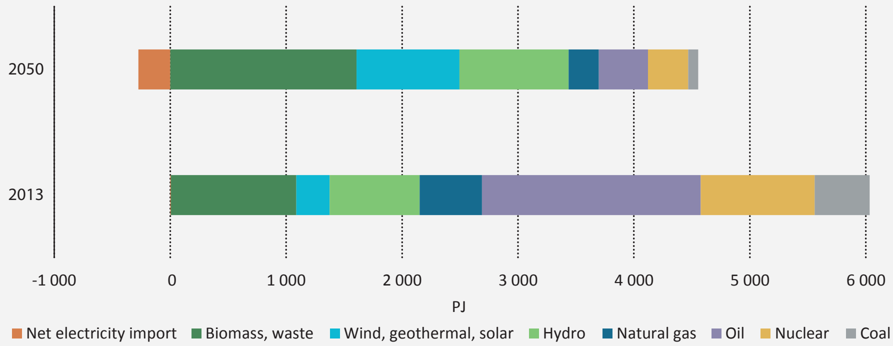


Note: Historical data smoothed using a 5-year rolling average to account for seasonal variations in emissions arising from the interplay between hydropower and coal power.
Figures and data in this report can be downloaded at www.iea.org/etp/nordic.

Key point *Emissions have already been decoupled from Nordic GDP across all sectors, and this must accelerate in order to achieve the CNS. Decarbonisation occurs more quickly in power and heat generation and in direct emissions from buildings, than in transport and industry.*

Policy and technology innovation will be crucial to achieve the continued decoupling of economic growth and emissions in the CNS. Policies and technologies implemented to date to weaken the link between economic growth and emissions have already captured the most cost-effective opportunities, leaving bigger challenges in sectors where progress has been inherently more difficult. Transport, which currently accounts for almost 40% of Nordic CO_2 emissions, delivers the greatest emissions reduction in the CNS. In the face of steadily rising demand for transport services, the success of taxation and subsidy approaches in power and heat generation provide a solid foundation for similarly assertive policies for transport. Industry, together with the oil and gas sector and other energy transformation (such as refineries), is currently the second-largest source of emissions at 28%. Unique to this sector is the need for innovative policies to achieve further decarbonisation without risking that industries will relocate to countries with more lax regulation. This, combined with limited technology options for reducing process emissions, leaves industry with the slowest decarbonisation rate in the CNS.

Figure ES.3 Nordic primary energy supply, 2013 and 2050 in the CNS



Figures and data in this report can be downloaded at www.iea.org/etp/nordic.

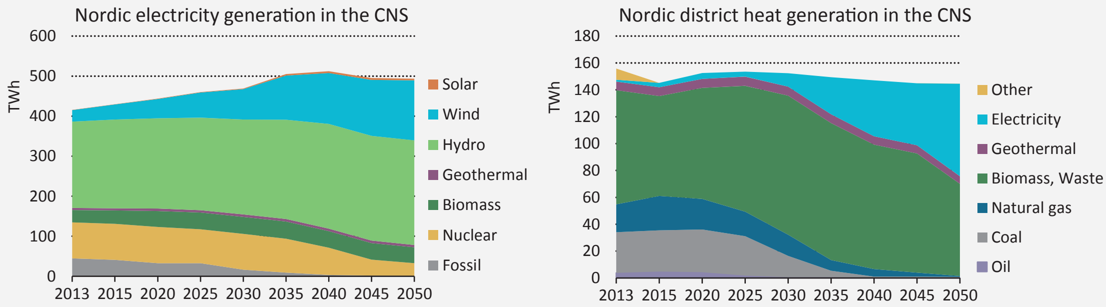
Key point *Under the CNS, Nordic primary energy supply decreases by 25% in 2050 compared with 2013 (excluding net electricity export). Energy supply from fossil fuels and nuclear decreases, while supply from bioenergy, wind and hydropower increases, as do net electricity exports.*

The CNS requires a dramatic change in the composition of primary energy supply, coupled with aggressive energy efficiency policies that substantially reduce demand. Bioenergy surpasses oil as the largest energy carrier in the CNS, with total demand for biomass and waste increasing from almost 1100 Petajoules (PJ) in 2013 to over 1600 PJ in 2050, corresponding to a share increase from 18% to 35%. At present, oil is the only energy source common to all five Nordic countries and its declining use in transport is the single most important source of emissions reduction in the CNS, alone accounting for almost 40% of total reductions. Primary supply for power and heat also undergoes a significant transformation, as outlined in the following section.

Power and heat already close to decarbonised, but thoroughly transformed nonetheless

Nordic electricity generation, already 87% carbon-free, is fully decarbonised by 2045 in the CNS. The most dramatic transformation of the Nordic power and heat system does not come from renewables displacing the small remaining share of fossil fuels. Rather, it comes from the combination of a decline of nuclear (reflecting the political phase-out of older capacity and the reality of increased competition from renewables) and a significant build-out of wind power (which leads to generation far exceeding domestic demand, even with the drop in nuclear generation). This facilitates the potential for net export of clean electricity to Europe, which requires increased system integration and flexibility to balance high shares of wind power. With lower implementation of energy efficiency measures, the 4DS requires greater total generation, more renewables build-out, and higher net export of electricity compared with the CNS.

Figure ES.4 Nordic electricity generation and heat production, 2013-50



Figures and data in this report can be downloaded at www.iea.org/etp/nordic.

