Study on opportunities and barriers to electrification in the Nordic region

Prepared by DNV on behalf of Nordenergi

NORDENERGI

Contents

NORDENERGI

Make the Nordics carbon-neutral ASAP powered by affordable clean Nordic electricity

In 2019, Nordenergi decided to commission a study on the opportunities and barriers of electrification in the Nordics, to contribute to the discussion on how Europe can become carbon-neutral by 2050. The power sector and increased electrification have a crucial role in delivering a decarbonised society, and joint planning is therefore, necessary. The Nordic power market is a frontrunner for cross-border collaboration with the creation of Nordel in 1962, the establishing of the Nordic Electricity Market forum in 2017, and Nord Pool, the world's first true cross-border power exchange.

Nordenergi has always adhered to market principles with the idea to achieve decarbonisation in the most cost-efficient way. Hence, achieving decarbonisation through a robust European or global carbon emissions trading system has always been a key priority for Nordenergi.

The consultancy DNV GL has conducted this study based on criteria drawn up by Nordenergi. The four Nordic markets: Denmark, Finland, Norway, and Sweden, are included in this study. On all four markets, separate electrification and decarbonisation studies have been commissioned. This Nordic electrification study is based on input from these four national studies that, to some extent, are based on different assumptions about the future.

According to the four national studies the electricity demand will increase with more than 60 percent between 2020 - 2040. Wind power is estimated to increase from 14 percent of the electricity mix in 2020 to 40 percent in 2050.

Moreover, Nordenergi has developed three strategic recommendations accompanying the study, which are necessary for achieving increased electrification and decarbonisation in the Nordics: joint transition planning, identifying Nordic strongpoints and facilitating the carbon-neutral customer.

These strategic recommendations include tackling barriers constraining the grid expansion in the Nordics, joint planning of capacity by the Nordic TSO's, building on early Nordic cooperation with a market-oriented approach, reward the consumers that choose carbon-neutral electricity and demand flexibility should be created with market signals ensuring level-playing field within the power sector.

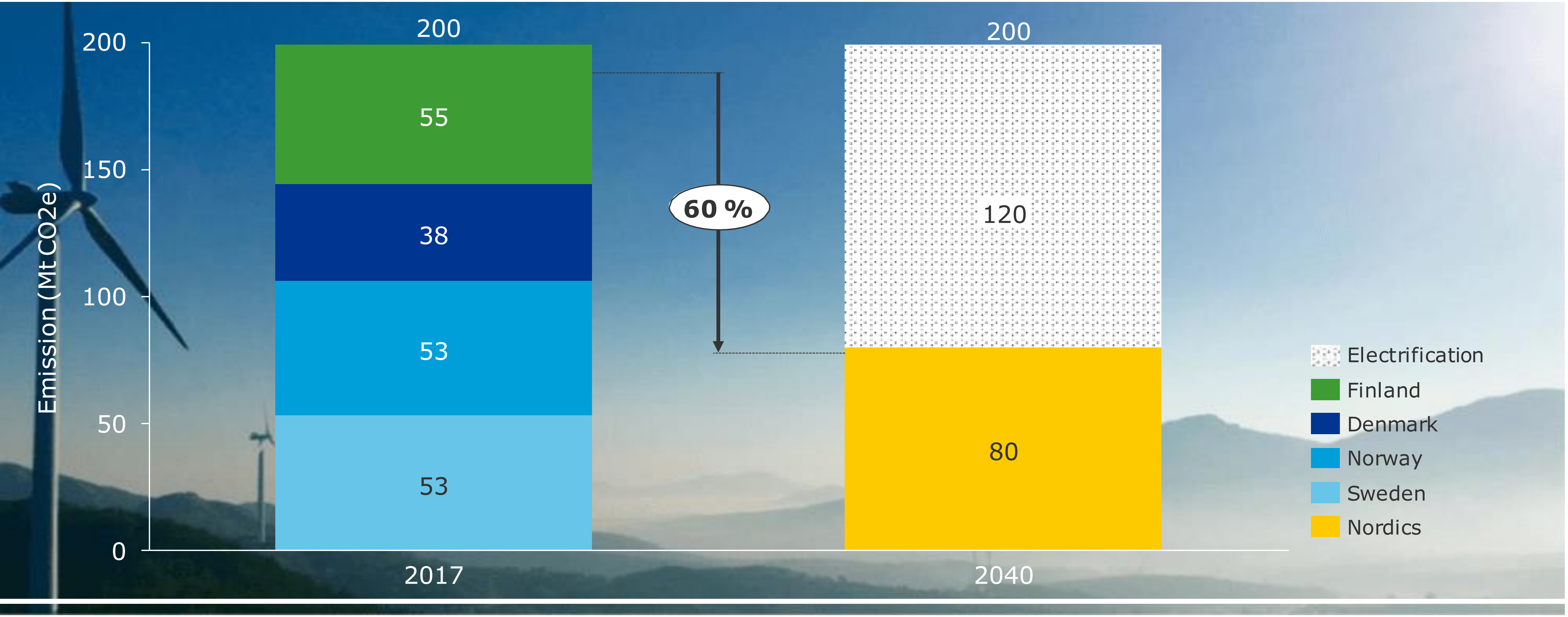
The strategic recommendations are necessary to follow to ensure that the Nordic countries reach carbon-neutrality well before 2050 with the help of the Nordic power sector

Gunilla Andrée, acting CEO Swedenergy	Lars Aagaard, CEO Danish Energy	Knut Kroepelien, CEO Energy Norway	Jukka Leskelä, CEO Finnish Energy
ENERGI FÖRETAGEN	DANSK ENERGI	Energy Norway	Energiateollisuus

EXECUTIVE SUMMARY

4

Rapid electrification can reduce Nordic emissions by 60 % by 2040



Electrification of industry and transport key drivers in a low carbon scenario

2020
Nordic electricity demand of **406 TWh**

Industry: 173 TWh

Transport: 9 TWh

Households and service: 204 TWh

Losses: 19 TWh

2050
Nordic electricity demand of **664 TWh**

Industry: 314 TWh (incl. 50 TWh P2X)

Transport: 111 TWh (incl. 42 TWh P2X)

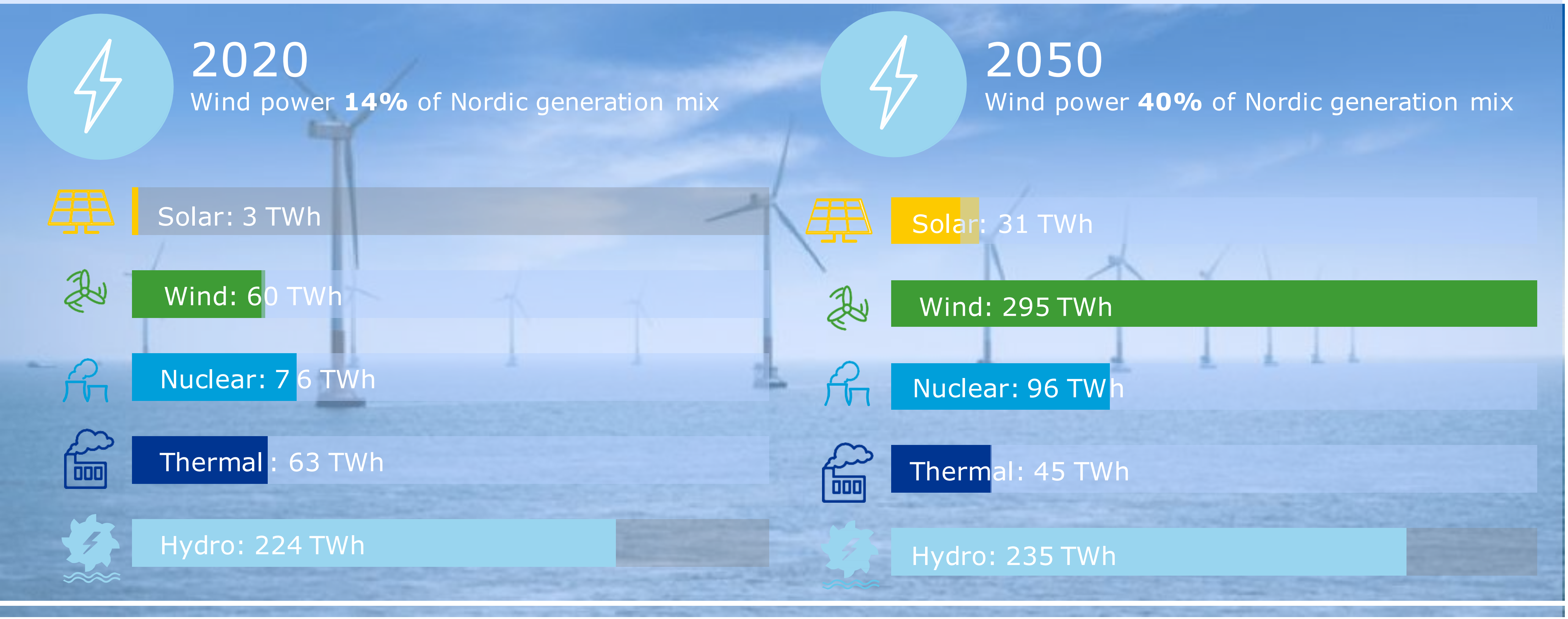
Households and service: 208 TWh

Losses: 31 TWh

The scenario is based on national reports and not modelling results

Power demand for P2X and/or hydrogen is included in the industry and transport demand

Wind power forecasted to become the main source of electricity in the Nordics



The scenario is based on national reports and not modelling results

Key barriers to delivering on electrification potential in the Nordics

GENERATION

ELECTRICITY GENERATION

- **Difficult build-out of generation capacity:** Long and uncertain permitting processes for generation and grid infrastructure, and local opposition to new projects are obstacles to new-builds.
- **Demand-driven growth uncertainty:** Risk associated with demand growth materialising or not can lead to lower than expected market access.

DEMAND

ELECTRICITY DEMAND

- **Limited grid availability:** Long grid re-enforcement processes, high connection costs and permitting uncertainty weakens electrification growth and reduces its timeliness.
- **Uncertain evolution of future electricity demand:** The realisation of demand potential is dependant on market signals, technology development and EU climate policy development.

SYSTEM ADEQUACY

ELECTRICITY SYSTEM ADEQUACY

- **Intermittency of wind and solar generation:** Supply and demand mismatch can lead to supply shortages as well as curtailment, weakening electrification and generation investment appetite.
- **Limited flexibility and storage capacity**: The nascent stage of development of new technology can be a hurdle to scaling up capacity. Regulation may not appropriately incentivise flexibility and demand-side participation.

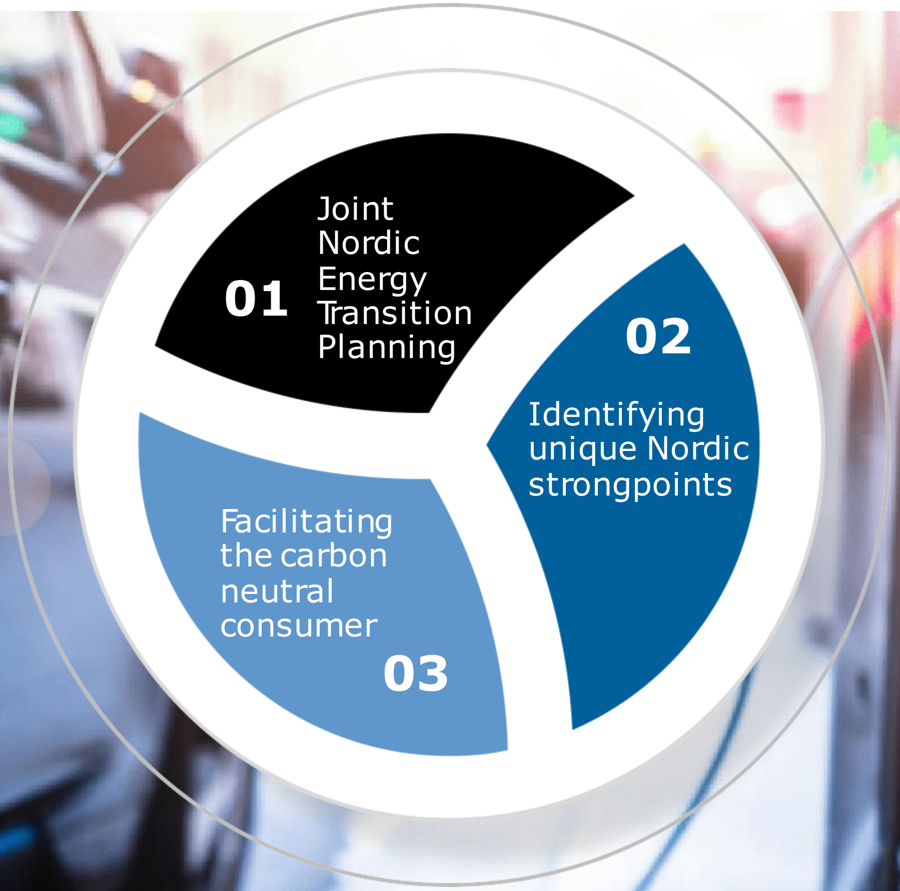
GRID

ELECTRICITY GRID

- **Long and uncertain planning processes:** Long planning and permitting processes makes grid upgrades and reinforcement time-consuming.
- **Long project development lead times:** The deployment of grid infrastructure often has long lead times, and can halt electrification progress.

Strategic recommendations for unlocking Nordic electrification potential

- **Joint Nordic energy transition planning:** Joint planning to ensure alignment between countries to coordinate power supply, grid and flexibility development to meet the rise in power demand from an electrification-driven energy transition with clean energy.
- **Identifying unique Nordic strongpoints:** Low carbon firm capacity from hydropower and nuclear, coupled with cost- competitive onshore wind and rising scope for offshore wind can facilitate the creation of power-to-x hubs and continued expansion of energy intensive industry.
- **Facilitating the carbon neutral consumer:** Consumers should be rewarded for choosing electric over fossil-fuelled solutions, and for adapting consumption to support the power system. Creating a cost-efficient transition to carbon neutral electricity with a holistic view of the energy system and the uptake of smart management that simplify the use of flexibility should be a key focus of policy.



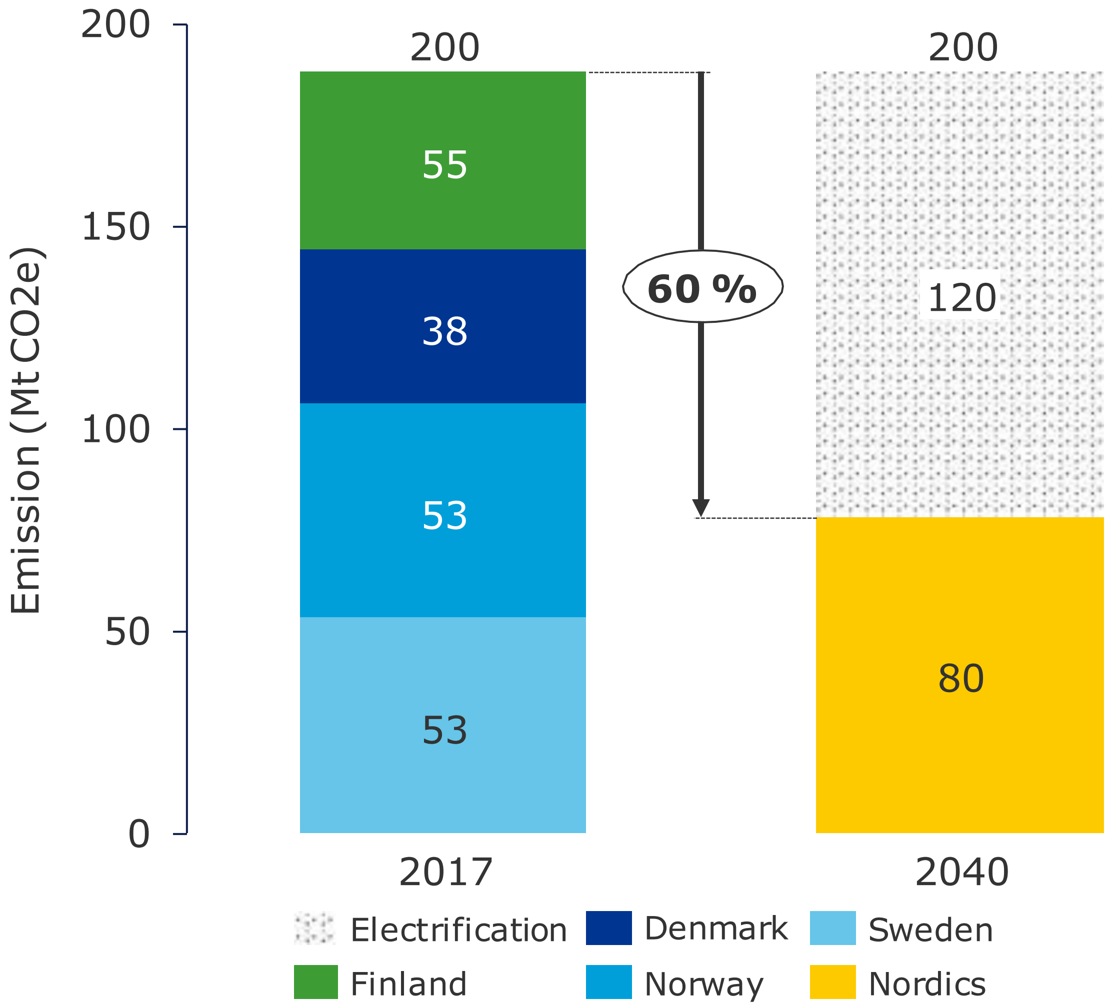
1

Electrification as a solution

Electrification in the Nordics is a key enabler for reaching carbon targets

Large potential to reduce emissions

- The Nordic countries have all committed to significantly reduce their carbon emissions towards 2050 compared to 1990-levels.
- There are different ways and approaches to achieve these targets; Emission reduction schemes, price on carbon emissions, subsidies, taxation etc.
- Electrification is a low hanging fruit to reduce emissions; both because it in many cases is cost efficient, offers the ability to increase the roundtrip efficiency of energy consumption and create emission reduction alternatives in hard-to-abate sectors.
- Electrification of transport, industry and heating (note: not buildings supplied by district heating) alone can reduce carbon emissions by 60 % towards 2050.
- To take advantage of this emission reduction potential; a rapid transition of the power sector is needed to facilitate the increased demand for electricity.