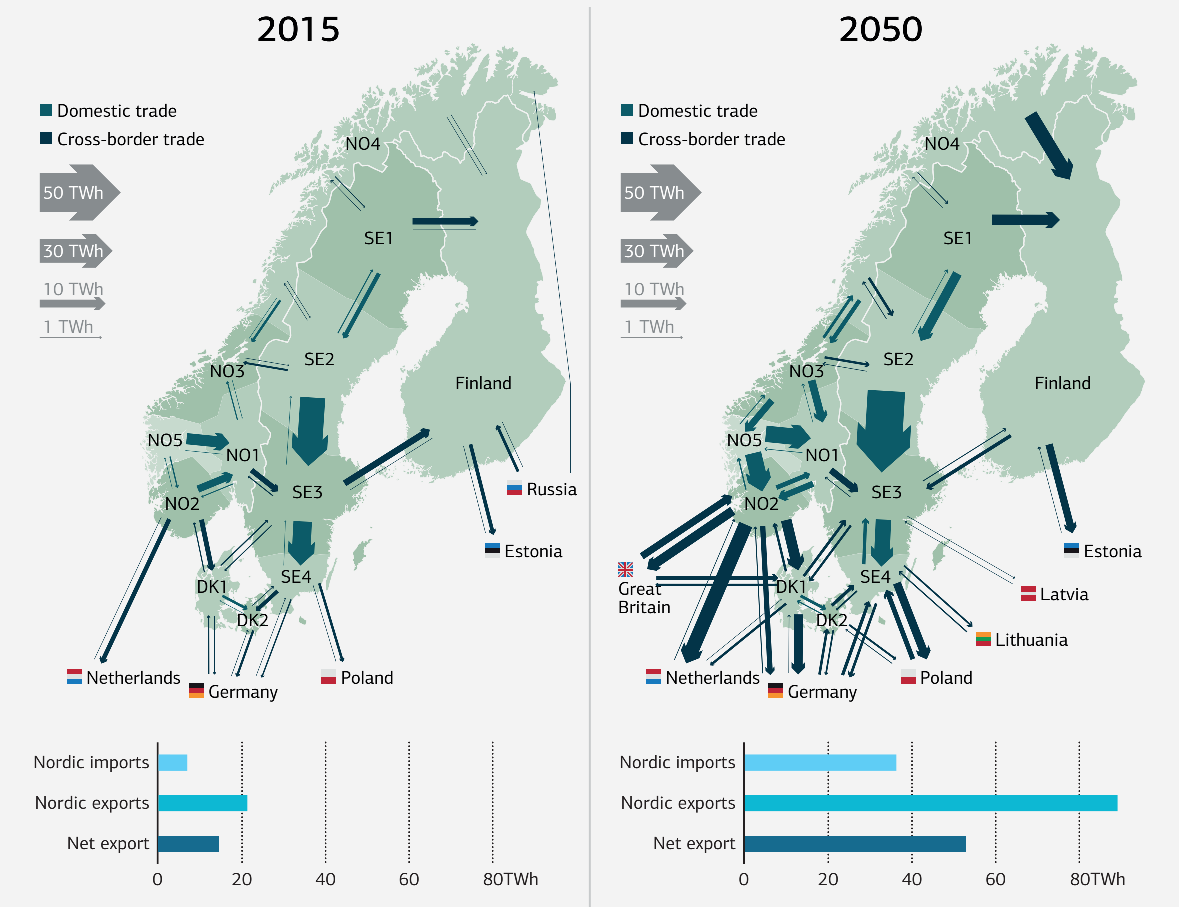
Key point *Wind displaces fossil and nuclear as Nordic electricity generation is expanded to service European demand. Heating networks transition from fossil fuels to heat pumps and electric boilers, adding flexibility to an integrated power and heat system.*

Wind generation increases five-fold, from 7% of Nordic electricity generation in 2013 to 30% in 2050 in the CNS, driven in part by the potential for greater electricity trade with Europe. This will put new demands on how the electricity system is operated and how the common Nordic electricity market is organised. The CNS shows that this transition is possible, and that the envisioned system can handle up to 70% variable renewable electricity in Denmark (as a share of demand). Two thirds of Nordic wind generation is onshore in 2050, underlining the importance of public acceptance. Nordic hydropower generation increases in the CNS though improvements to existing capacity and new small-scale capacity. Nordic hydropower will be increasingly valuable for regulating the North European power system.

Hydropower alone is not enough. The high penetration of variable wind power will require balancing though a combination of flexible supply, demand response, storage and electricity trade. With a large share of hydropower, high transmission capacity and a well-functioning electricity market, the Nord Pool area is already well suited for integration of wind resources. Denmark has demonstrated how operation measures significantly improved the flexibility of its co-generation fleet. More targeted use of dispatchable hydropower for balancing and action to enhance the flexible operation of thermal generation (mainly in co-generation) play key roles in the CNS. Electrification of the heating and transport sectors (e.g. through heat pumps and electric boilers for district heating, and through EVs), together with flexible demand from industry, are central demand response measures in the CNS. Better system integration between electricity and district heating systems, and potentially between electricity and gas through power-to-fuel technologies, allows storage of excess electricity as heat or carbon-neutral gaseous or liquid fuels.

Greater electricity trade will reduce system costs and enhance flexibility, but long lead times for setting up interconnectors and strengthening the grid may delay achieving the full potential. With rising shares of variable renewables in both Nordic and other European countries in the CNS, it will be economically attractive to increase transmission capacities among countries. Anticipated electricity demand from continental Europe could greatly expand the market for low-cost, low-carbon electricity generated in the Nordic countries. This allows the Nordic region as a whole to become a major net exporter (at 53 TWh/year net in the CNS) as average generation costs in continental Europe are expected to stay higher than in the Nordic region. Seizing this trade opportunity depends on three things: build-out of wind capacity and necessary flexibility to handle variability, reducing Nordic demand through energy efficiency, and setting up the necessary interconnectors and domestic grid strengthening to enable trade.

Figure ES.5 Nordic electricity trade in 2015 (left) and 2050 in the CNS (right)



Notes: Trade with Russia is assumed to fall to zero in 2050. Iceland is not included in the figure as it is not yet connected with any other electricity system and the potential for Icelandic interconnectors was not modelled. This map is without prejudice to the status of or sovereignty over any territory, to the delimitation of international frontiers and boundaries, and to the name of any territory, city or area.
Figures and data in this report can be downloaded at www.iea.org/etp/nordic.

Key point *Anticipation that electricity prices in Europe will be higher than in the Nordic region in the CNS creates an attractive trade opportunity; expansion of variable renewables and interconnector capacity could lead to net Nordic exports of over 50 TWh in 2050.*

Nuclear power decreases from 22% of Nordic electricity generation in 2013 to 6% in 2050 in the CNS, as other low-carbon technologies become more competitive. A variant scenario in which nuclear is phased out more quickly – by 2030 in Sweden and with no new reactors constructed in Finland after the completion of Olkiluoto 3 – sees CO_2 emissions from the Nordic area increase by 7 Mt in 2030 as it prompts an increase in gas capacity to partially make up the shortfall in generation. It also pushes up CO_2 emissions in the rest of Europe by 2 Mt, mainly by reducing the export potential from Nordic countries. A higher dependence on international trade of electricity is also a potential concern for consumers, especially industry. These factors highlight the benefits of using existing nuclear capacity through the economic lifetime of each plant.

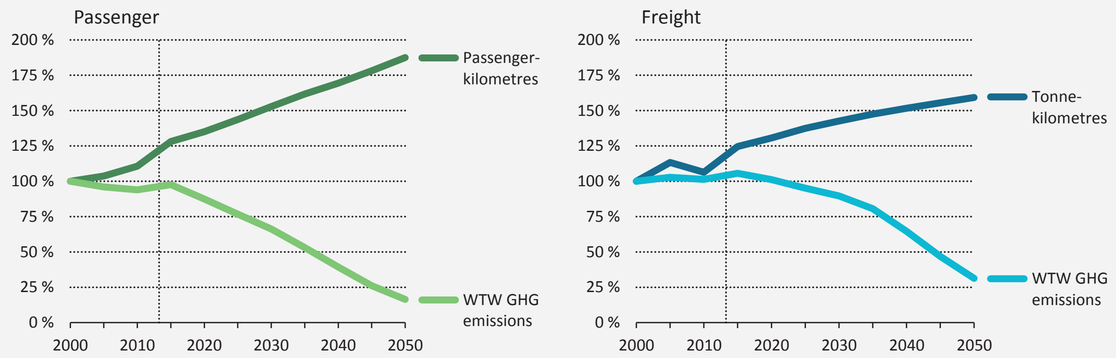
The Nordic region seems less likely to see the solar boom other countries are experiencing. Growth is constrained by a limited solar resource, dense urban areas with less rooftop area and favourable conditions for competing wind power. The economic potential of solar electricity in the CNS is 4 gigawatts (GW) peak capacity and 4 TWh of annual generation, or less than 1% of total generation in 2050. The total technical potential of rooftop PV alone is significantly higher – estimated to be 32 TWh. If met, it would account for around 6% of electricity generation in the CNS in 2050, comparable to the annual demand from all EVs on Nordic roads in 2050. In a case study of the Helsinki metropolitan area, nearly all of the estimated suitable rooftop potential becomes utilised by 2050 under the CNS, accounting for over 20% of total electricity supply. The possibility exists that RDD&D on electricity storage and new solar concepts (e.g. power-to-gas and to liquids) will increase the competitiveness of solar power. In sum, while installed solar capacity in Nordic countries is relatively low in the CNS, policy and technology uncertainties make it too early to rule out a pathway in which solar would play a more prominent role.

The role of district heating will increase under strict climate policy targets, but the role of co-generation may become less important. Under the CNS the amount of co-generation decreases by 40% in Nordic urban areas. Electricity grows to account for almost half of the heat in district heating networks in 2050, through utility-scale heat pumps and electric boilers, both of which provide important flexibility for variable renewables integration.

Radical transformation of transport will be most visible change to consumers

Transport accounts for the largest share of emissions reduction. Transport requires a dramatic emissions slash in the CNS, from about 80 million tonnes of carbon dioxide ($MtCO_2$) in 2013 to just over 10 $MtCO_2$ in 2050. The target can be achieved through a three-pronged strategy of reducing transport activity (avoid), shifting to more efficient or less carbon-intensive transport modes (shift), and adoption of more efficient or less carbon-intensive transport technologies and fuels (improve). Improvements to technologies and fuels play the largest role in transport in the CNS, largely because Nordic countries have already introduced many policies based on avoid and shift strategies (such as road tolls, parking fees, access/parking restrictions and promoting public transport and cycling over cars). However, the potential of additional avoid/shift levers should not be discounted out of hand; it is still difficult to predict the impacts of disruptive technologies such as autonomous vehicles or shifts in cultural/behavioural paradigms influencing the potential of shared mobility services. Over time, improved city planning can also facilitate both reduced travel demand and shifts to more efficient modes.