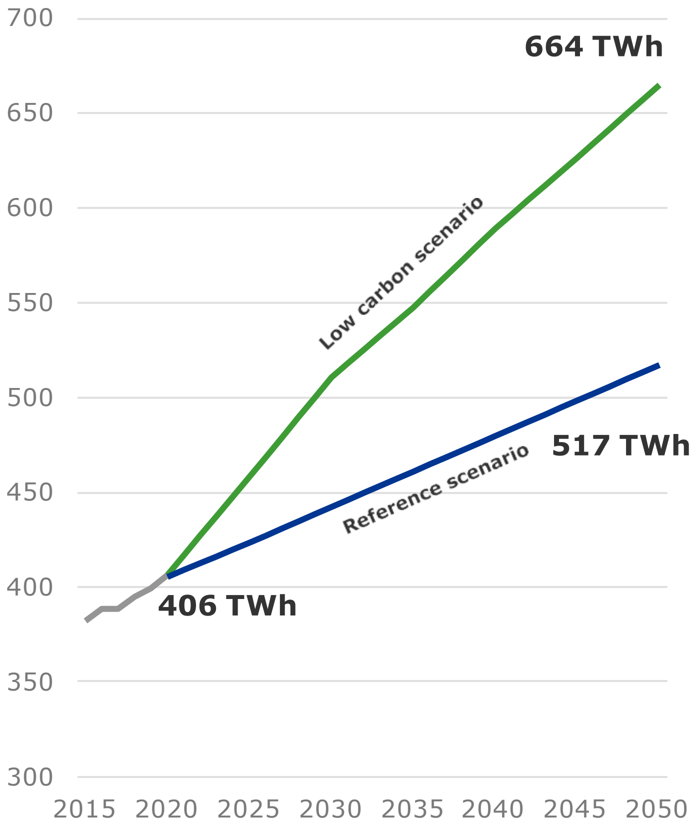


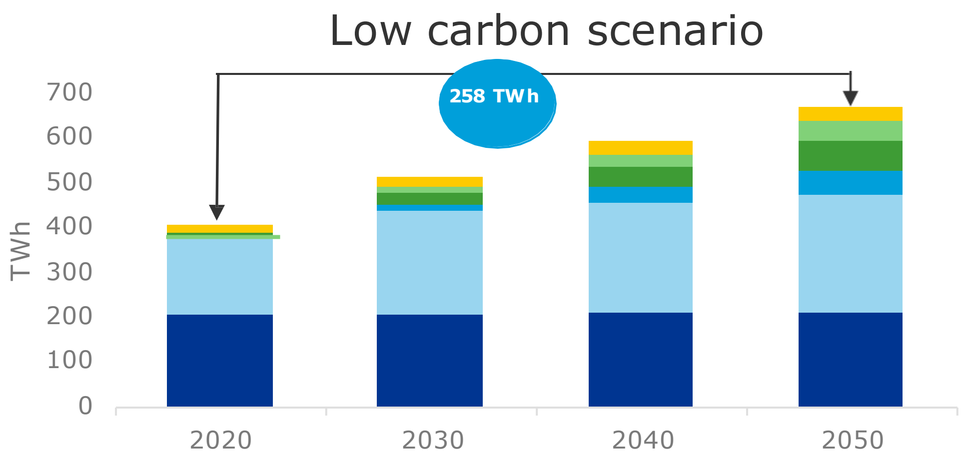
Electricity demand in the Nordics could grow by 60 % towards 2050

A low carbon pathway to reach climate goals will increase Nordic demand by over 250 TWh towards 2050

The electrification of alternative energy use will be a key decarbonisation driver in the Nordics over the coming three decades. In our Low carbon scenario, total power demand increase by more than 60% between 2020 and 2050.

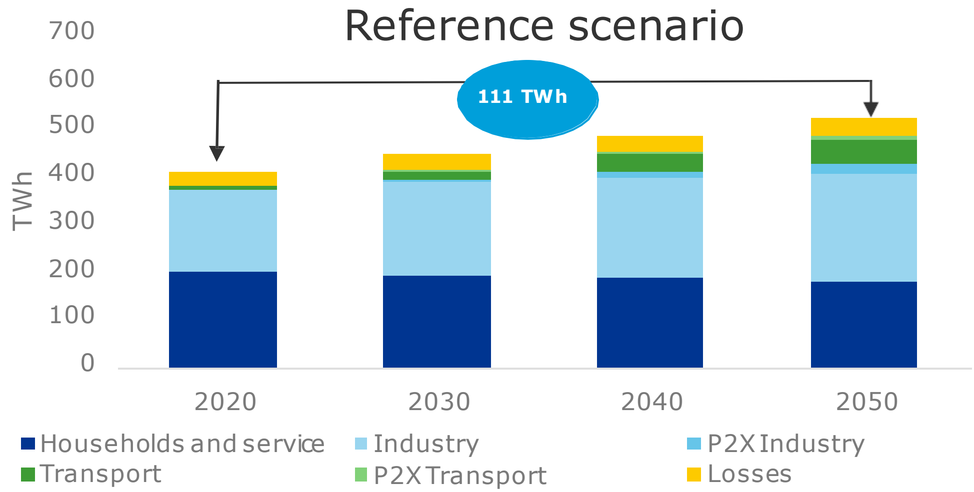
Development trajectories for electricity demand in the Nordics under two scenarios





Scenario assumptions

- The Low carbon scenario is aligned with decarbonisation aspirations in each Nordic country – with electrification playing a key role in reducing carbon emissions.
- We forecast total power demand to increase by more than 60% between 2020 and 2050 – entailing a net growth of 258TWh. The main growth will be within industry and transport, including electricity consumption for power to X in these sectors.
- Norway and Sweden will remain the largest consumers of electricity over this timeframe, while Denmark registers the fastest net demand growth.



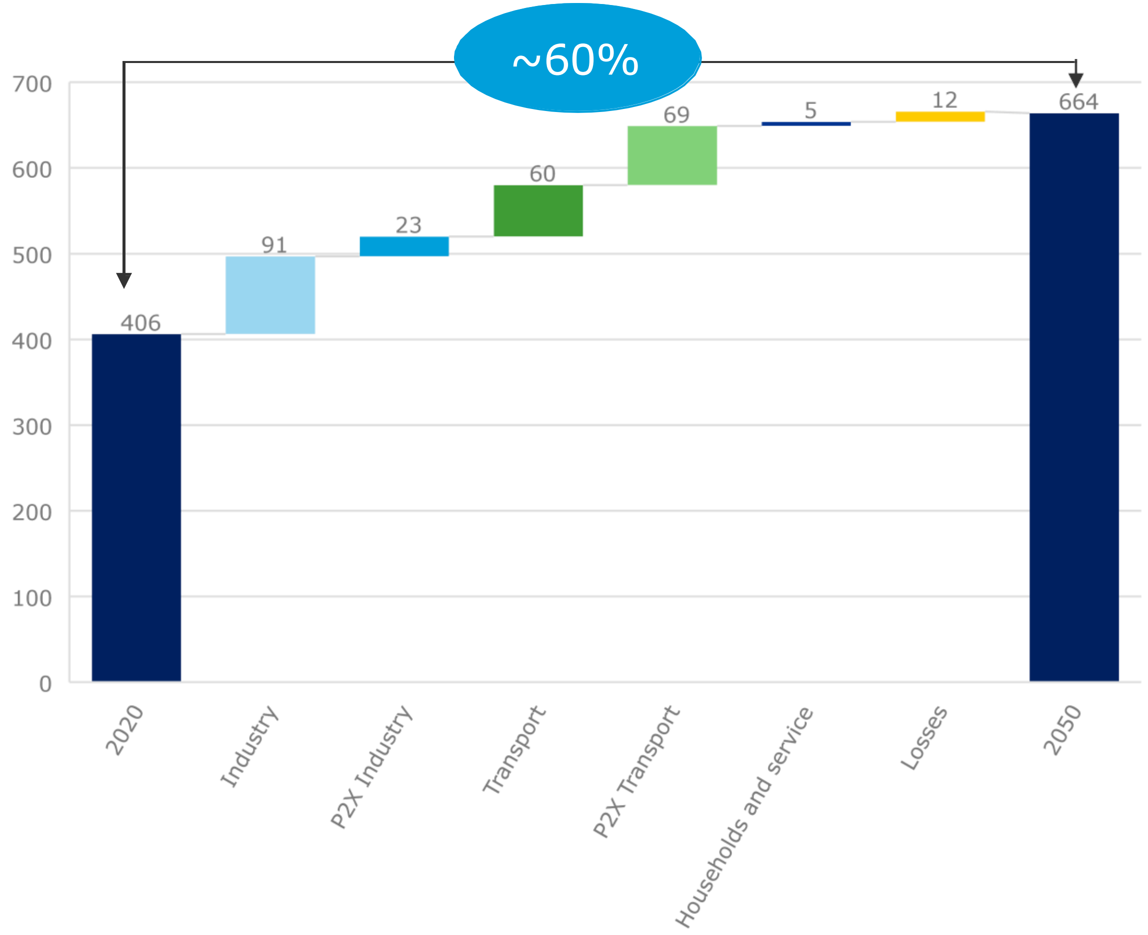
Scenario assumptions

- The reference scenario follows Norwegian Water and Energy Directorate's (NVE) Nordic electricity market forecast from 2020-2040. The scenario is aligned to national studies for 2020. We have assumed the growth trajectory from 2030 to 2040 to continue to 2050.
- This scenario still includes a growth in Nordic electricity demand, but to a lower extent than the Low carbon scenario.
- The total growth of 111 TWh from 2020-2050 will mainly come from electrification of industry and transport.

Electrification of industry and transport will drive the increase in demand

Power to X technology in these sectors will be a key enabler to utilise the emission reduction potential

Delta demand increase per sector in the Nordics between 2020 an 2050, TWh



Households and service

- This category involves all electricity demand from households and the service sector, from heating, lightning and different applications.
- Buildings energy, which in the Nordics is mainly from heating, stays relatively constant towards 2050. Even though building square meters will increase, energy efficiency measures will level the growth out.

Industry

- This includes existing industry, which can be defined as all related activities in the extraction of raw materials and their conversion into finished goods, as well as new industry like data centres.
- Electricity demand from this sector will increase significantly due to growth and electrification of both existing and new industry.

Transport

- Transport is the sector consuming the largest amount of energy, and there is a large potential for electrification of this energy use.
- The category includes road transport, railway, maritime and aviation.
- 100% electrification of passenger cars is expected, as well as electrification of other transport where electrification is a preferred zero emission solution.

Power to x

- Power to x (P2X) is collective name of all activities converting electricity into other energy carriers. P2X can play a key role supporting decarbonisation, particularly for segments of sectors hard to decarbonise through electrification.
- A flexible demand for Power to x will be important for tackling surplus electricity in systems with high share of variable renewable generation.

DNV·GL

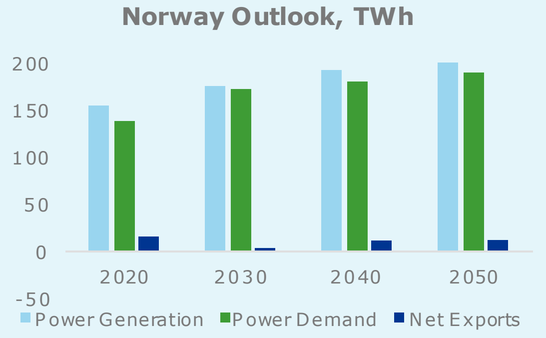
Nordic Country Overview

Norway

Key decarbonisation targets: Reducing carbon emissions by 90-95% by 2050

Key Features:

- More mature in terms of driving electrification efforts. Global electric vehicle deployment leader.
- Will comprise about 20% of total net demand growth from electrification in the Nordics between 2020 and 2050.
- Generation growth to remain robust amid consumption growth, supporting Norway's position as a electricity net exporter

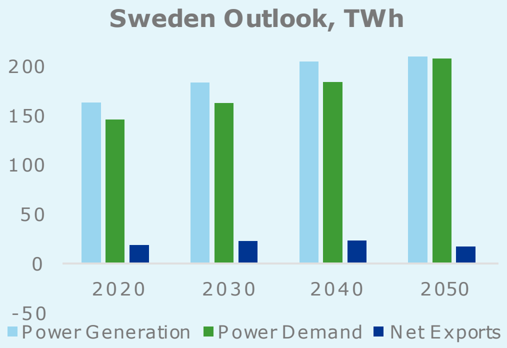


Sweden

Key decarbonisation targets: Net zero GHG emissions by 2045

Key Features:

- Electricity demand to be driven by a combination of transport and industry electrification.
- Will comprise about 24% of total net demand growth from electrification in the Nordics between 2020 and 2050
- We anticipate a significant growth in wind power generation in line with the demand increase

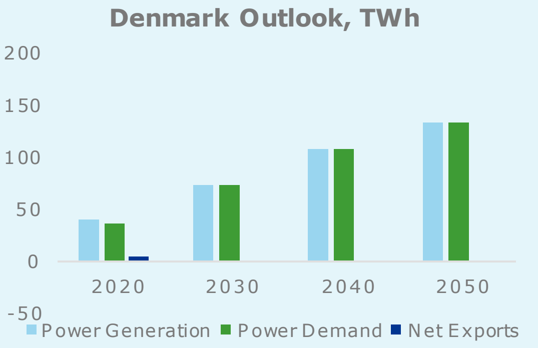


Denmark

Key decarbonisation targets: Reducing carbon emissions by 70% by 2030

Key Features

- To register a rapid power demand growth from a low base over the next three decades
- Will comprise about 38% of total net demand growth from electrification in the Nordics between 2020 and 2050
- Rapid growth in wind generation will be accompanied by a surge in power-to-X demand, amid big Danish aspirations for both segments.

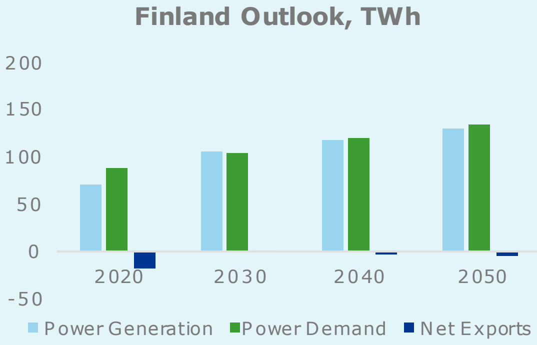


Finland

Key Targets: Carbon neutrality by 2035 - carbon negative soon after 2035

Key Features:

- Industry electrification to be the main driver of electricity demand growth.
- Will comprise about 18% of total net demand growth from electrification in the Nordics between 2020 and 2050
- We anticipate a surge in wind power generation, coupled with a ramp-up in nuclear generation.



Generation and power demand outlook based on a low carbon scenario.

2

Deep dive into the demand sectors

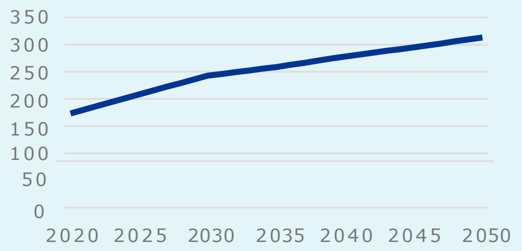
Overview - Key demand sectors in the Nordics

Industry

Key Views:

- The industry segment will be the main driver of electricity demand growth in the Nordics over the coming decade.
- This will be a combination of demand from new industry (i.e. new datacentres, manufacturing) and the electrification of existing industry (i.e through feedstock conversion).
- Demand growth for direct electrification will tail off towards 2050 in line with contracting opportunities coupled with rising efficiency, while demand for power-to-gas for industrial purposes will increase.

Industry demand, TWh

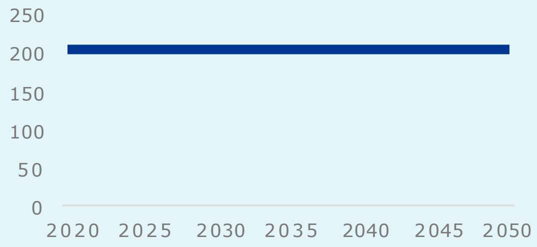


Households and Services

Key Views:

- Electricity demand in the households and services segment will remain stagnant over the coming decades.
- Rising efficiency through smart energy management, coupled with already high electrification in applications such as heating, will curb the growth potential.
- According to our low carbon scenario, the households and services segment will comprise about 200-210TWh of annual electricity demand leading up to 2050.

Households and service demand, TWh

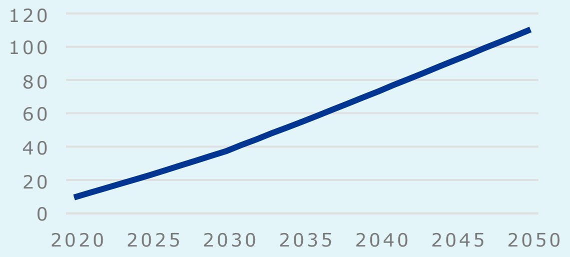


Transport

Key Views:

- Transport electrification will register a steady growth momentum over the next three decades and be a key source of electricity demand growth.
- Light duty vehicles will be the driver of this growth. Direct electrification of heavy duty trucks, maritime and aviation will be relatively limited, while power-to-gas as a transport fuel will add electricity demand to these segments.
- According to our low carbon scenario, electricity demand from transport will total 111 TWh by 2050 (including P2X for transport).

Transport demand, TWh



Power-To-X

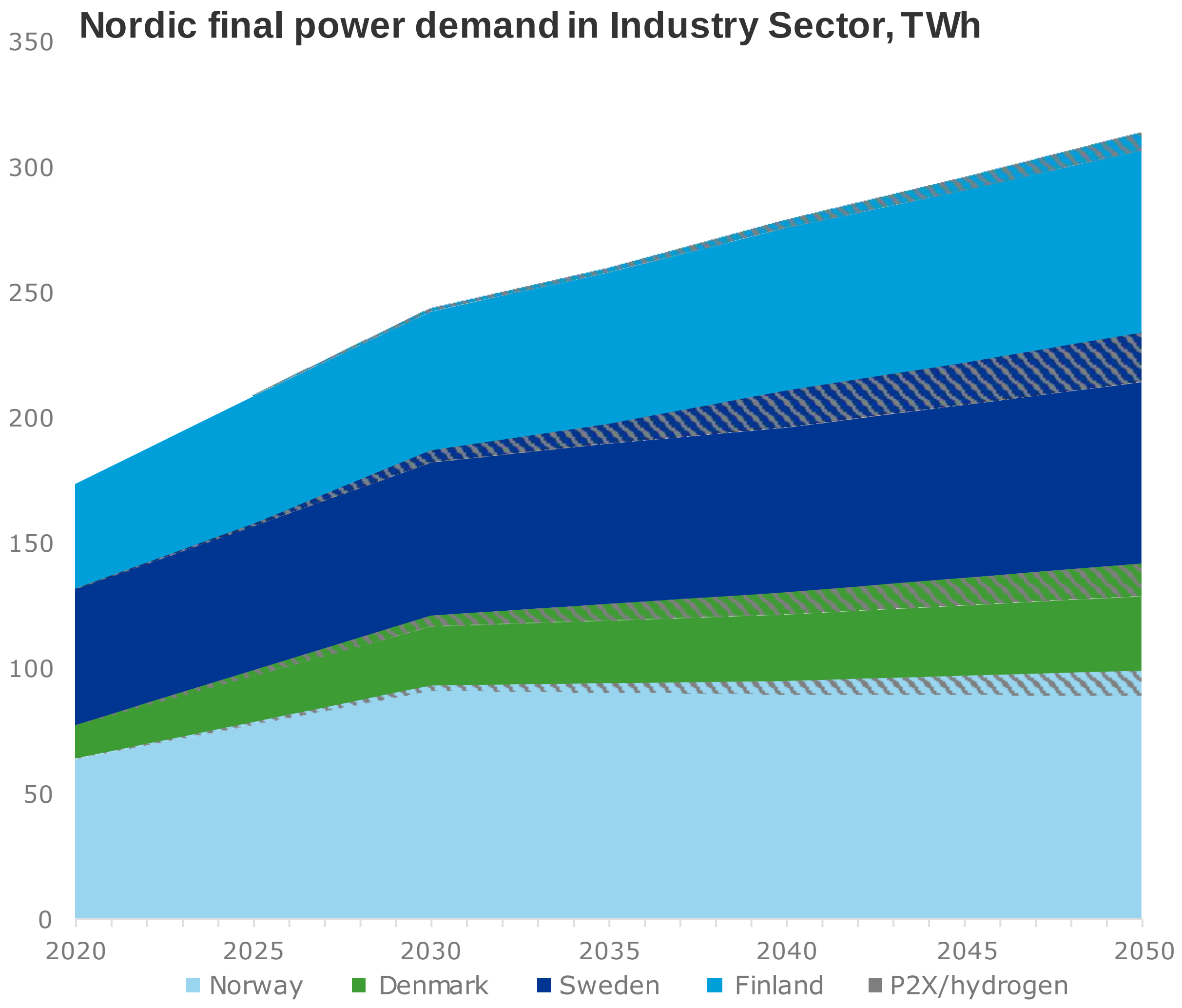
Key Views:

- Power-to-x (P2X) is a collective term representing additional electricity demand, such as power-to-gas (hydrogen)
- P2X footprint is small in the Nordic market, and could make the most pronounced impact after 2030 in terms of increasing electricity demand. Especially in Denmark the electricity demand for P2X is forecasted to grow substantially.
- P2X can play a key role supporting decarbonisation in hard-to-abate sectors
- P2X growth driven by decarbonisation push across sectors, by extension sector could become substantial source of flexible load.
- Clean and cheap Nordic electricity generation highlights scope for region becoming a P2X export hub over time.
- The power demand for P2X/hydrogen production is distributed to the transport or industry sector based on where the "X" is forecasted to be used.