Figure ES.6 Decoupling of transport emissions from activity in the CNS



Notes: WTW GHG = well-to-wheel greenhouse gas emissions, the calculation of all emissions from the production of the fuel source to those associated with end-use in transport. Passenger-kilometres is the measure of kilometres travelled by individuals in a given year; tonne-kilometres refers to the distance associated with tonnes of freight transport.
Figures and data in this report can be downloaded at www.iea.org/etp/nordic.

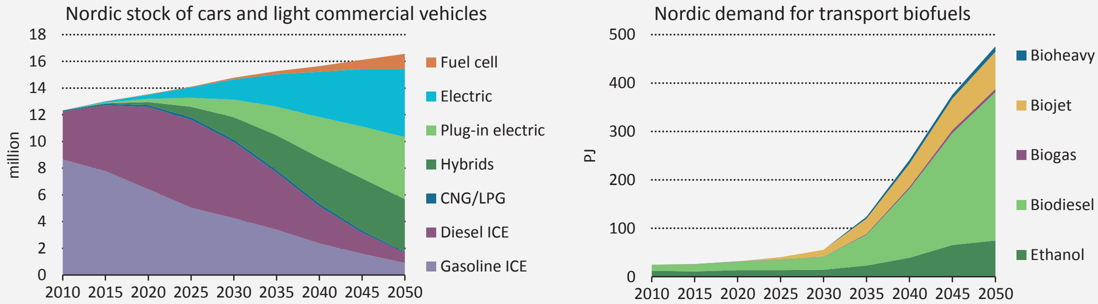
Key point *Despite steady growth in demand for transport services, emissions drop dramatically through efficiency, technology and fuel switching, and modal shifts.*

Adoption of new technologies can spur a radical reduction in transport energy use despite rising demand for transport services. Transport's total energy use in the CNS decreases by over 20% compared with 2000, despite a 70% increase in overall passenger and freight activity. By 2050, fossil fuels account for only 25% of transport final energy demand. Energy-savings potential is greatest in passenger cars, and is greater in urban areas (35% reduction between 2013 and 2050) than in rural areas (22%). Higher population densities and shorter traveling distances in urban areas facilitate greater use of energy efficient technologies such as public transport and cycling.

With EVs having a share of 60% for the passenger vehicle stock in 2050 (compared with an average of 45% in the OECD), the CNS puts the Nordic region in a leadership role for low-carbon transport. EVs are particularly attractive in urban areas, which have shorter driving distances, more acute air quality and noise issues, and economies of scale for charging infrastructure. EVs also make up about 70% of light commercial vehicles (LCVs) in urban areas by 2050. Individual cities (and even countries) can be expected to lead the uptake of EVs, resulting in important learning effects that can facilitate a broader uptake across the entire Nordic region. Battery electric vehicles (BEVs) and hybrids account for the majority of EVs, with more limited prospects for hydrogen fuel-cell electric vehicles (FCEVs). This is due to greater infrastructure costs, as well as the flexible production of hydrogen facing strong competition from other technologies providing flexibility to the electricity system. Electricity accounts for 10% of final energy use in transport in 2050, but thanks to the high powertrain efficiency of electric motors, electricity's share of transport activity is much higher: 64% of road and rail passenger kilometres and 42% of road and rail freight activity. In the CNS, transport uses 32 TWh of electricity in 2050, or 6% of total generation. EVs alone account for 5% of total generation.

Figure ES.7

Transformation of Nordic vehicle stocks and biofuel demand in the CNS



Figures and data in this report can be downloaded at www.iea.org/etp/nordic.

Key point *The CNS requires an almost complete phase-out of fossil-fuelled cars and a rapid roll-out of EVs, especially in urban areas. Biofuel imports are needed to decarbonise long-distance transport modes.*