Charts highlight electricity demand by sector in a Low carbon scenario, in TWh

Industry – The main near-term driver of electricity demand growth

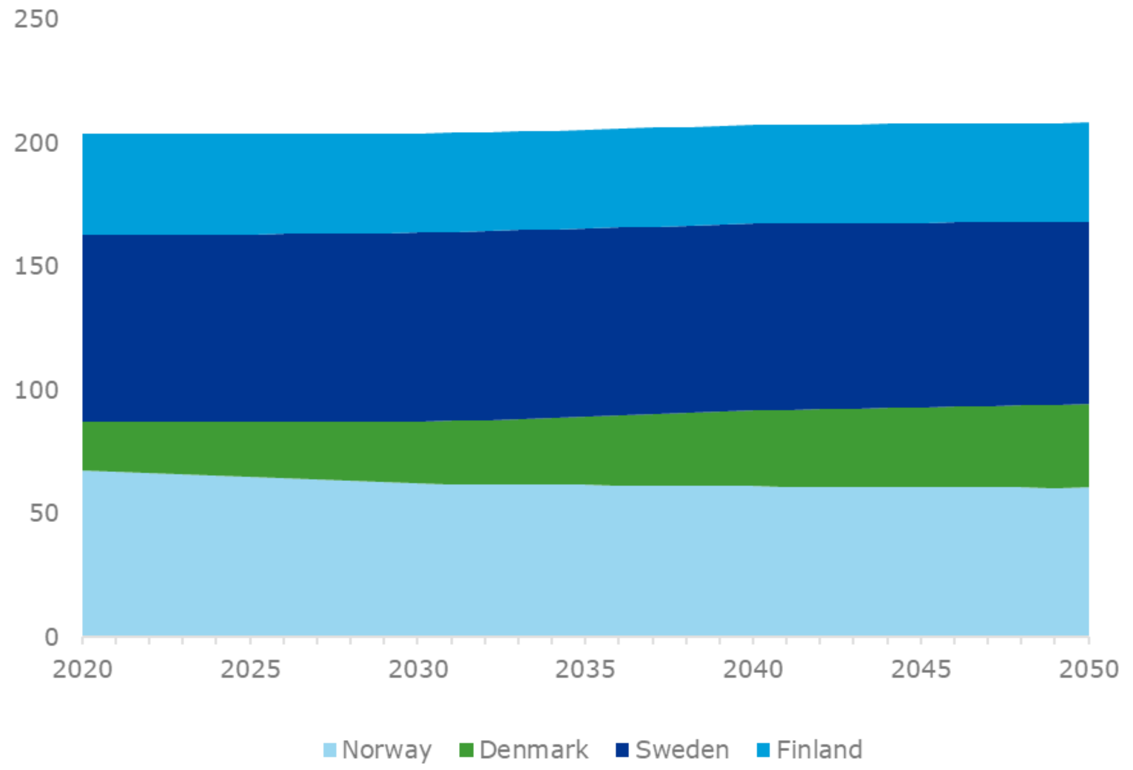
- The industry segment will be the key driver of electricity demand growth in the Nordic market leading up to 2030.
- Increasingly stringent carbon pricing will help spur increasing efforts to reduce emissions across industry, with electrification offering an energy-efficient solution - given electricity's relatively higher conversion rate compared to fossil fuel feedstock.
- This electrification will be through a combination of **new industry demand** (i.e. from new facilities such as datacentres or battery manufacturing) and from **existing industry** (i.e. new factories and replacing existing energy carriers energy with electricity).
- The forecast includes forecasted power demand for P2X for use in industrial processes (shaded area). Some industrial sectors and processes are harder to electrify, but can indirectly stimulate electricity demand by converting existing use of fossil fuels to hydrogen or other P2X products. For Norway, Sweden and Finland, P2X is based on the national report's forecasts for industrial demand for hydrogen produced by electrolysis. For Denmark, the P2X forecast also includes other e-fuels. Electricity demand for P2X is further described in slide 20.



Households and Services – Stagnant growth amid efficiency gains

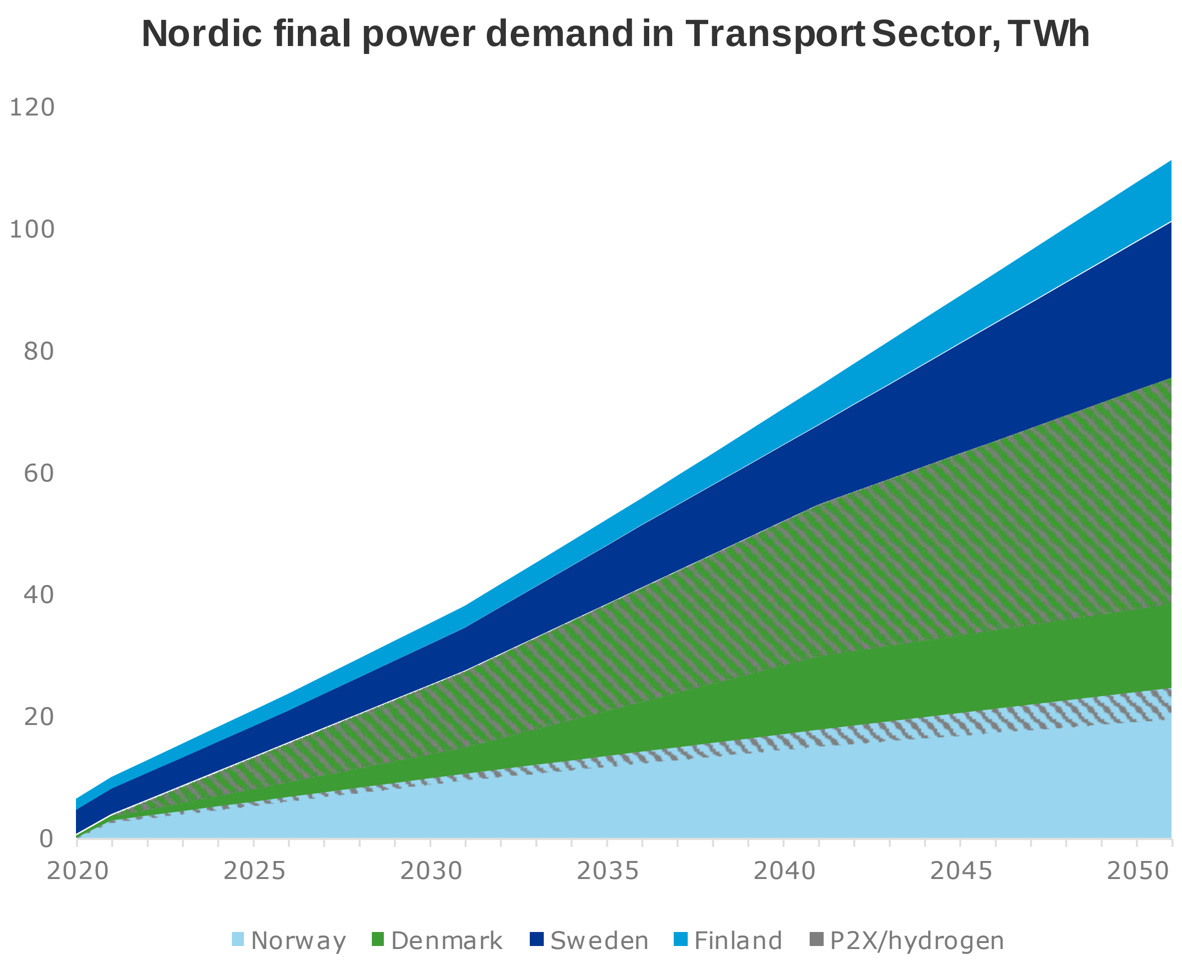
- Our low carbon scenario maintains that the households and services segment will register stagnant electricity demand leading up to 2050.
- Smarter management of traditional electricity demand, coupled with more efficient consumer applications, will curb demand growth in this segment. This trend is further underscored by relatively muted population growth in the Nordics.
- In terms of heating, we note that electric solutions already have deep penetration in the Norwegian market – with increasing efficiency of such solutions i.e. heat pumps set to curb longer-term electricity demand. We expect a similar dynamic to curb electricity demand growth from heating in district heating and heat pumps both in individual installations in Sweden and Finland, where electric heating to a lesser extent is deployed in the market.
- Denmark is forecasted to be the only Nordic country with net electricity demand growth in the households and service sector. Heating in Denmark is currently more based on feedstock-fuelled district heating, and we expect a greater deployment of heatpumps, as well as an overall growth in other classical demand.

Nordic final power demand in households and services, TWh



Transport – Steady increase in growth momentum expected

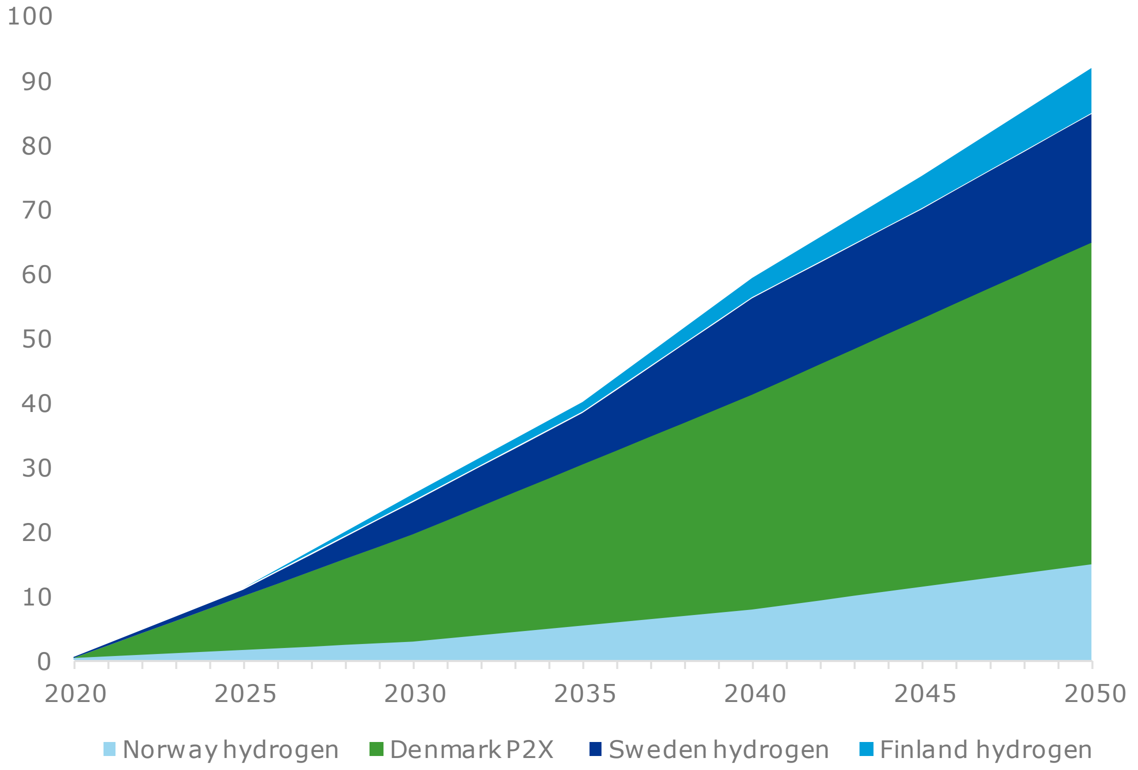
- The electrification of transport will be a key driver of electricity demand growth across all four Nordic markets over the coming three decades.
- We take into account two categories for transport, namely **light duty vehicles** (main part being passenger cars) and **other transport** (i.e. heavy lorries, rail, public transport, maritime, aviation etc).
- Power demand for transport is in this forecast reflected both in direct electrification and indirect electrification throuhg P2X demand for producing hydrogen or other fuels for transport.
- The Danish scenario presents a large potential for P2X in parts of the transport sector more challenging to electrify directly, such as heavy duty road transport, aviation and maritime sector. For Norway, some electricity demand for hydrogen as a fuel is forecasted. The national reports for Sweden and Finland do not mention demand for hydrogen or other e-fuels for transport.
- The process of converting power to hydrogen and back to power in a fuel cell electric vehicle is only half as efficient as direct-use of electricity in battery-electric vehicles.
- The by most important driver of electricity demand in the transport sector will be light duty vehicles – supported by falling technology costs and greater availability of charging infrastructure.



Power-to-X – Key to decarbonising hard-to-abate sectors

- Power-to-x can play a key role supporting decarbonisation efforts across the Nordics, particularly for segments of the industry and transport sectors hard to decarbonise through electrification.
- P2X is a collective term representing additional electricity demand, such as power-to-gas, power-to-liquid or power-to-heat.
- The definition of P2X by national reports in the Nordics highlights different perspectives on the role envisioned for P2X:
  - **Denmark:** The P2X scenario grows substantially to 50 TWh in 2050, and includes hydrogen, ammonia, methane and other e-fuels.
  - **Norway:** No separate P2X category, but a hydrogen demand of 15 TWh in 2050
  - **Sweden:** No separate P2X category, but a hydrogen demand of 15 TWh in the steel industry in 2040, extrapolated to 20 TWh in 2050*.
  - **Finland:** No separate P2X category, but a hydrogen demand of 7 TWh from the steel industry in 2050.
- The electricity demand for P2X is assigned to the sector where the «X» is expected to be used.
- By absorbing peak generation, the P2X can also offer a key source of demand-side flexibility that could faciliate greater utilisation of wind power in the Nordics. This is of particular importance in Denmark, given the market's reliance on wind generation and limited access to more flexible generation.

Nordic final power demand for Power-to-X, TWh

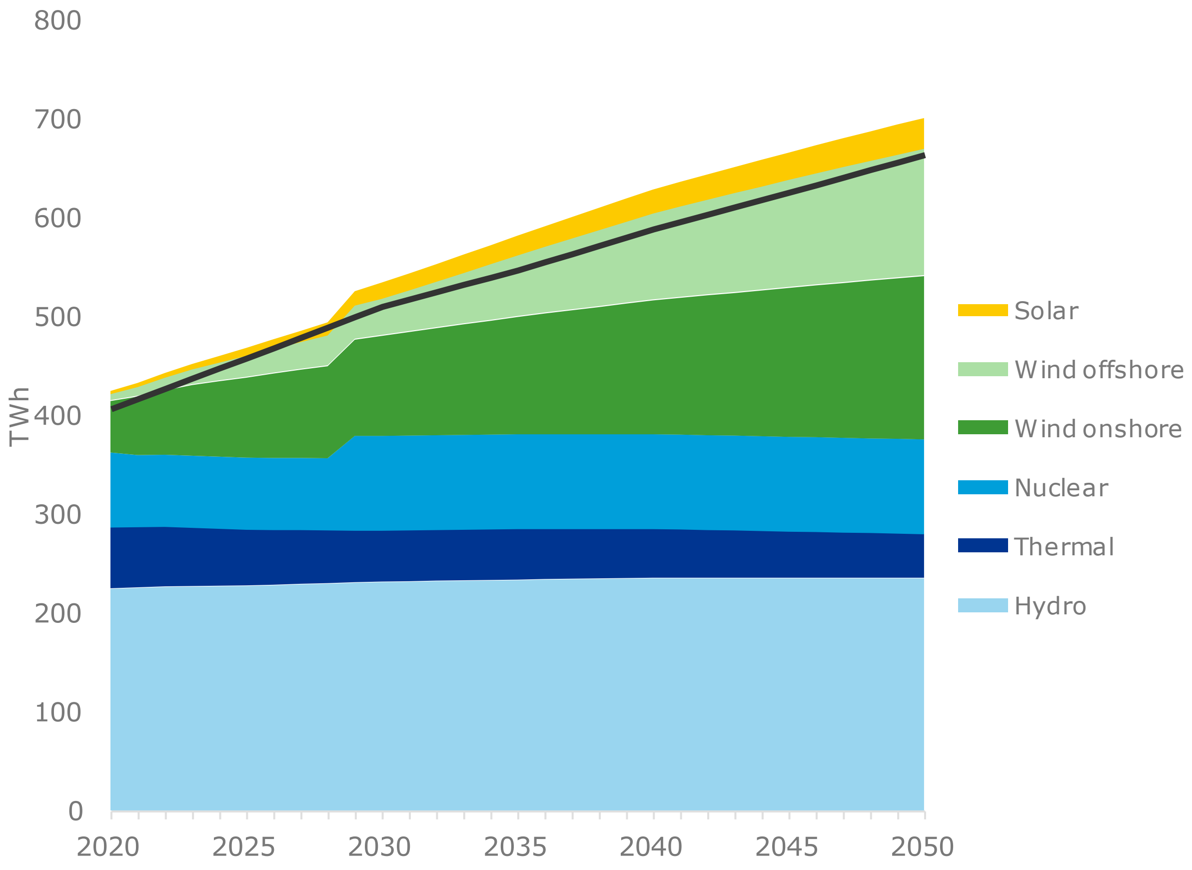


*The Swedish mining company LKAB has, after the finalization of this analysis, announced an increased electricity demand of 55 TWh per year 2045. LKAB foresee to introduce hydrogen in the reduction process of their manufacturing of fossil free iron. Hence, a large electrolyser capacity is needed. Full report in Swedish.