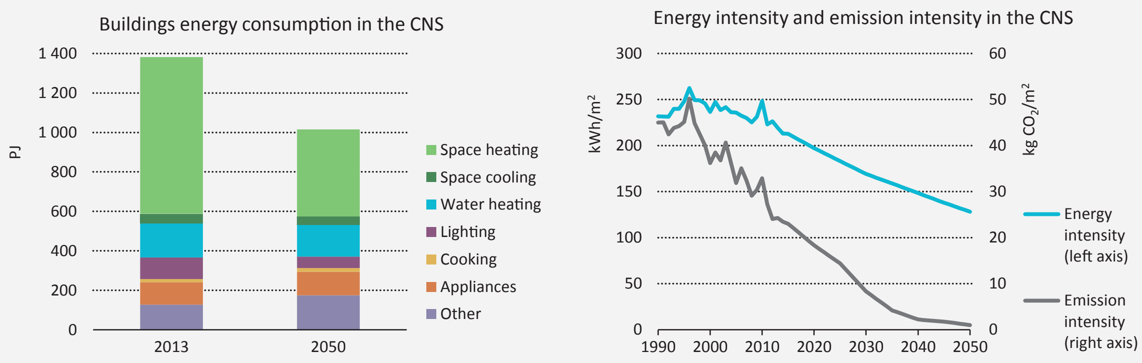
Long-distance transport is less suited to electrification than urban transport and will require biofuels or significant advances in competing low-carbon technologies. The CNS sees biofuels underpinning long-distance, heavy-duty road and marine freight, as well as aviation. Electrification is rolled out where feasible, for example in medium-sized trucks serving urban environments, with plug-in hybrids accounting for 10% of the truck stock in 2050. Development of electric highways (e-highways) and hybrid heavy-duty trucks however is not a major element of the CNS, even though e-highways on major axes of the road transport network could support the bulk of road freight transport activity while curbing costs. Incremental costs for e-highway vehicles could also be contained, thanks to the limited requirement of battery capacity. Pilot projects to build knowledge of the technical feasibility and the cost profile of this solution, already underway in Sweden, should be pursued more broadly. High-speed rail (HSR) is developed on the major axes among larger Nordic cities in the CNS. Although constrained by the Nordic geography and population density that raises costs, HSR covers around 15% of the transport demand that would otherwise be met by aviation in 2050.

Biofuels comprise nearly two-thirds of total final energy use in transport in 2050. Supplying this demand will depend on a well-functioning international market, sustainable production and distribution, and politically acceptable trade partners. The CNS shows 50% of the anticipated increase in biofuel use in transport is supplied by a fourfold increase in net biofuel imports. By 2050, net imports meet approximately 16% of total biomass demand from all sectors in the Nordic region, even as global demand for bioenergy increases. Aiming for greater domestic production would imply diverting biomass away from higher value uses in industry or producing biofuel from less economic domestic feedstocks. Increased RDD&D efforts on supply of low-cost biomass feedstocks and on integrated process concepts to produce advanced biofuels could make these more cost competitive. Nordic and broader international co-operation is particularly important in this area. Hydrogen deployment for transport vehicles, which may compete with biofuels, is coupled with higher investment risks and higher investment costs for both vehicle manufacturing and the deployment of a fuel distribution infrastructure. Creating a vehicle market with sufficient volume to make it profitable for carmakers to diversify the range of models powered with hydrogen will be a challenge, and will require major policy co-ordination to support the deployment of hydrogen refuelling infrastructure within and beyond the Nordic region.

More rapid renovation of existing Nordic building stock needed to lower energy demand

The CNS requires a tripling of the current rate of improvement in space heating energy intensity of Nordic buildings. This must occur primarily though deep energy renovation of existing buildings, which will constitute 70% of the Nordic stock in 2050. The buildings sector accounts for one-third of final energy demand in the Nordic countries, with space heating being the largest end-use (nearly 60% of total building final energy consumption). Despite dropping by 0.8% per year since 2000, the average energy intensity of space heating across the Nordic building stock remains at 126 kilowatt hours (kWh) per square metre (m^2) – 12% higher than the European Union (EU) average. The CNS requires energy intensity to fall by 2.2% annually. This would bring the average energy intensity of space heating in the Nordic building stock to around 60 kWh/m^2 in 2050. At present, long payback periods under low energy prices and split incentives in rental situations hamper efforts to accelerate energy efficiency investments.

Figure ES.8 Energy efficiency improvements in Nordic buildings



Notes: Emission intensity (kgCO_2/m^2) is the direct and indirect emissions from energy use per square meter of floor area. PJ = petajoule.
Figures and data in this report can be downloaded at www.iea.org/etp/nordic.

Key point *Energy efficiency efforts cause energy demand from buildings to drop to 1990 levels in 2050, despite significant increases in floor area. Space heating and lighting have the most potential for energy efficiency improvements.*

Efficiency gains in Nordic buildings can unlock biomass and electricity for use in other sectors, avoiding infrastructure investments in power and heat, and CO_2 emissions in transport and other sectors. The emission intensity of buildings energy use in the Nordic countries is currently much lower than the EU average. The intensity falls to zero around 2045 as the CNS eliminates both direct emissions and upstream emissions from power and heat supply. This means that the emissions reduction gain associated with energy efficiency measures may be limited in relation to the cost. However, it is important to note that reducing buildings energy demand can facilitate Nordic electricity export, avoid grid infrastructure investments, unlock biomass to substitute fossil fuels in transport and enable deployment of new technologies such as low temperature DHC. More broadly, reduced demand also brings important energy security benefits. In the longer term, renovation efforts will be supplemented by more advanced building technologies, enhanced urban planning and roll-out of intelligent energy management systems that empower consumers and encourage behaviour change.

Urban buildings contribute relatively less to energy savings in the CNS than rural buildings. This reflects lower potential in urban areas for zero-energy buildings (ZEBs) and near-zero energy buildings (nZEBs), and the need to balance investments in energy efficiency and district heat supply. High urban densities, limited on-site renewable potential and cultural heritage conventions constrain the potential for broad nZEB implementation in urban areas. Despite this, energy demand in Nordic urban buildings drops to 1990 levels by 2050 in the CNS, even as floor area increases by over 25%. Broader deployment of district heating, heat pumps and solar heating helps to transition the energy supply away from fossil fuels and direct electric heating. In cities with district heating, it may be more cost-effective to pursue only moderate building energy efficiency improvements together with investments in low-carbon district heat supply with lower temperatures and peak demand. Policies to incentivise energy efficiency improvements must therefore be coordinated with concurrent developments in local district heating systems to ensure optimal investment decisions are taken.