3

Deep dive into power generation

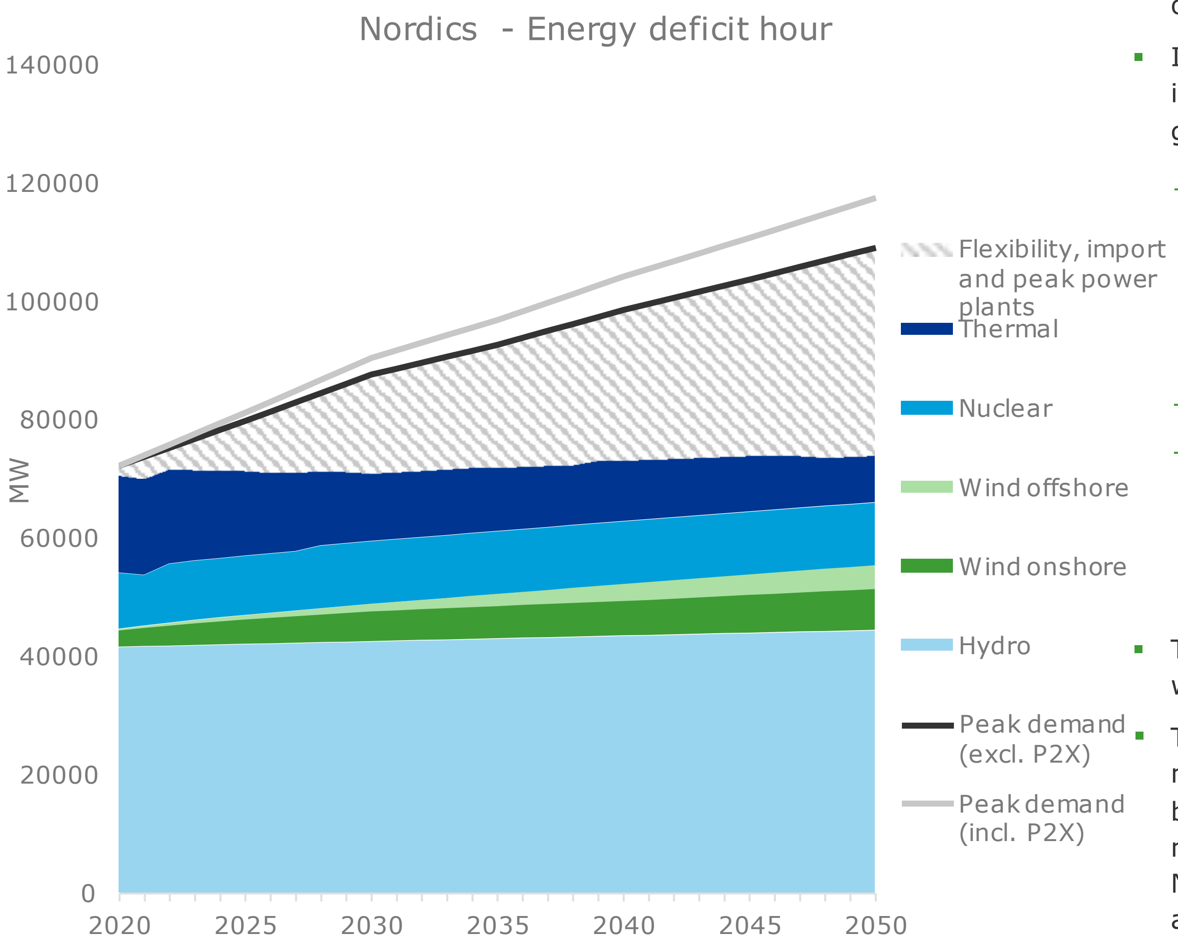
Wind power to drive clean Nordic power generation growth



- The Nordic countries have favorable wind conditions, with relatively high wind speeds and weather patterns that are less correlated with continental wind power generation. In order to keep up with the rising demand in a low carbon scenario, a large increase in wind power is necessary, with annual Nordic wind generation growing from around 60 TWh today to 295 TWh in 2050. Wind power would thus turn into the major source of electricity in the Nordics in this scenario.
- Despite the Nordic countries not being the most favorable for solar power, generation from solar PV is expected to increase from almost zero to 30 TWh in 2050.
- In this scenario, nuclear power generation remains stable in Sweden and increases in Finland in the 2020s.
- We expect a small inrease in hydropower generation. Utilizing the Nordic hydropower for energy storage and flexibility will become increasingly important as the share of renewables increase, and it will be important to help neighbouring countries balance their electricity system.
- The scenario shows a small decrease in thermal generation. Coal-fired power plants will be phased out over the coming years. The remaining thermal generation in 2050 will to a large extent use non-fossil fuels like biomass.

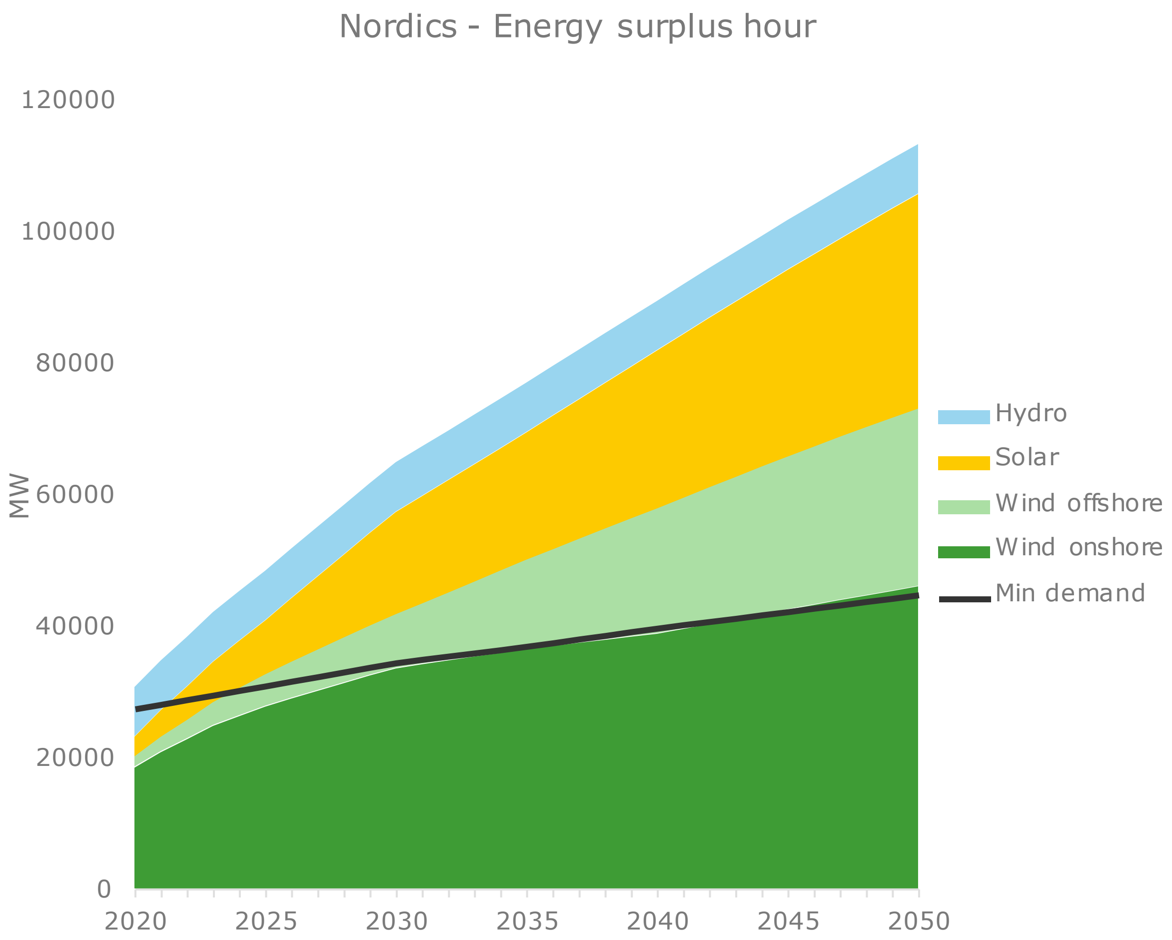
The generation scenarios are based national reports (see Appendix 6.2), with minor adjustments. Note that these are not DNV GL modelling results.

Flexibility solutions increasingly important to addressing system adequacy challenges



- The increasing share of renewables in the Nordics leads to higher variations in generation output, and electrification creates a more dynamic and complex demand profile.
- In order to assess system adequacy of the low carbon scenario, a «worst case» hour per year is analysed, representing a winter hour with high electricity demand and low renewable generation. The following methodology is used:
  - Peak demand in one hour (MW) increasing in line with total consumption.
    - Demand side flexibility from electric heating and electric vehicle charging is assumed, shifting parts of the electricity demand from energy deficit hours to energy surplus hours. Without any demand side flexibility, the peak load would have a steeper growth than the total load.
  - We assume the P2X sector to be flexible and consume less power during deficit hours.
  - The installed capacities in MW required to achieve the generation scenarios in TWh is calculated based on estimated numbers of full-load hours per technology. Availability of the different generation technologies in a deficit hour is assumed to be 0% for solar, 15% for wind, 75% for thermal, 80% for hydro and 90% for nuclear plants. Grid constraints are not considered.
- The figure shows the development of an extreme energy deficit hour for the Nordics as a whole in the low carbon scenario.
- The gap between the peak demand and the available generation continuously increasing. It needs to be addressed by implementing solutions such as increased interconnection capacity, both between the Nordic countries and continental Europe, and with market signals motivating flexibility from batteries, EV vehicle to grid and demand response solutions. A Nordic strong point is the large availability of firm low carbon power generation. If necessary, a potential expansion of firm capacity can complement import and flexibility solutions to address future deficit challenges.

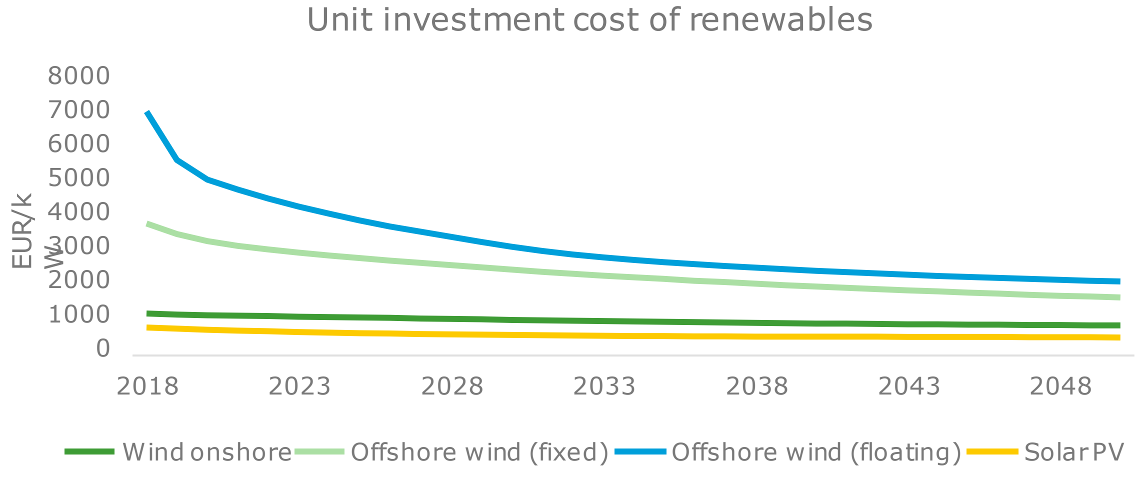
Flexibility Solutions increasingly important to solve energy surplus challenges

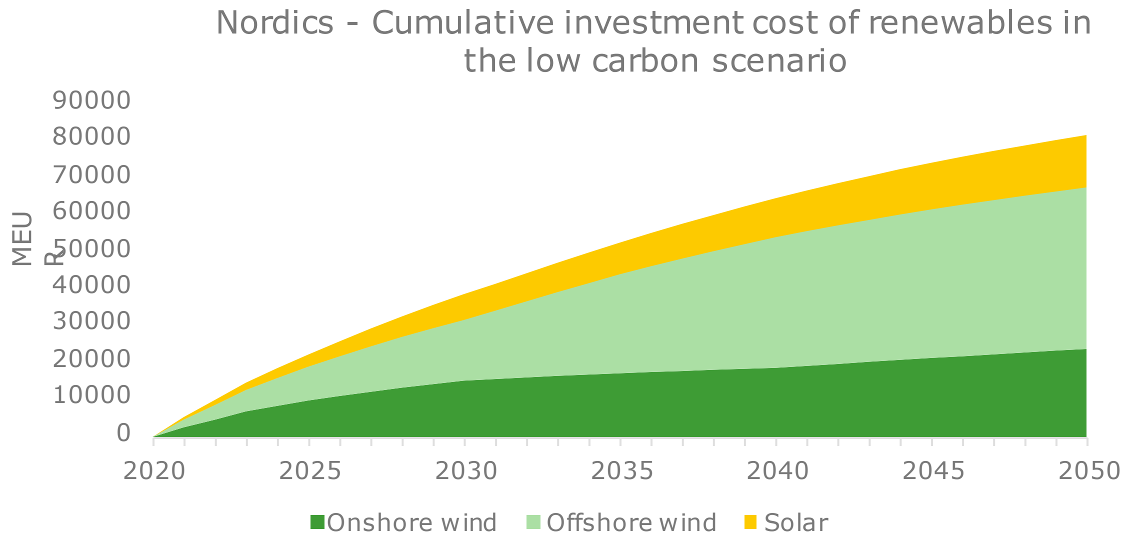


- While periods of energy deficit might be the most critical, there is also an increasing number of energy surplus hours that must be considered.
- With large growth in installed VRES capacities there is an increasing risk of curtailment in hours with high winds and sun combined with low electricity demand.
- The weather is often similar in the Nordic countries, so it is likely that surplus and deficit hours occur in several countries at once, challenging the whole Nordic and European system.
- The figure illustrates what an extreme energy surplus hour can look like, using the following methodology:
  - Minimum electricity demand in one hour (MW) follows the increase in total demand
  - All solar and wind capacity is available
  - 7.5 GW of Nordic run-of-river hydropower is generating
- To ensure a balanced development of the power market, even in hours with high intermittent renewable generation, all actors (consumers, flexibility providers and producers) should be faced with correct price signals. This will incentivize all market participants to make the correct decisions.

Steadily declining renewables costs to support generation growth

- The costs of renewable generation is constantly declining due to cost learning rates.
- Solar PV and and onshore wind already have the lowest levelized cost of electricity (LCOE) in many regions. DNV GL forecasts the cost decline to continue as installed capacity increases, but slow down and stabilize towards 2050.
- The costs of offshore wind are still high, especially floating wind due to its novelty, but are forecasted to fall significantly in the coming years with global capacity additions. DNV GL forecasts unit investment costs of offshore fixed and offshore floating wind to fall by 50% and 58% from 2020 to 2050, respectively.
- Total investment costs for the added solar and wind power capacity in the Nordics for the low carbon scenario is estimated to reach 80 billion Euro in total by 2050.
- With the Nordic generation capacity development presented in slide 21, annual investment costs will be highest in the 2020s and decrease towards 2050 as the volumes of new capacity and unit costs are expected to decline.





Source: DNV GL, Energy Transition Outlook 2020 and Energy Transition Norway 2020

A combination of flexibility technologies is needed in the future power system

- The need for flexibility increases in line with the electricity demand and share of renewable generation. Flexibility from the consumer side can be:
  - **Demand shifting**: consumption is shifted from surplus hours to deficit hours. This is especially applicable to demand for heating and electric vehicle (EV) charging.
  - **Demand shedding:** Large C&I customers that reduce their consumption based on price signals
  - **Demand increase (Power to x):** A flexible demand that can be activated when there is surplus renewable generation. This will be important to avoid curtailment of wind, improve the business case for wind developers and reduce the need for subsidies. The power can be used to produce i.e. hydrogen (or other gases or liquids) or heat.

- In addition **battery energy storage systems (BESS)** will be important especially to help with deficit challenges. Battries can be both stationary batteries and potentially EV batteries delivering **vehicle-to-grid (V2G)** services. They utilize price volatility by charging in hours with low power price and discharging in hours with high power price.

- There is a need for a balanced combination of various flexibility technologies and potentially an increase in firm generation capacity in order to solve the challenges in the future power system.

4

Barriers and solutions

Barriers – Overview of the main hurdles to electrification

- The Nordic region can meet its decarbonisation targets through the deep electrification of energy use, enabled by the availability of cost-competitive clean electricity generation.
- A key component for facilitating and stimulating electrification will be to identify and address barriers that could hinder this evolution. While there are unique barriers at the local level to the electrification of demand and growth in clean power generation, **the main barriers are shared across the Nordics** and can thus be solved in collaboration.
- The barriers can be divided into four main categories;

1	**Electricity demand**	Consumers usually have more than one choice, with electricity cost-competitiveness key. Various segments have different barriers, i.e. sunk costs curb industry electrification.
2	**Electricity generation**	Time-consuming and uncertain permitting processes coupled with uncertainty with regards to power demand materialising are obstacles to expanding capacity.
3	**Electricity grid**	Key to connecting new demand and generation and ensuring system adequacy. Often hindered by the long time required for planning, permitting and construction.
4	**System adequacy**	Increasing volumes of intermittent renewables generation will increase the challenges associated with balancing power supply and demand.

Key barriers to delivering on electrification potential in the Nordics

DEMAND

ELECTRICITY DEMAND

- **Limited grid availability:** Long grid re-enforcement processes, high connection costs and permitting uncertainty weakens electrification growth and reduces its timeliness.
- **Uncertain evolution of future electricity demand:** The realisation of demand potential is dependant on market signals, technology development and EU climate policy development.

GENERATION

ELECTRICITY GENERATION

- **Difficult build-out of generation capacity:** Long and uncertain permitting processes for generation and grid infrastructure, and local opposition to new projects are obstacles to new-builds.
- **Demand-driven growth uncertainty:** Risk associated with demand growth materialising or not can lead to lower than expected market access.

SYSTEM ADEQUACY

ELECTRICITY SYSTEM ADEQUACY

- **Intermittency of wind and solar generation:** Supply and demand mismatch can lead to supply shortages as well as curtailment, weakening electrification and generation investment appetite.
- **Limited flexibility and storage capacity**: The nascent stage of development of new flexibility and storage technology can be a hurdle to substantially scaling up capacity. Regulation may not appropriately incentivise flexibility and demand-side participation.

GRID

ELECTRICITY GRID

- **Long and uncertain planning processes:** Long planning and permitting processes makes grid upgrades and reinforcement time-consuming.
- **Long project development lead times:** The deployment of grid infrastructure often has long lead times, and can halt electrification progress.

Solving demand barriers through grid access and appropriate carbon price

Barrier: Grid availability

- Grid availability can be limited, with long reinforcement processes limiting the connection of new electricity demand
- Grid connection costs can be high and the permitting process can be long and uncertain for building new electricity-intensive industrial facilities

Identified solutions

- Predictable and transparent processes for grid reinforcement, planning ahead for electrification
- Well-developed framework for establishing new electricity-intensive industrial facilities that can streamline connections and stimulate investor interest

Barrier: Uncertainty around demand evolution

- Long-term demand evolution assumptions may not materialise and are challenging to factor into planning. In some "hard-to-abate" sectors (such as heavy duty transport) there are still high costs connected to switching from fossil fuels to electricity or hydrogen
- Electrification of transport is dependant on development of charging stations that can meet future demand, and can be limited by slow (and costly) infrastructure development, especially in rural areas

Identified solutions

- A robust EU ETS mechanism and EU industrial policy will be key drivers to facilitate consumer decarbonisation by increasing the economic attractiveness of low emission solutions.
- Subsidise the parts of the transport sectors that need a "start push"

Solving generation barriers through robust permitting and flexible power offtake

Barrier: Difficult to build-out generation capacity

- Long and uncertain permission processes, both for power plants and grid infrastructure
- The debate between climate and environment – local opposition in the form of NIMBYISM can be a pertinent challenge
- Coordinating that new generation capacity comes online at the same time as new demand is challenging. Temporary oversupply and low capture prices for new generating capacity is thus a risk.

Identified solutions

- Develop solid, transparent and predictable permitting processes to increase public acceptance and investor confidence
- Improve visibility of long-term planning and educate consumers on positive impact of generation facilities
- Support hydrogen value chains or other power-to-x, facilitating surplus power consumption

Barrier: Demand-driven growth uncertainty

- Uncertainty over the extent long-term demand growth materialises poses a risk for reduced market access for power generating capacity.

Identified solutions

- Robust planning for electricity demand growth and concrete measures to realise power demand potential.
- A sufficient cost for carbon emissions in order to ensure that the polluter pays and low carbon solutions are attractive has a big impact on power capacity investment and R&D plans. This intensifies emission reduction efforts for generators, enabling consumers to decarbonise by consuming clean electricity.

Solving system adequacy barriers through flexibility deployment

Barrier: Intermittency of wind and solar generation

- Intermittency of wind and solar generation challenges the power system balance by widening supply shortages during critical deficit hours – weakening electrification appetite for demand sectors
- A widening gap between load and surplus generation can lead to both very low prices and supply curtailment, hitting investment appetite for generators

Identified solutions

- Expand cross-border transmission capacity to ensure efficient allocation of power generation resources across the Nordics.
- Facilitate uptake of short/long-term flexibility solutions to absorb generation surpluses and plug supply deficits, as discussed below.
- Expand market-based remuneration for system services.

Barrier: Limited flexibility and storage capacity

- The nascent stage of development of new flexibility and storage technology can be a hurdle to substantially scaling up capacity. Regulation may not appropriately incentivise flexibility and demand-side participation.

Identified solutions

- Ensure that the pricing signal is attractive for flexibility resources on the supply and demand side when system inadequacy is forecasted. In addition, have a realistic view on the need for firm capacity to supplement the other flexible technologies.
- Enable "stacking of revenues" for battery storage and ensuring market access for various flexibility providers to provide different flexibility services.

Solving grid barriers through flexibility and long-term planning for electrification

Barrier: Long and uncertain planning processes

- Grid expansions face long and uncertain permitting procedures
- New transmission lines often face substantial popular opposition at the local level

Identified solutions

- Long-term grid planning should consider requirements for electrification and decarbonization
- Joint planning process across the Nordics, identifying the most value-adding solutions

Barrier: Long grid development lead times

- Long lead times for grid capacity deployment can reduce the timeliness of connecting new demand.

Identified solutions

- Improve and enable alternatives to grid investments, such as energy storage solutions and demand side flexibility, for example by developing cost-reflective tariffs.

Holistic solutions key to addressing barriers in an efficient manner

- A number of barriers have been highlighted, of which the impact of popular opposition to the building of new infrastructure and grid connection challenges overlap across the demand, generation, adequacy and grid segments.
- Notably, these barriers are to varying degrees shared across the Nordic markets, and the solutions are thus also similar across borders. We have grouped some key solutions below:

Robust permitting processes:

Robust permitting processes, both for power generation and new industry, will help facilitate timely grid connections and power sector infrastructure deployment. This will support electrification rates and clean generation growth while mitigating popular opposition.

Grid capacity and access planning

Long-term grid investment planning that incorporates the demand from electrification and the corresponding need for clean power generation is key to providing long-term visibility for generators, consumers and network operators.

Facilitating electrification

CO_2 emission costs must be high enough to sufficiently reward zero emission solutions over alternatives. Hard-to-decarbonise energy demand segments such as heavy-duty transport and industry should also be supported with financial incentives and support to deploy required infrastructure to kickstart decarbonisation efforts through electrification.

Facilitating generation and flexibility growth

Flexibility resources can be stimulated with appropriate price signals, electricity market access and a focus on establishing P2X value chains. With flexibility capacity, the business case for renewables will improve by reducing power price cannibalisation, while system adequacy challenges are mitigated.

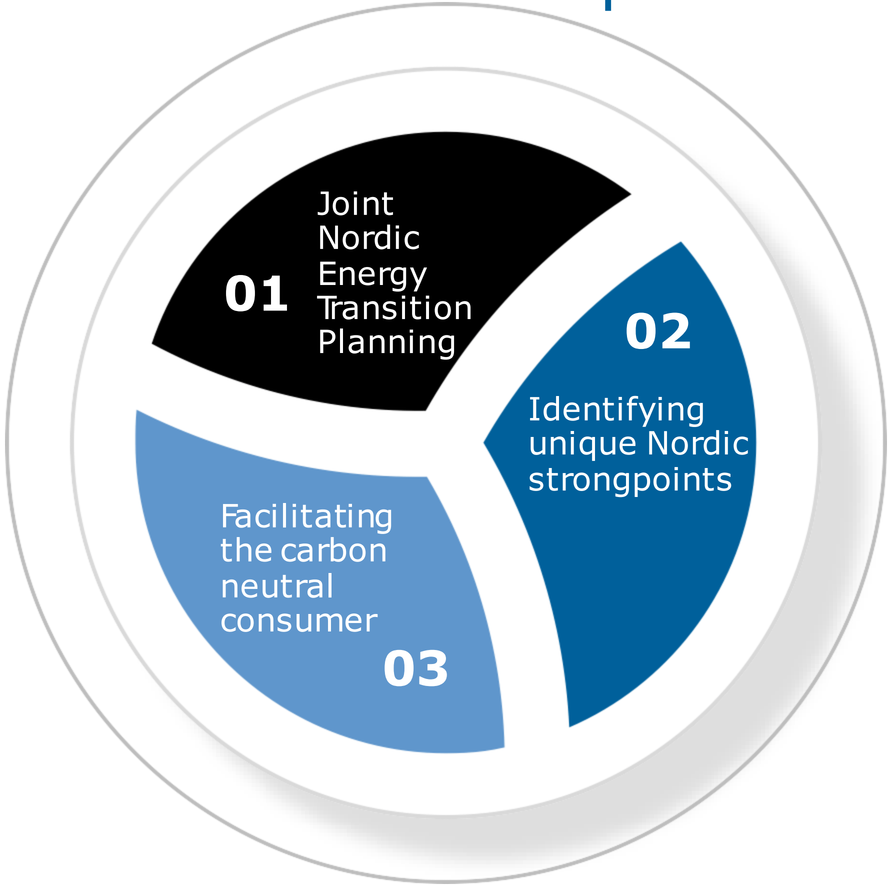
5

Strategic recommendations

Strategic recommendations for unlocking Nordic electrification potential

Continued deep decarbonisation is required for Nordic markets to deliver on ambitious climate targets. This report has highlighted that there is substantial scope for electrification to drive carbon reductions across sectors. The growing sense of urgency to mitigate climate change will further cement the importance of the electricity sector as a facilitator of economy-wide decarbonisation. In order to unlock this potential, three strategic recommendations have been formulated.

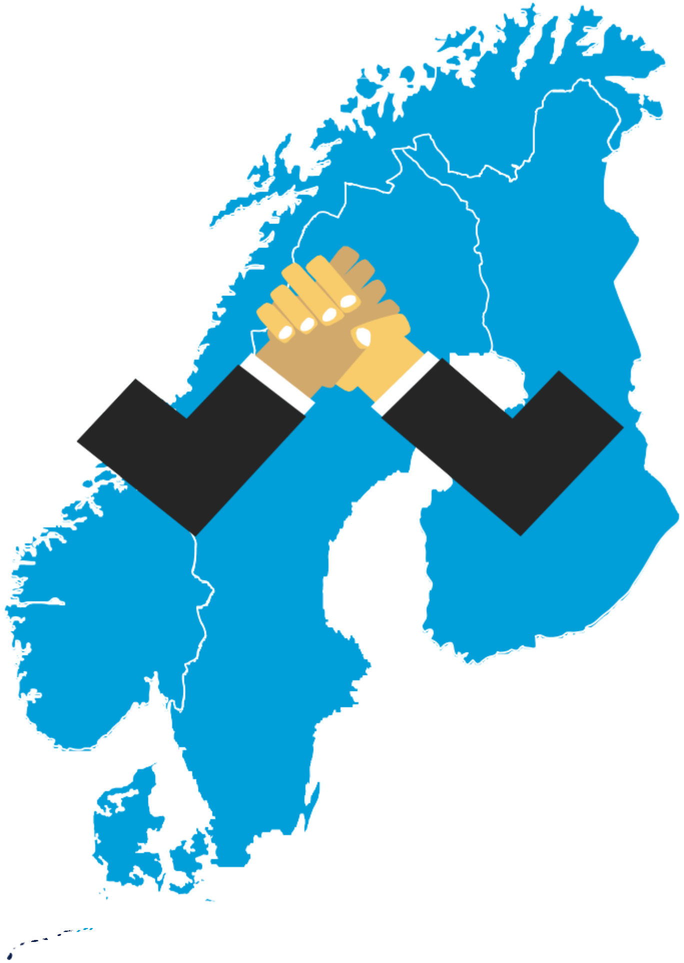
- **Joint Nordic energy transition planning:** Joint planning to ensure alignment between countries to coordinate power supply, grid and flexibility development to meet the rise in power demand from an electrification-driven energy transition with clean energy.
- **Identifying unique Nordic strongpoints:** Low carbon firm capacity from hydropower and nuclear, coupled with cost-competitive onshore wind and rising scope for offshore wind can facilitate the creation of power-to-x hubs and continued expansion of energy intensive industry.
- **Facilitating the carbon neutral consumer:** Consumers should be rewarded for choosing electric over fossil-fuelled solutions, and for adapting consumption to support the power system. Creating a cost-efficient transition to carbon neutral electricity with a holistic view of the energy system and the uptake of smart management that simplify the use of flexibility should be a key focus of policy.



NORDENERGI

Strategic recommendations (I) – Joint Nordic energy transition planning

- **Identifying and tackling barriers for grid development:** Barriers prolonging grid expansion is a major obstacle associated with increasing the electrification of energy-use across the Nordic markets and the EU more broadly, including electrification in combination with hydrogen use in heavy, long haul road transport, aviation and maritime transport.
- **Frontrunner in carbon-free transport:** Charging infrastructure expansion and increased joint Nordic strategy to promote electrification in combination with hydrogen use in heavy, long haul road transport, aviation and maritime transport.
- **Alignment of flexibility markets and grid development:** Flexibility markets can give a better utilization of the grid, but substantial grid development is still necessary on all voltage levels.
- **Increased Dialogue and co-operation:** The *Nordic Electricity Market Forum* constitutes a unique and important platform for the necessary involvement of stakeholders. As a vision and a road map is formulated, the next step is finding suitable arrangements to activate working groups suited to the purpose between the yearly Forums.
- **Long-term planning for resource complementarity:** A shared Nordic holistic planning approach to electrification strategies must be built on the complementarity of energy resources across the Nordics. The enhanced cooperation of the Nordic TSO within long-term planning and system operations is fundamental.
- **Common market needs common rules:** It is vital that the relevant regulation is synchronised and implemented in a harmonised way to create a level playing field and making it possible for market participants to benefit from a larger market.



Strategic recommendations (II) – Identifying Nordic market strongpoints

- A key component of a holistic electrification strategy will be to identify competitive advantages for electricity-use and power generation in the Nordics. Notably, this will be to deepen the penetration of clean electricity in final energy use by leveraging the potential for clean and cost-competitive power generation.

- **Electricity use:** A competitive low-carbon power generation segment, coupled with small populations and technology-friendly consumers in a highly digitized economy, make the Nordics a prime market for ramping up:
  - More **electricity-intensive industry**
  - **P2X production** both for domestic use and exports
  - Availablility of **predictable flexibility-resources** in production and consumption

- A long and beneficial history of Nordic co-operation in general and in electricity especially with the creation of Nordel in 1962 and the world's first true cross-border power exchange, Nord Pool.

- **Competitive low carbon generation:** The Nordic market has an advantage by using competitive price-setting mechanisms for both the wholesale and the retail market. The Nordic market design provides a sound investment climate. Furthermore, low carbon firm capacity from hydropower and nuclear, coupled with favourable wind conditions onshore and offshore makes wind power a strongpoint across the Nordics.

Strategic recommendations (III) – Facilitating the carbon consumer

- The power consumer is the foundation of a strategy that seeks to increase the penetration of electricity in energy use. First, the consumer needs to choose electricity over fossil fuels, and second market signals should stimulate flexible consumption. We call on correct market conditions and a level playing field for demand flexibility which is central to achieve efficient pricing and resource allocation in all competitive markets.
- **Switching from fossil fuels to electricity:** The cost of carbon emissions needs to reward the consumers that opt for low carbon solutions, aided by other incentives where necessary at the sector level to ensure that the switch away from fossil fuels is economically viable and attractive for businesses. The EU ETS ensures that decarbonization is done in the most cost-efficient way for society and Nordenergi therefore support expanding the system to other sectors, but it is also important to maintain the system's robustness. For sectors not included in the EU ETS, a carbon price signal is necessary to facilitate a cost-efficient transition to a carbon-neutral economy.
- **A reliable power system that meets consumption needs:** The power demand stemming from increasing electrification levels will to a large extent be met by intermittent renewables. It is therefore key to foster markets that promote an efficient use of both production and consumption which benefits society. A holistic view of the energy system and the uptake of smart management that simplify the use of flexibility should be a key focus of policy.

6 Appendix

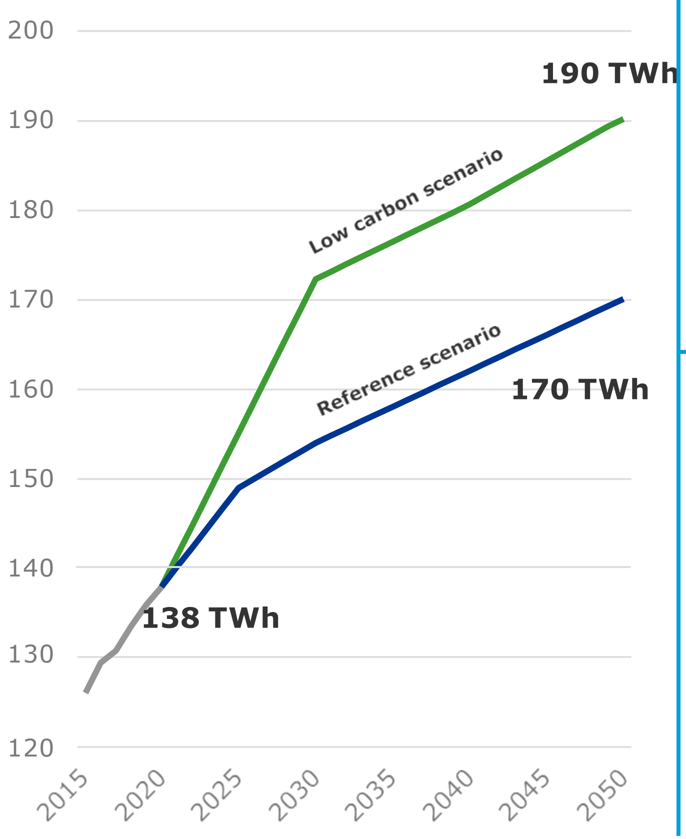
6.1 NORDIC COUNTRY OVERVIEW

The electrification journey is underway in Norway

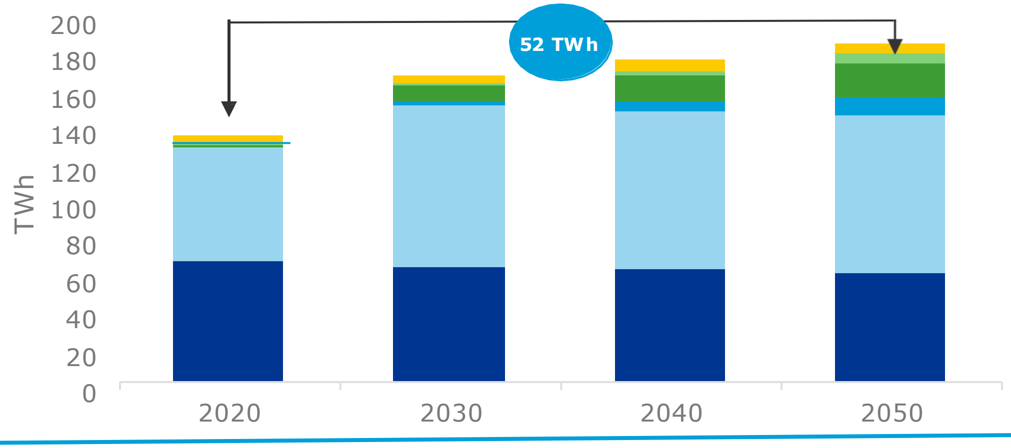
A Low carbon pathway can increase demand by 50 TWh towards 2050

Norway is well-positioned to reduce carbon emission through the electrification of key segments such as transport and industry. The uncertainty of future growth in electricity demand is linked to establishment of new industries, the speed of transition from fossil fuel energy carriers and adaption of new technology.

Development trajectories for electricity demand in Norway under two scenarios



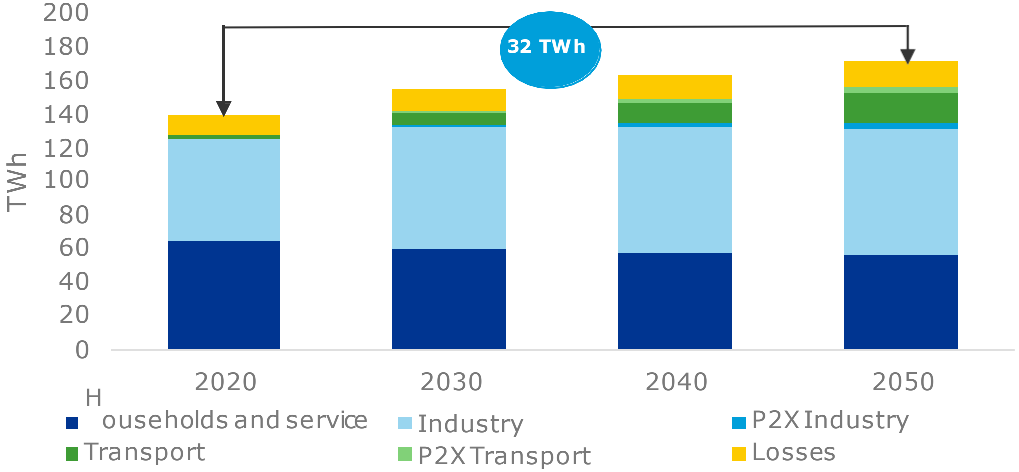
Low carbon scenario



Scenario assumptions

- Norway will meet their carbon emission targets of 50-55 % GHG emission reduction by 2030 and 90-95 % by 2050 relative to 1990-levels.
- Electrification is the key enabler for emission reduction in the short term.
- The main electricity demand growth is from electrification of industry and transport, as well as electricity used to produce hydrogen
- Strong national- and EU-level policies are implemented to enable a green transition and ensure appropriate carbon emission reduction actions are taken

Reference scenario



Scenario assumptions

- The reference scenario follows Norwegian Water and Energy Directorate's (NVE) Nordic electricity market forecast from 2020-2040. We have assumed the growth trajectory from 2030 to 2040 to continue to 2050.

DNV·GL

Norway – Key sector demand outlook

Industry

- The industry sector in Norway is already highly electrified compared to other industrial countries.
- New industry like data centers will increase demand by 12 TWh to 2050.
- Electrification of oil and gas facilities in the north sea and the conversion of energy feedstock in established industries will be the main drivers for an additional increase in industry demand. Electricity demand for hydrogen in industry reaches 10 TWh in 2050.