Cities can lead the way in system integration of transport and buildings

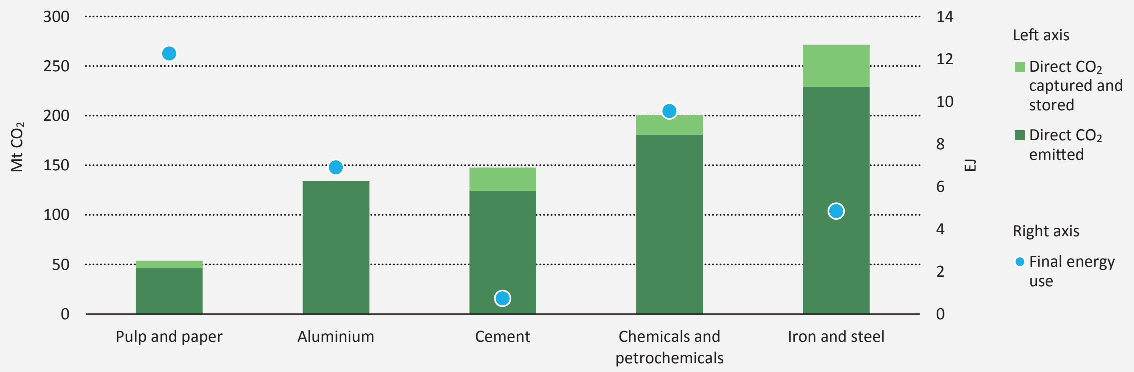
- ***Nordic urbanisation in the coming decades is expected to occur at double the rate of recent decades, offering a unique opportunity to transition to low-carbon urban energy systems.*** *Significant investment will be needed in new buildings, retrofits of existing buildings and new transport infrastructure to service the growing urban population. These investments should be optimised to not only lower emissions, but also to improve energy services. The greater density of urban areas leads to faster roll-out of EVs and charging infrastructure, public transport, cycling, district heating and cooling, and utilisation of excess heat. This tempers the additional costs to achieve the CNS in urban areas compared with rural areas.*
- ***All Nordic capitals have ambitious GHG mitigation targets and most aim to achieve carbon neutrality. Copenhagen and Oslo have set earlier zero-carbon targets than are stated in national plans.*** *Nordic capitals are up to 30% more energy efficient than average Nordic urban areas in buildings, and up to 40% in transport, due largely to higher population densities and better infrastructure. Energy efficiency improvements contribute to per-capita energy demand of all urban transport and buildings decreasing by 20% in the next 15 years (to 2030) and by another 20% in the following 20 years (to 2050) in the CNS.*
- ***Nordic urban areas are particularly advanced in the system integration of energy, with high penetration of district heating and cooling networks as well as electric heating and cooking. Small but growing electric transport systems are also becoming integrated.*** *In urban areas, up to 76% of the energy consumed in buildings and transport could be delivered through smart electricity and district heating and cooling grids by 2050, compared to 61% today. In 2013, district heating provided 35% of heating for urban buildings in the Nordic region, substantially higher than rates in the European Union (9%) and in OECD countries (3%). In the Nordic capitals of Stockholm, Helsinki, Copenhagen and Reykjavik, high shares of district heating – already between 80% and 100% – are expected to be maintained in the long term. The penetration of electricity and district heating networks in the Nordic region gives urban areas the potential to provide significant flexibility to balance variable renewable energy.*

Industry the most difficult sector to decarbonise, requires innovation in technology and policy

The necessary 60% reduction in direct industrial CO_2 intensity in the CNS (from 2013 levels) requires aggressive energy efficiency, fuel and feedstock switching to lower-carbon energy mixes, deployment of low-carbon innovative processes (including CCS) and international co-operation. All Nordic economies, except Denmark, are highly dependent on energy-intensive industries and use more energy per unit of GDP than the OECD average. Energy efficiency measures reduce Nordic total final industrial energy consumption by 9% in the CNS in 2050 (compared with 2013 levels for similar industrial activity). However, industry has the slowest rate of decarbonisation due to process-related emissions and competitiveness issues for globally traded commodities; industry accounts for almost half of remaining emissions in 2050 in the CNS. As long as policies stimulate decarbonisation without compromising competitiveness, Nordic countries are in a favourable position to ensure the long-term sustainability of energy-intensive industries in the global economy. This implies balancing stringent carbon policies with measures to improve the competitiveness of industry, such as public RDD&D support or reduction of other taxes.

The lingering challenge of process-related emissions in industry necessitates broad deployment of innovative low-carbon processes including CCS in the CNS. Process-related emissions from iron and steel, cement, aluminium and chemicals industries contribute 19% of the Nordic region's industrial CO_2, compared with an average of 13% in the OECD. Typically, such emissions can only be reduced through integration of CCS or developing breakthrough process technologies that move away from carbon-based raw materials. Even with very aggressive action to increase energy efficiency, to switch to low-carbon fuel and feedstock, and to increase recycling, the CNS shows the need for wide application of CCS in cement, iron and steel, and chemical industries, which cumulatively account for almost 30% of total direct industrial CO_2 emissions reduction over the period 2020-50. Progress to date on developing and deploying CCS has been slow and unco-ordinated; joint efforts between countries with significant industrial emissions (Sweden and Finland), and countries with storage potential and competencies within oil and gas (Norway and Denmark) must be scaled up in order to achieve the CNS.