Households and service

- Households and service demand is expected to remain fairly constant, with population and economic growth being levelized out by energy efficiency measures.
- Heating in Norway is already highly electrified, and electricity demand from heating is expected to remain constant.
- Increased deployment of heat-pumps, both for households and the service sector will ensure the total energy demand for heating in Norway will be reduced.

Transport

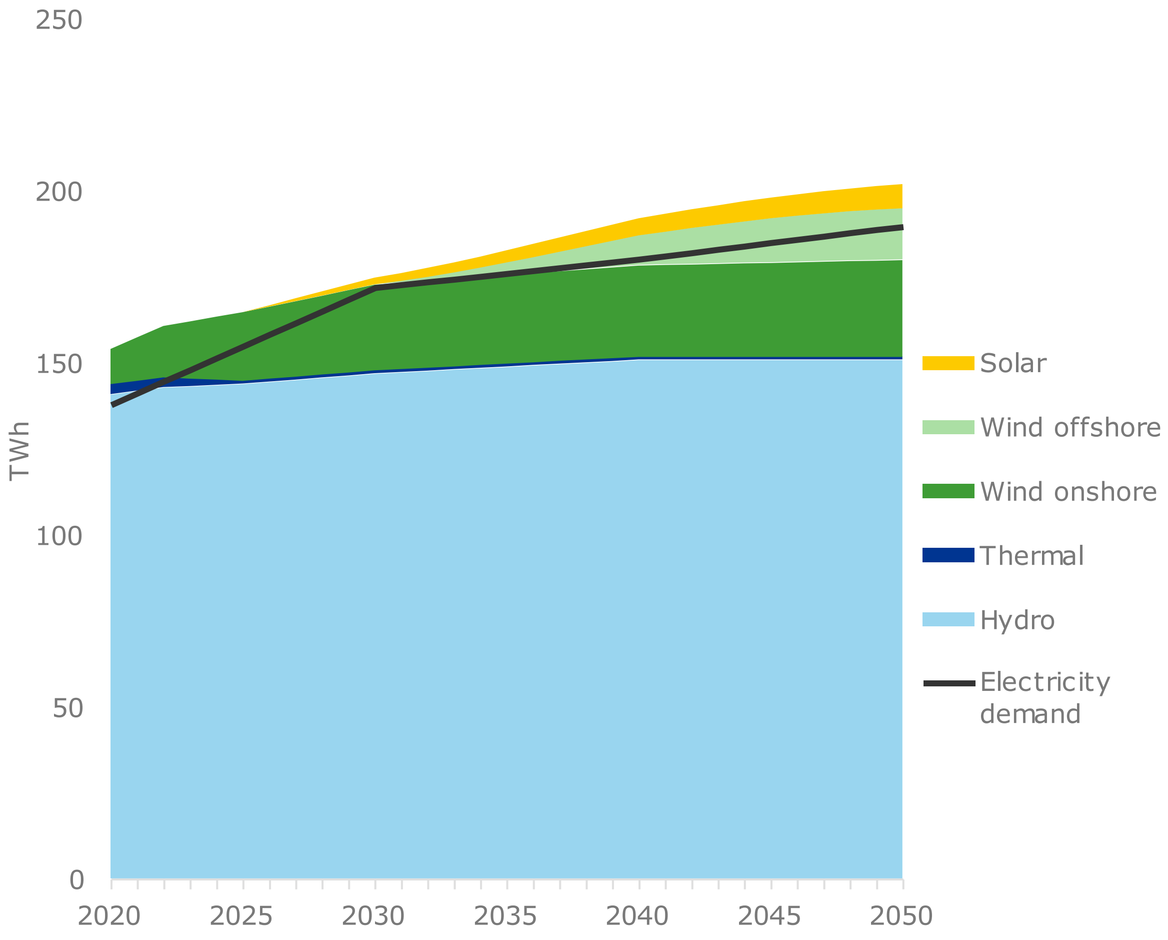
- Norway is already a global leader in electric vehicle deployment
- The main growth in this segment is from further electrification of passenger cars and light duty vehicles, reaching 12 TWh in 2050.
- In addition, an increase of 8 TWh electricity demand is expected from other transport like long distance trucks and the maritime transport sector, as well as 5 TWh for vehicles that operators on green hydrogen.

Power-To-X

- Power-to-X capabilities in Norway will be mostly linked to conversion of energy feedstock in difficult to abate sectors, such as aviation and high temperature application in industry.
- Hydrogen will have a slow pick-up rate towards 2040, but as the technology matures and global uptake increases, we expect the learning rate to be at a level which makes the technology financially attractive for more sectors towards 2050. The total power to gas consumption of 15 TWh is distributed between the industry and transport sector.

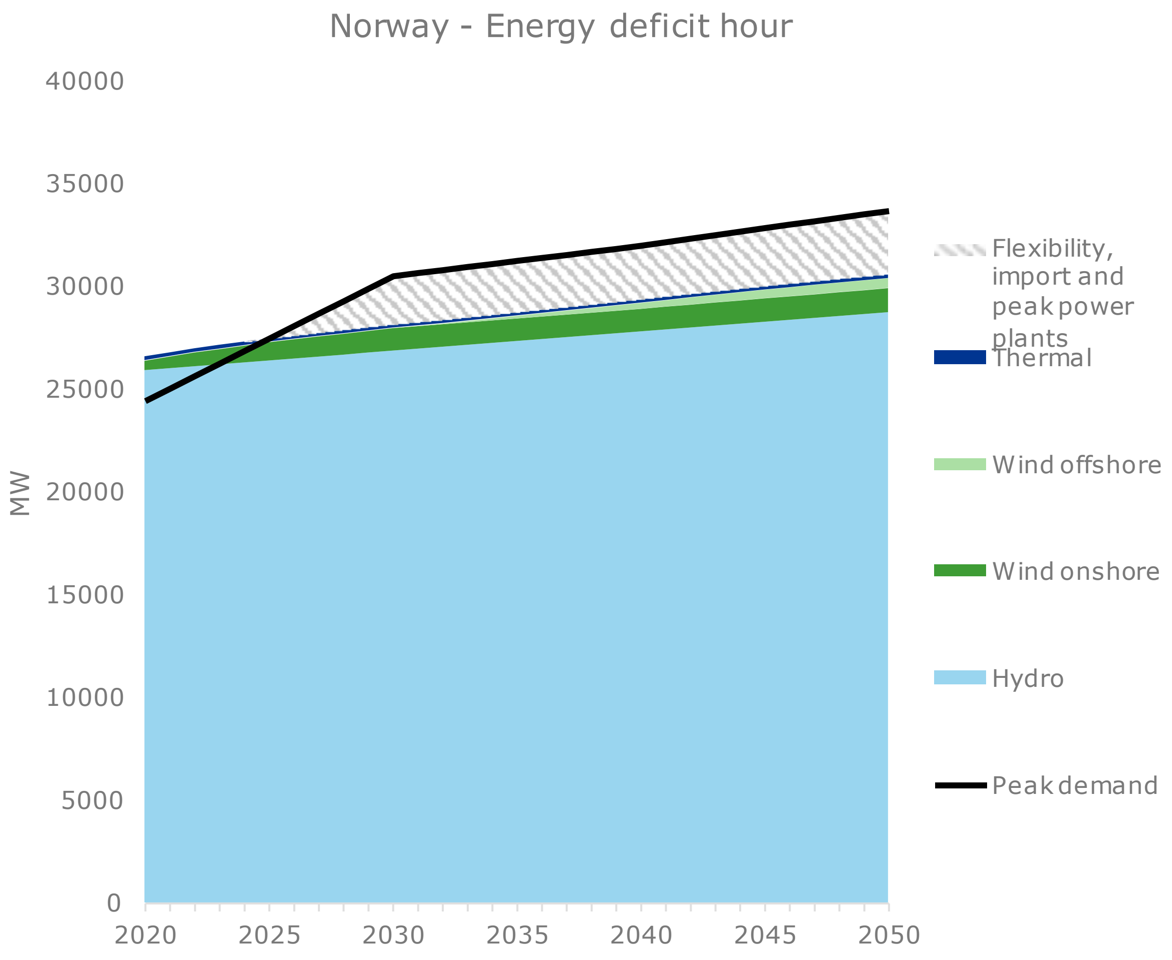
1) IEA

Norway - Forecasting generation for a low carbon scenario



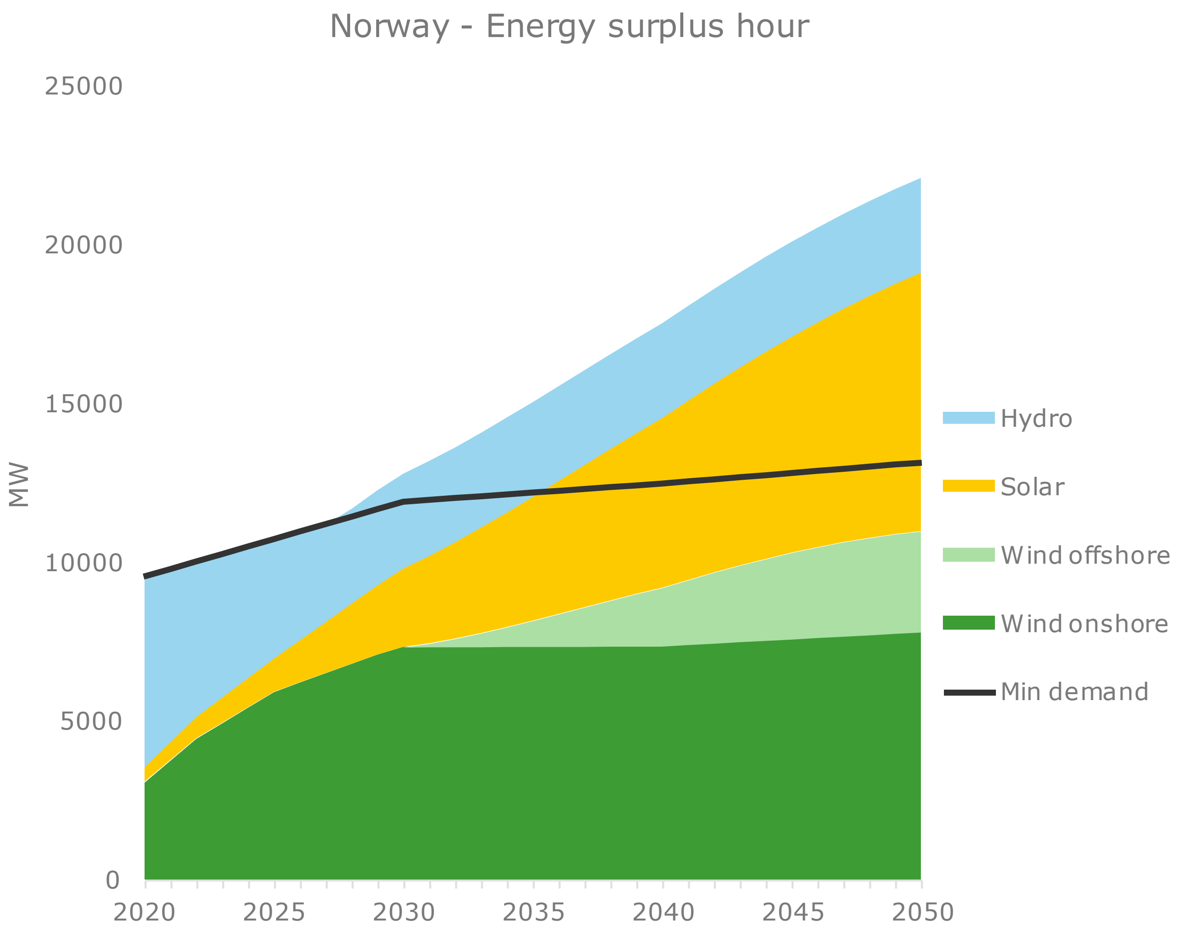
- Norway remains a net exporter of electricity in the low carbon scenario.
- Hydropower will remain the dominant power generation source in Norway. An increase in electricity generation from hydropower of 10 TWh is expected, due to capactiy development and increase in inflow.
- This scenario includes a large increase in wind power, from 10 TWh today to above 40 TWh in 2050. Up to 2030, the growth will be in onshore wind, while after 2030 most of the additional capacity is expected to be in offshore wind. A potential risk that could slow down onshore wind development is local protests. This may, however, lead to an acceleration within the development of offshore wind technology.
- Solar PV will also increase to approximately 7 TWh in 2050. Solar PV has a low capacity factor, especially in the Nordic countries, and 7 TWh generation means approximately 8 GW of solar PV capacity, expected to be installed mostly in the southern parts of Norway.

Norway – System adequacy assessment – Energy deficit hour



- In Norway, hydropower will continue to play an important part in balancing the system and secure system adequacy in Norway (and other Nordic and European countries).
- The figure illustrates the scenario development of an ”energy deficit” hour in Norway, where electricity demand is high and renewable generation is low.
- With the assumptions described in slide 14, there will be enough domestic hydropower generation to cover peak demand until 2025. As electricity demand increases further, Norway will also be reliant on other solutions, such as import, batteries, EV vehicle-to-grid and demand response to cover peak demand, but not to the same extent as the other Nordic countries.

Norway – System adequacy assessment – Energy surplus hour



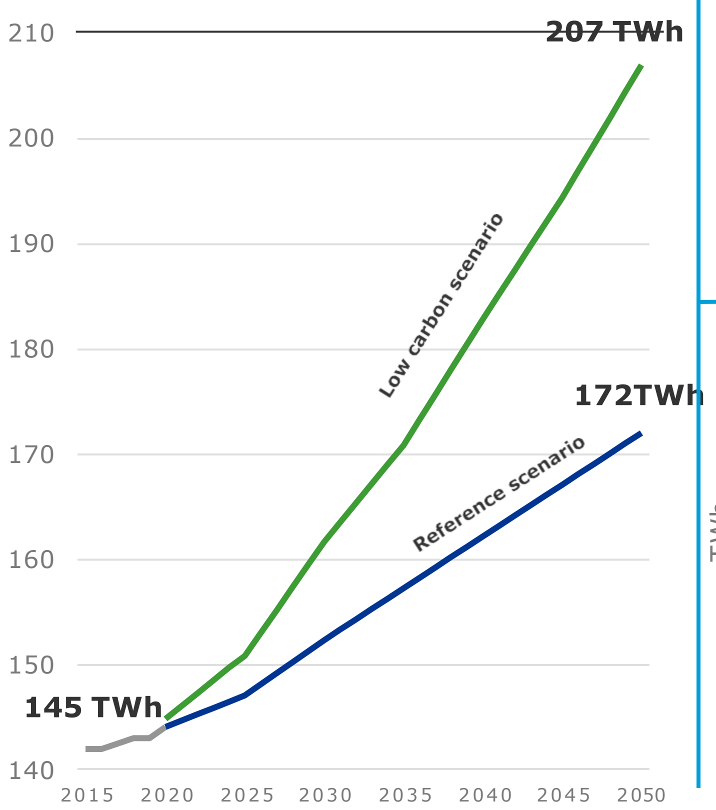
- The figure illustrates the scenario development of an energy surplus hour in Norway, where solar and wind power is generating at maximum capacity while electricty demand is at a minimum level.
- After 2030, the assumed capacities for wind and solar surpass the scenario for minimum hourly electricity demand, and flexibility solutions like demand side flexibility and battery storage systems (in addition to flexibility from hydropower storage plants) will be important to absorb surplus electricity that is not exported. Power-to-x, which for Norway is assumed to be Power-to-hydrogen is expected to consume power when there is a surplus and electricity prices are low.

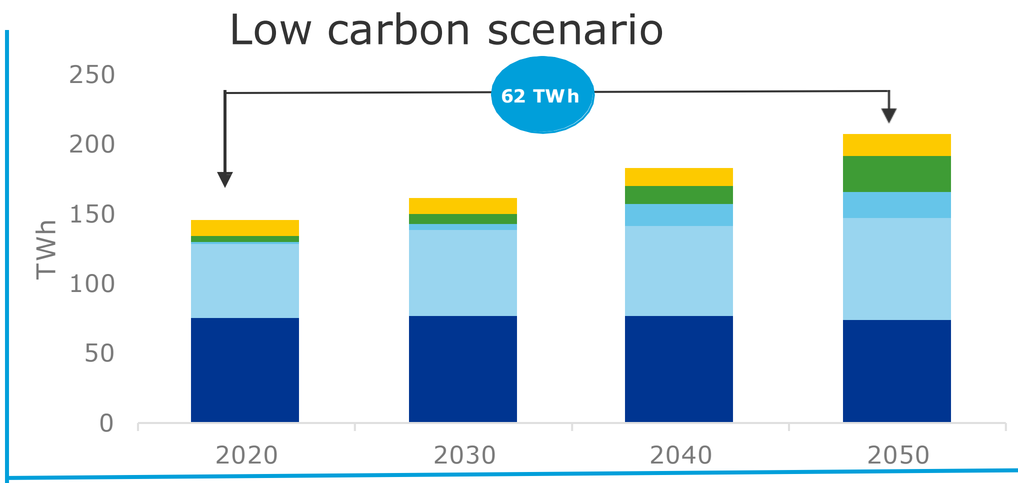
Electrification is a key enabler for emission reductions in Sweden

A low carbon pathway can increase demand by 60 TWh towards 2050

Sweden is set to register robust electricity demand growth in a low carbon scenario, driven by a combination of the electrification of industry and transport, as well as longer-term demand from the P2X segment.

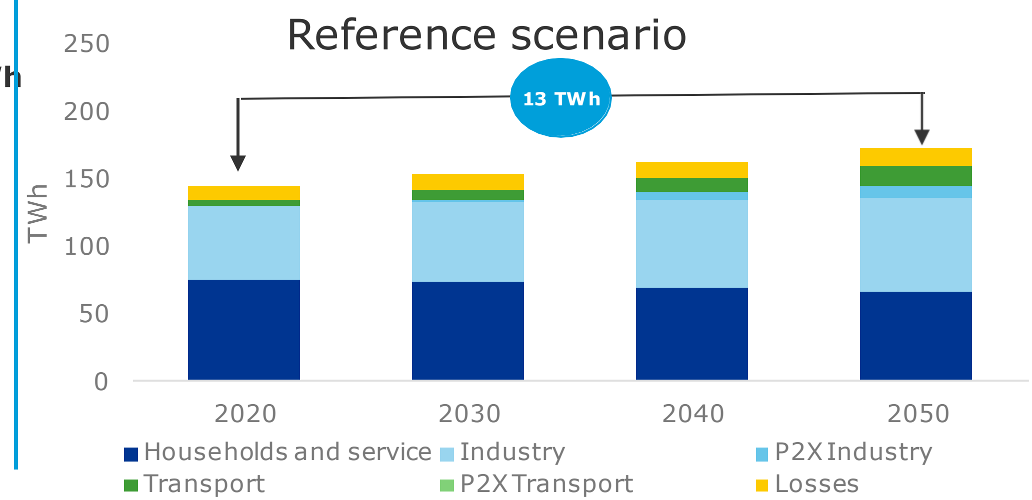
Development trajectories for electricity demand in Sweden under two scenarios





Scenario assumptions

- Sweden will meet their carbon emission targets of net zero GHG emissions by 2045.
- This scenario forecasts an increase in Sweden's electricity demand of more than 60 TWh, totalling 207 TWh in 2050.
- The main growth is from electrification of transport, reaching 26 TWh in 2050, as well as growth in existing industry, new industry (including power-to-hydrogen)



Scenario assumptions

- The reference scenario follows Norwegian Water and Energy Directorate's (NVE) Nordic electricity market forecast from 2020-2040. We have assumed the growth trajectory from 2030 to 2040 to continue to 2050.

DNV·GL

Sweden – Key sector demand outlook

Industry

- Large-scale electrification is envisaged in several industrial sectors, in some cases in connection with an expected breakthrough for new technology.
- New industries, such as datacenters and battery factories, will lead to an increase in electricity demand of up to 8 TWh in 2050.
- Electrification of high temperature processes is expected to continue replacing fossil fuel-based heating processes and increase the demand by an additional 2 TWh by 2050.
- Hydrogen will play a large role especially in the steel industry, where hydrogen-based reduction of ore is assumed through the so-called HYBRIT technology. HYBRIT is assumed in the long term to lead to an increased electricity use of 20 TWh electricity per year in 2050.

Households and service

- Efficient electrification of heating, notably through the installation of heat pumps where district heating is not an option, will result in a reduction of demand from heating application from 19 TWh in 2019 to 15 TWh in 2050.
- The demand for heat through electric applications in the service industry specifically, is expected to support growth in electricity demand towards 2050 by 5 TWh.

Transport

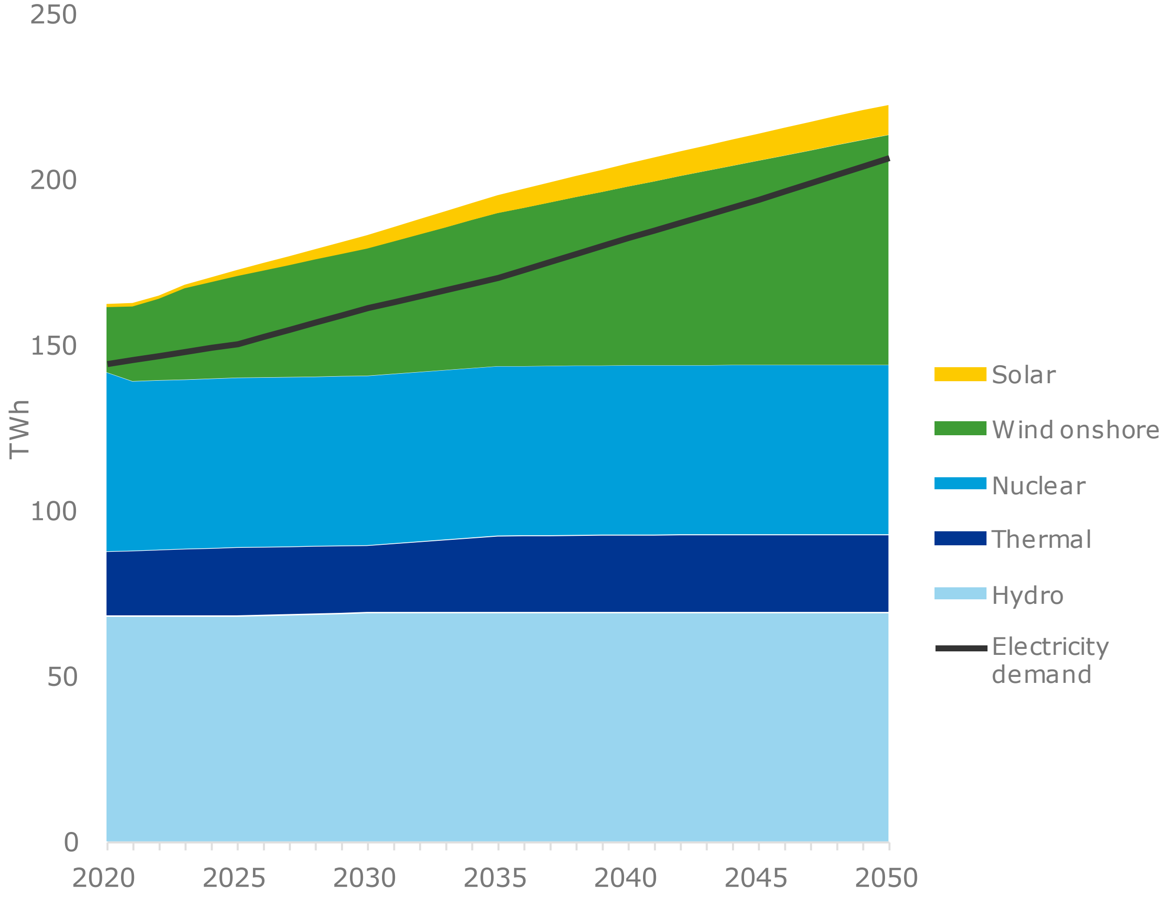
- Electrification of transport is still limited to railway and light duty vehicles (4 TWh in 2019).
- Electrification of the transport sector is expected to grown significantly (up to 4 Mn EVs in 2045) for both light- and heavy-duty vehicles with light duty having the most rapid uptake (20 % of fleet by 2030).
- The electricity demand is based on the targets referenced in the NEPP study from 2019. They estimate that the transport sector would consume electricity totalling 7 TWh in 2030 and 19 TWh in 2045.

Power-To-X

- Power-to-X capabilities in Sweden will be mostly linked to conversion of energy feedstock in established industries.
- Even though the technology offers great demand side flexibility, the uptake will be limited to sectors needing to reduce carbon emissions.
- In this scenario, Power-to-X is limited to the 20 TWh of hydrogen forecasted in the steel industry sector

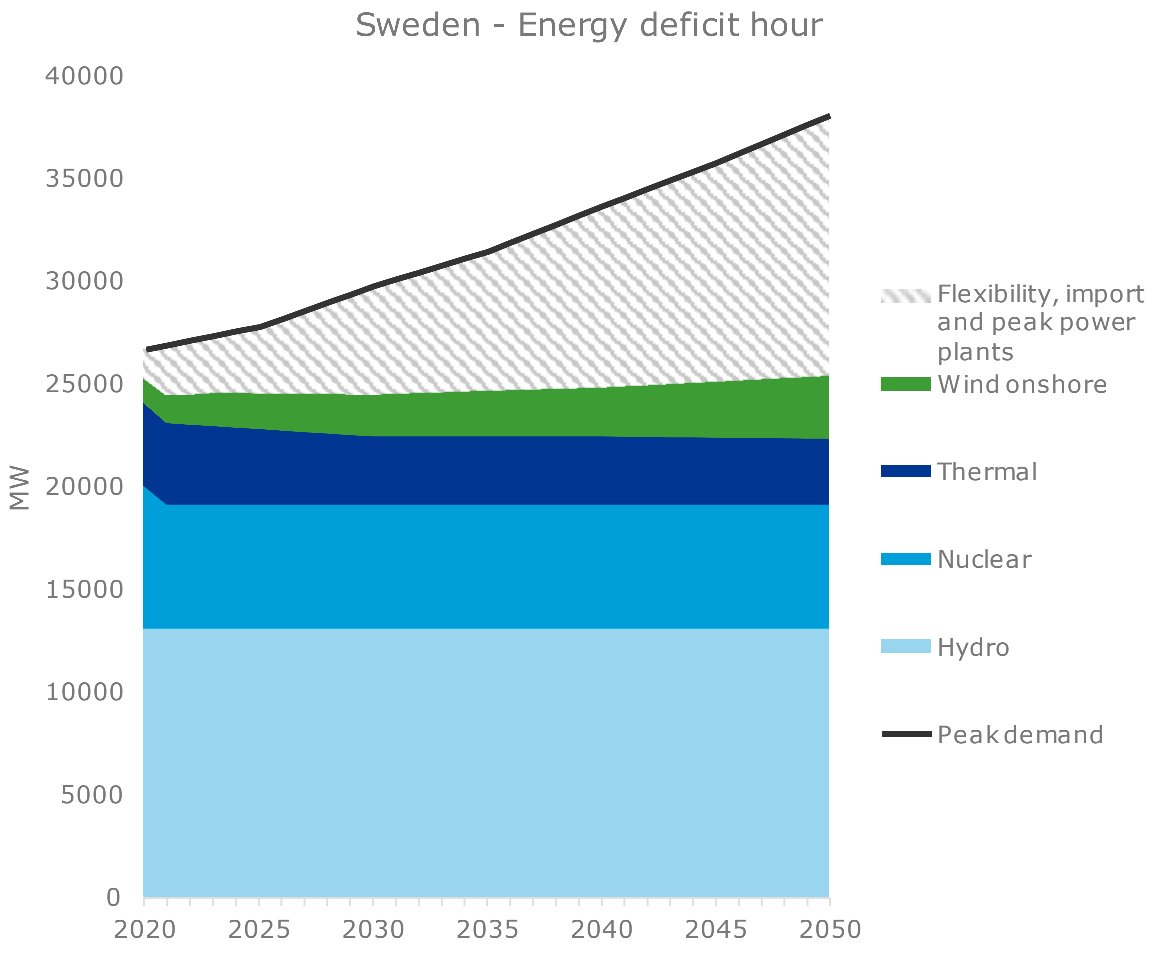
1) https://www.iea.org/reports/putting-co2-to-use

Sweden - Forecasting generation for a low carbon scenario



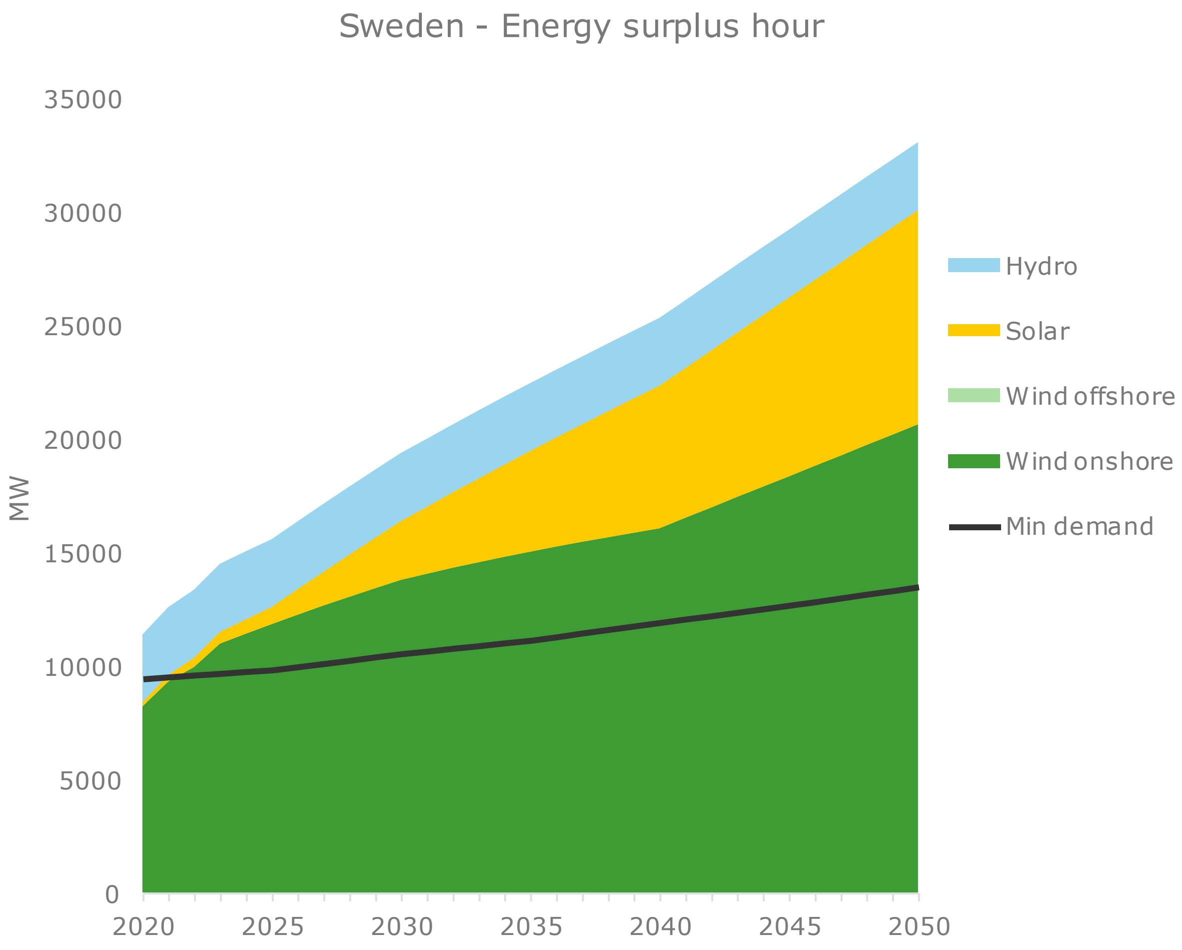
- The main uncertainty when it comes to the future Swedish electricity mix is the future of nuclear. In this scenario, installed nuclear capacity is expected to remain at 2021-level towards the end of the analysis timeframe
- In this scenario there will be a significant growth in onshore wind power in line with the demand increase. We expect wind power generation to increase from 20 TWh in 2020 to 70 TWh in 2050, growing to become the main source of electricity in Sweden, sligthly higher than hydropower.
- Solar power will increase to 9 TWh.
- Hydropower and thermal generation will remain fairly constant.

Sweden – System adequacy assessment – Energy deficit hour



- In Sweden, the generation scenario keeping most of the nuclear capacity improves system adequacy compared to a scenario where this is replaced by more wind power.
- The figure illustrates the scenario development towards 2050 of an ”energy deficit” hour in Sweden, where electricity demand is high and renewable generation is low.
- With the assumptions described in slide 14, Sweden will be increasingly reliant on import and various flexibility solutions to balance supply and demand in energy deficit hours. Demand side response (mainly load shifting from energy deficit hours to energy surplus hours) based on price signals can provide flexibility, as well as battery energy storage systems (both stationary batteries en electric vehicle batteries).

Sweden – System adequacy assessment – Energy surplus hour



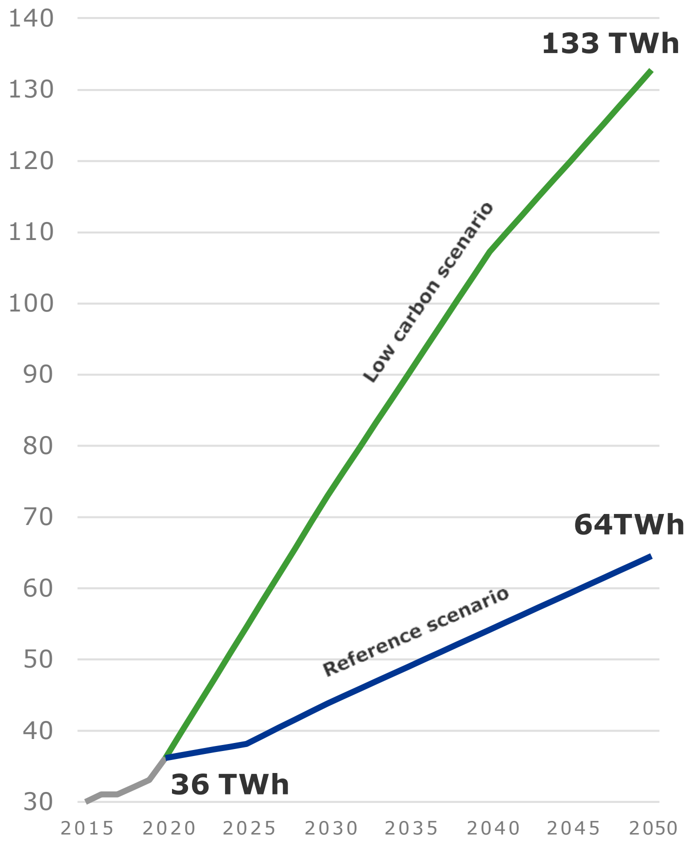
- The figure illustrates the scenario development of an energy surplus hour in Sweden, where solar and wind power is generating at maximum capacity while electricty demand is at a minimum level.
- As installed wind and solar capacity increases, the risk of curtailment increases.
- Demand side flexibility and battery energy storage systems will be important to absorb surplus electricity that is not exported.
- Flexible demand activated when there is surplus generation and prices are low will help balance the system and increase the capture price for wind power. Power-to-x is not a separate category in the Swedish demand scenario, as this (such as hydrogen production) is included in the transport or industry demand.

Electricity demand to triple in Denmark towards 2050

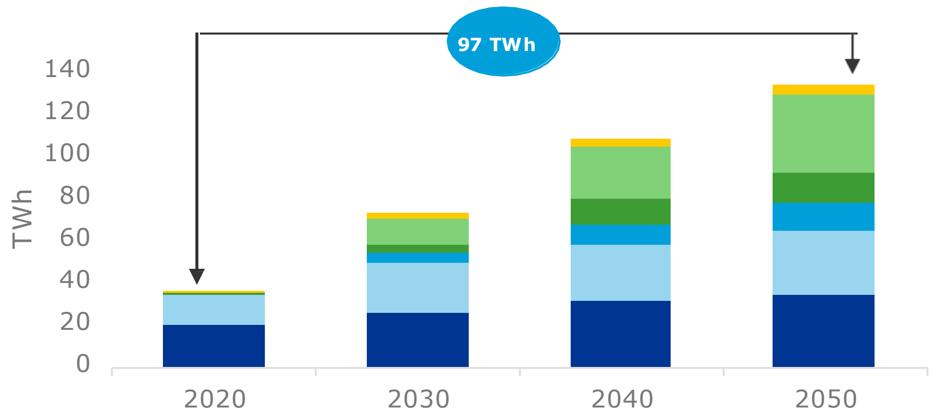
A low carbon pathway can increase demand by 76TWh towards 2050

Denmark is set to register surging growth in electricity demand in a low carbon scenario relative to current levels. Power to x application will drive this growth, facilitating an anticipated surge in wind generation growth in the market, but also buoyed by electrification of heating, industry and transport.

Development trajectories for electricity demand in Denmark under two scenarios



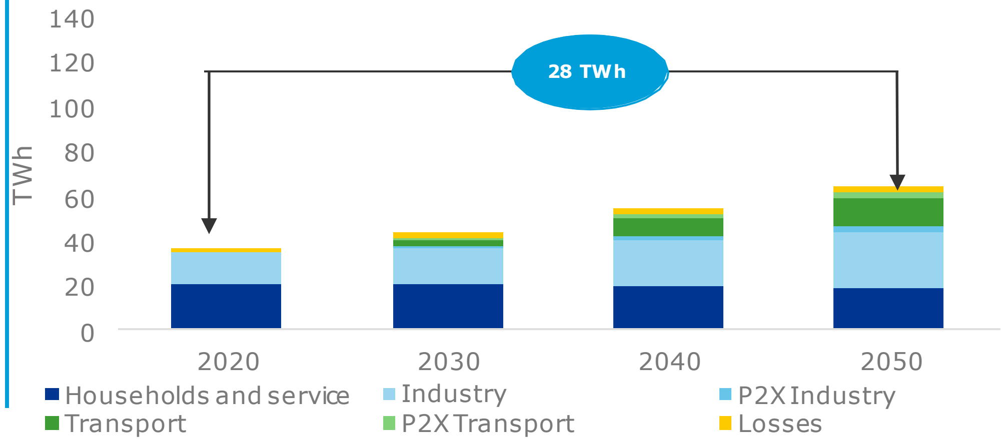
Low carbon scenario



Scenario assumptions

- Denmark will meet their carbon emission targets of 70% GHG emission reduction by 2030.
- In the low carbon scenario for Denmark, electricity demand is more than tripled, from 36 TWh in 2020 to 133 TWh in 2050.
- The main increase is from industry and transport, where power-to-x adds up 50 TWh of additional electricity demand in these sectors. Direct electrification of transport and industry will also contribute to the large increase, as well as electrification of heating

Reference scenario



Scenario assumptions

- The reference scenario follows Norwegian Water and Energy Directorate's (NVE) Nordic electricity market forecast from 2020-2040. We have assumed the growth trajectory from 2030 to 2040 to continue to 2050.