Figure ES.9 Nordic cumulative direct industrial CO_2 emitted, and captured and stored in the CNS by sector, 2020-50



Note: Final energy use is given in cumulative terms for the 2020-50 period in the CNS. Energy use in blast furnaces and coke ovens is included in the iron and steel sector; energy use as feedstock is included in the chemicals and petrochemicals sector.
Figures and data in this report can be downloaded at www.iea.org/etp/nordic.

Key point *CCS plays an increasingly important role in industrial sectors with high shares of process-related CO_2, as no current alternative prospects exist for cost-competitive CO_2 mitigation.*

International co-operation, for example through international carbon pricing or energy performance auditing mechanisms, plays a crucial role in mitigating the risks of low-carbon investments that are needed to decarbonise industry, and thereby reduce potential impacts on competitiveness. It also reduces the risk of "carbon leakage", if industry investments are shifted to countries with more lax regulation. Given the size and risk involved in investments, a cross-sectoral collaborative Nordic approach should be considered — for instance, to finance demonstration and market establishment of innovative low-carbon processes and to identify systemic sustainability gains along product value chains. Specific legal frameworks and cross-country collaboration are needed to implement technologies that are key for the CNS. Such is the case for deploying CCS, which requires adoption of internationally co-ordinated regulations that encourage the safe and effective design and operation of CO_2 storage facilities. There are promising opportunities for CCS applied to bioenergy (BECCS) in Nordic industry, which could provide negative emissions.

Additional investments to achieve the CNS are concentrated in buildings, industry and transport

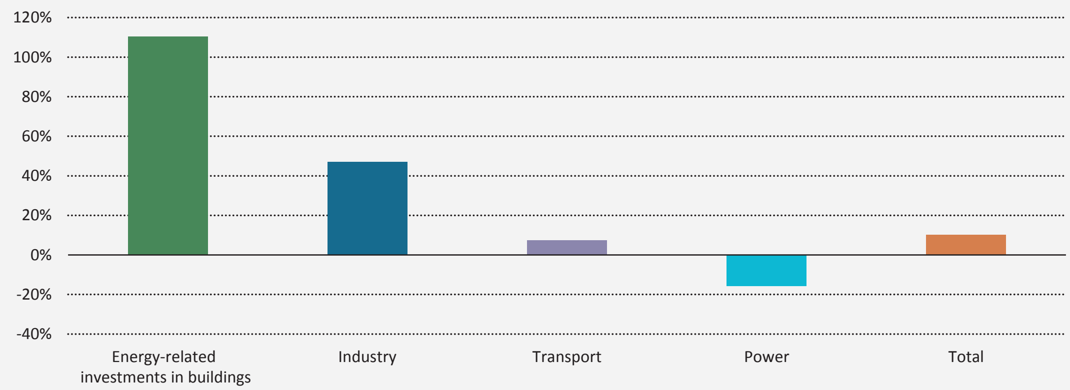
Achieving the CNS would entail a 10% increase in investments over that needed for the 4DS over the period 2016 to 2050. This represents additional investments beyond those of the 4DS of about USD 333 billion,[3] totalling less than 1% of the cumulative GDP over the period. Beyond climate change benefits, costs will be directly offset to a certain degree by fuel savings (which could be significant depending on the development of future oil prices). Additional benefits, such as reduced health costs due to air quality improvements and increased energy security, are likely to tip the economic equation firmly in favour of the CNS. Recent studies have estimated the external costs related to health impacts from air pollution in the

3 USD PPP 2014.

Nordic countries (of which energy is the primary source) to be around USD 9 billion to USD 14 billion annually. These alone are roughly equal to the additional investments in the CNS.

The greatest relative investment increases are required in buildings and industry, while power is less costly in the CNS than in the 4DS. Investments in buildings need the largest acceleration to achieve the CNS, seeing a doubling of 4DS levels. Of the approximately USD 170 billion in additional cumulative buildings investments, roughly USD 155 billion goes to building envelopes to drastically reduce space heating demand. The remainder goes to more efficient space and water heating equipment, appliances and lighting. An increase of 47% is required in the five industry sectors analysed, which together account for 80% of the total final energy use by industry in the Nordic region. This represents about USD 30 billion cumulatively, mainly associated with energy efficiency improvements and the deployment of low-carbon innovative processes including CCS. Transport accounts for the largest share of additional cumulative investments at USD 200 billion, but this is less than a 10% increase on 4DS levels. Infrastructure investments related to non-urban rail account for a significant share of additional transport investments. The CNS has around 15% lower investments in power generation compared with the 4DS. This is mostly a result of reduced final electricity demand (-15% in 2050), which also reduces the need for transmission and distribution investments.

Figure ES.10 **Relative increase in cumulative investments over 4DS levels required to achieve the CNS, 2016-50**



Note: Numbers show the difference in cumulative investments between the 4DS and CNS, as a share of the 4DS

$\left(\frac{\text{cumulative investments in the CNS - cumulative investments in the 4DS}}{\text{cumulative investments in the 4DS}} \times 100\right)$.

This metric highlights which sectors require the greatest relative increases in investments and how significant they are, compared to investments that would be needed even under a less ambitious scenario such as the 4DS. In the power,- industry, and transport sectors all investments in new industrial capacity (for the energy-intensive subsectors), vehicles, power plants and supporting infrastructure like roads and electricity grids are included. For buildings, only improvements of the thermal envelope (i.e. not the entire building construction) and equipment for end-use services such as lighting, cooking, heating and cooling, are covered. Only additional investment needs between scenarios are comparable across sectors, but not absolute investment requirements.
Figures and data in this report can be downloaded at www.iea.org/etp/nordic.

Key point *Relative to the investment needed for the 4DS, achieving the CNS requires an increase of 10%. Buildings require the greatest relative increase, followed by industry; power costs less in the CNS due to reduced demand.*

Short-term policy recommendations

Governments, individually and in a co-ordinated manner across the Nordic region, will need to play a lead role in stimulating actions to achieve the ambitious pathway outlined by the CNS. Specifically, they need to act in four key areas:

1. **Strengthen incentives for investment and innovation in technologies and services that increase the flexibility of the Nordic energy system.** Policies should accelerate the roll-out of key flexibility technologies (such as heat pumps for district heating and EVs) and critically, incentivise their utilisation for flexibility through market mechanisms and regulation. Markets must also adequately compensate flexibility services such as demand response in industry and buildings, as well as the flexible operation of thermal power plants. Less visible information technology (IT) infrastructure (such as smart meters) and IT platforms (such as applications to empower consumers or control systems to shave peak loads in district heating) will be important in achieving a rapid penetration of these flexibility services.

2. **Boost Nordic and European co-operation on grid infrastructure and electricity markets.** Coordinated effort to strengthen domestic grids and install new transmission lines is needed to establish the future Nordic and European electricity system envisioned in the CNS. Regional collaboration on infrastructure planning is needed to ensure optimal investments and avoid bottlenecks in the grid. Co-ordination among Nordic governments is vital to ensure that policy accelerates technological and regulatory progress in order to reduce total costs. Co-operation in reforming the common Nordic electricity market to allow greater flexibility and accommodate higher shares of variable renewables will also be important.

3. **Take steps to ensure long-term competitiveness of Nordic industry while reducing process-related emissions.** More variable and potentially higher electricity prices will put additional pressure on energy-intensive industry in the Nordic region, stressing the need to step up low-carbon industrial innovation. Governments should act to reduce the risk of such investment and use public funding to unlock private finance in areas with significant emission reduction potential but a low likelihood for independent private-sector investment. Policy should, wherever possible, seek to incentivise reduced emissions, for instance by removing exemptions from carbon taxation. Co-operative Nordic action to decrease uncertainty regarding CO_2 transport and storage infrastructure development could also mitigate risks for industry investing in CCS.

4. **Act quickly to accelerate transport decarbonisation using proven policy tools.** Even as Nordic countries pursue different technology strategies in parallel, they should not wait to draw on the wide range of available policy instruments to stimulate fuel efficiency, low carbon technologies and shifts to more efficient transport modes. Governments should build upon positive experiences with measures such as congestion charging in urban settings, differentiated vehicle registration taxes, bonus-malus regimes, and altered parking fees, while also stepping up investments in infrastructure for cycling, public transport and rail. Policies should also incentivise modal shifts from road freight to sea and rail, and from cars to public transport and cycling. Furthermore, policy makers may be able to exploit the current context of low oil prices to increase fuel taxes above current levels. Air quality, noise and congestion benefits should be considered in parallel with energy and climate objectives. Nordic collaboration can play a role, for instance through co-ordinated expansion of EV-charging infrastructure and cross-border rail networks, as well as through RDD&D cooperation on low-carbon fuels or on large-scale demonstration of potentially disruptive solutions such as shared mobility services.

The full report, together with all figures and data, can be downloaded for free at *www.iea.org/etp/nordic*

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The image shows an aerial view of a river delta in Iceland.

Nordic Energy Technology Perspectives 2016

Cities, flexibility and pathways to carbon-neutrality

Nordic Energy Technology Perspectives 2016 *presents a clear technological and economical pathway for the Nordic region towards a nearly carbon-neutral energy system in 2050. Nordic countries' success can send a strong signal to the global community that the ambitions of the Paris Agreement from COP21 are achievable.*

The report identifies opportunities for policy makers and the private sector in three strategic areas:

1. Incentivise and plan for a significantly more distributed, flexible and interconnected Nordic electricity system. A decentralised electricity supply with a high share of wind is likely to achieve a carbon-neutral system at lower cost than a system reliant on nuclear and thermal generation. But the shift will require flexibility measures beyond those now provided by Nordic hydropower, as well as a significant increase in cross-border electricity trade.

2. Ramp up technologies to decarbonise energy-intensive industries and long-distance transport. Emissions from industries like steel and cement are the most challenging to reduce, requiring rapid advances in the demonstration and deployment of carbon capture and storage (CCS) and other innovative technologies. Electrification will be at the core of most low-carbon transportation, but long-distance transport will likely require large volumes of biofuels.

3. Tap into cities' positive momentum to strengthen national decarbonisation and enhance energy efficiency in transport and buildings. Driven in part by air quality, health and congestion objectives, many Nordic cities lead their countries' decarbonisation efforts, with more ambitious targets and advanced roll-out of electric vehicles.

Visit www.iea.org/etp/nordic to download the full report.

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