Denmark – Key sector demand outlook

Industry

- Denmark foresees a large demand increase from industry, increasing from current demand of 13 TWh to 30 TWh in 2050.
- Attractive new industries such as datacenters, and energy conversion in existing industry will contribute to a demand increase of respectively 9 and 11 TWh by 2050.
- The uptake of heat-pumps for high temperature applications, i.e. up to 300 Celsius, is expected to grow exponentially towards 2050 (totaling 3 TWh in 2050).

Households and service

- Traditional electricity demand will remain stagnant in line with smarter electricity management and muted population growth.
- District heating will continue to play an important role in the heating sector. However, heat pumps will continue to gain market share.
- Net impact of uptake of electricity-based solutions in the heating sector, especially heat pumps, is forecasted to grow with 9 TWh by 2050.
- The main driver of demand growth from heating is that Denmark currently largely uses feedstock for district heating, meaning that heat pumps will represent net demand growth (in contrast to other Nordic markets where their efficiency lead to a reduction in electricity demand relative to direct electric heating).

Transport

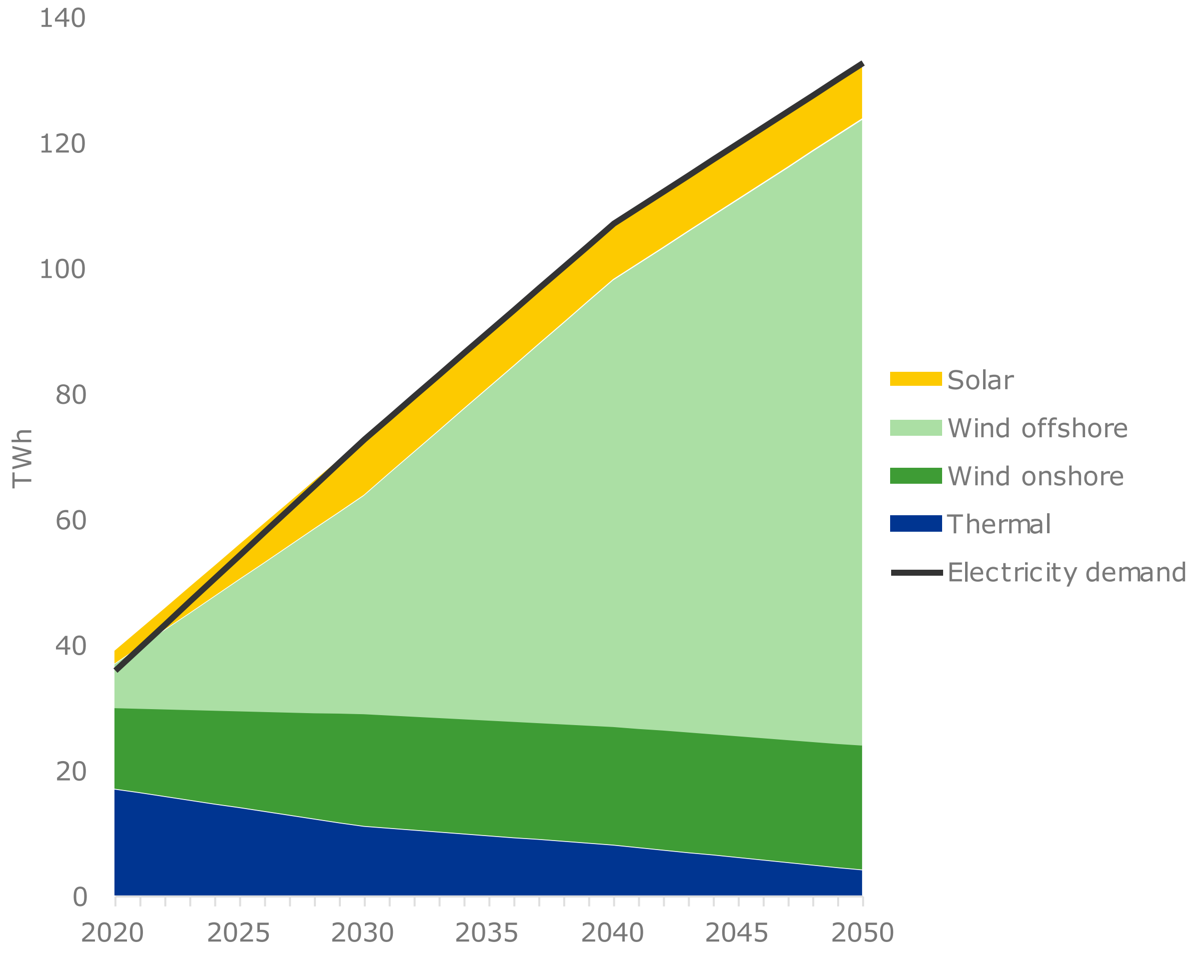
- Electrification of transport is at present limited in Denmark (0.1 TWh in 2019).
- Electrification of transport within the light duty vehicle segment is assumed to grow significantly and be fully electrified by 2045 (14 TWh).
- The rest of the transport sector is expected to use bio- and synthetic fuels.

Power-To-X

- In this scenario, a large potential for P2X in Denmark of 50 TWh is forecasted.
- We foresee a large uptake to facilitate the transition towards fully decarbonized electricity production and reduction of emission in hard to abate sectors.
- The surge anticipated in wind generation in Denmark over the coming decade further cements the importance of P2X to absorb power supply surpluses.
- Further we expect targeted policy incentives to overcome the challenges associated with high investment and storage costs.

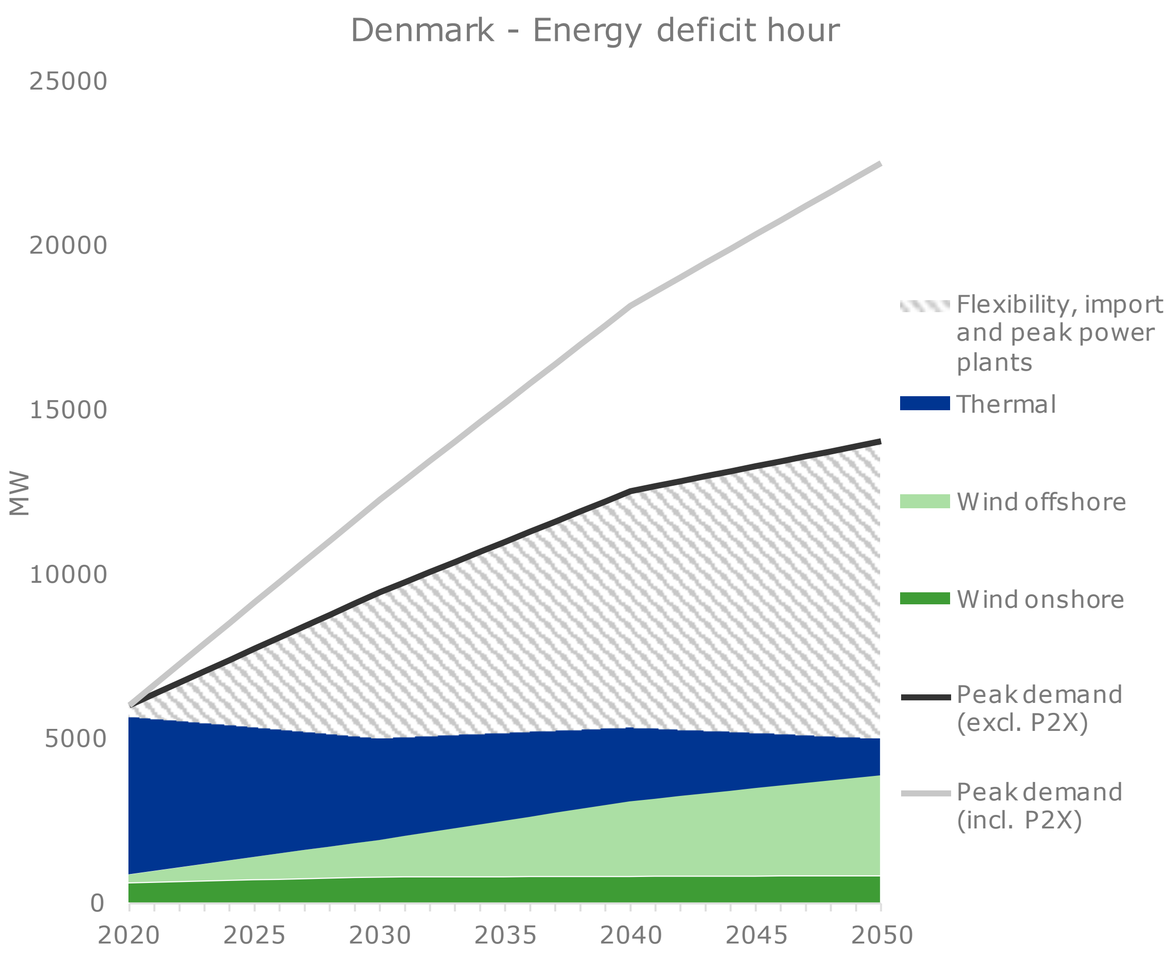
1) https://www.iea.org/reports/putting-co2-to-use

Denmark - Forecasting generation for a low carbon scenario



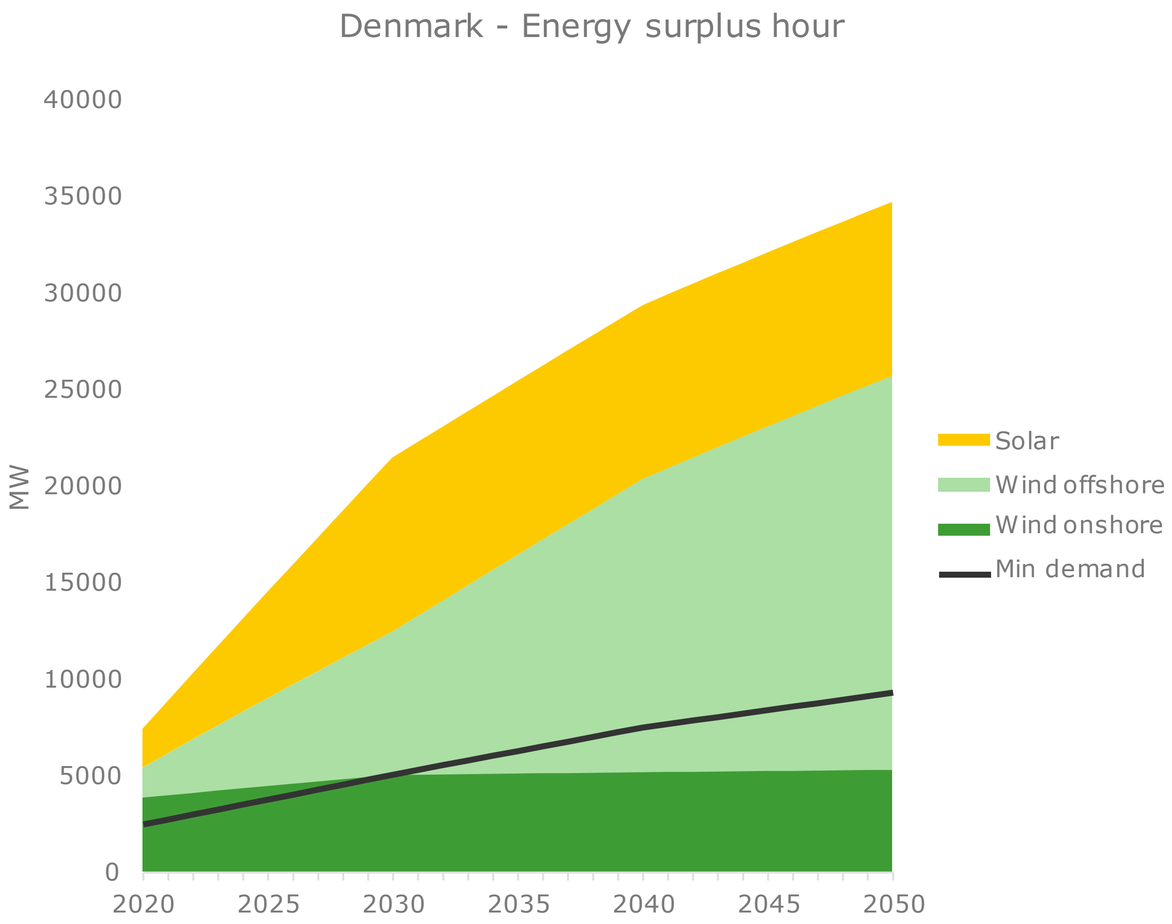
- In order to follow the massive increase in electricity demand in Denmark, a rapid increase in new renewable power generation capacity well beyond current levels is necessary.
- Wind power will make up more than 90% of electricity generation in Denmark by 2050, and is projected to increase from approximately 20 TWh today to 120 TWh in 2050. The major part of wind generation in 2050 (approximately 80%) will be from offshore wind.
- Installed solar PV capacity is already growing rapidly in Denmark, but the development will slow down in favor of southern European countries. 9 TWh solar power generation is expected in 2050.
- The large share of variable renewable generation will create a large demand for transmission capacity, flexibility and energy storage.
- Within thermal generation, coal and lignite will be phased out in the 2020s, and natural gas in the 2030s, and biomass generation will also be slightly reduced.

Denmark – System adequacy asessment – Energy deficit hour



- The massive growth in demand in the low carbon scenario for Denmark, combined with the large share of variable renewable generation, can lead to substantial system adequacy challenges.
- With the assumptions of wind power availability of only 15% in a deficit hour, Denmark will not have enough available generation capacity to serve domestic peak demand, even from today. Denmark will be increasingly reliant on import and various flexibility solutions to maintain electricity balance.
- We assume the P2X sector to be flexible and consume less during deficit hours.
- The gap between peak demand and available capacity can be filled with import, battery discharge, additional demand side flexibility such as flexible heating and industrial demand shedding.
- Electric vehicles can play and important role in the Danish power system as the number of cars and charging infrastructure increases. EVs can contribute both through vehicle-to-grid services and by flexible charging, where charging is shifted from peak load hours to surpus hours with low electricity price.
- With the large variations in wind power output a significant growth within various energy storage solutions is forecasted in Denmark.

Denmark – System adequacy asessment – Energy surplus hour



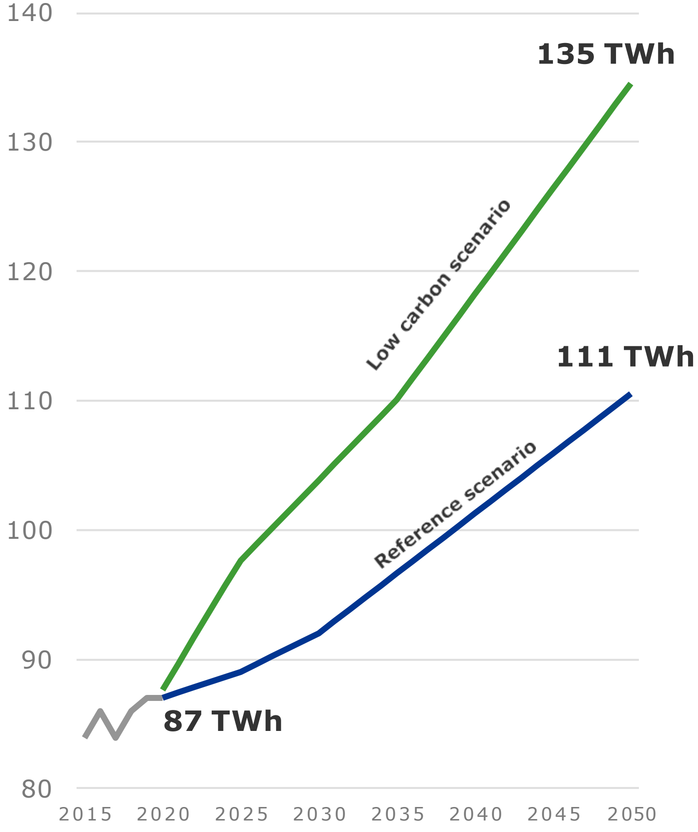
- In contrast to the deficit hour in the previous slide, the domination of wind power in the Danish electricity mix can lead to large electricity surplus when wind and sun is high and electricity consumption is low. The potential development of an extreme surplus hour is shown in the figure. It shows that solar and wind generation can surpass the electricity demand in low load hours already today.
- In surplus hours Denmark is an electricity exporter, exporting cheap wind power to countries with higher power prices. However, export capacity is limited, and in hours with high wind and solar generation neighbouring countries most likely have similar weather, and the possibility to export decreases.
- In order to balance the electricity system there will be a large need for flexibility solutions. A flexible demand (power to x) activated when there is surplus renewable generation will be important to avoid curtailment. This will improve the business case for wind developers and reduce the need for subsidies.
- It is assumed that power-to-x will mainly be hydrogen production from electrolysis. The power price limit in which this will be turned on and off depends on the market for hydrogen.
- Looking at this and the previous slide it is clear that there can be a business case for flexibility solutions benfiting on power pice price volatility such as batteries.

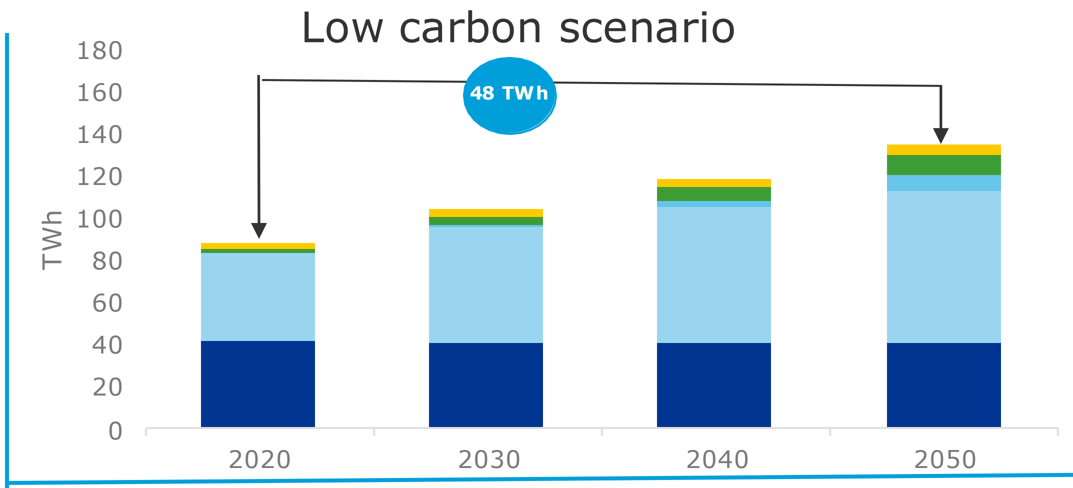
Electricity demand to register robust growth in Finland towards 2050

A low carbon pathway can increase demand by 47TWh towards 2050

Electrification of industry, both through the conversion of energy carriers in existing industry, as well as demand from new industry, will drive electricity demand growth in Finland towards 2050.

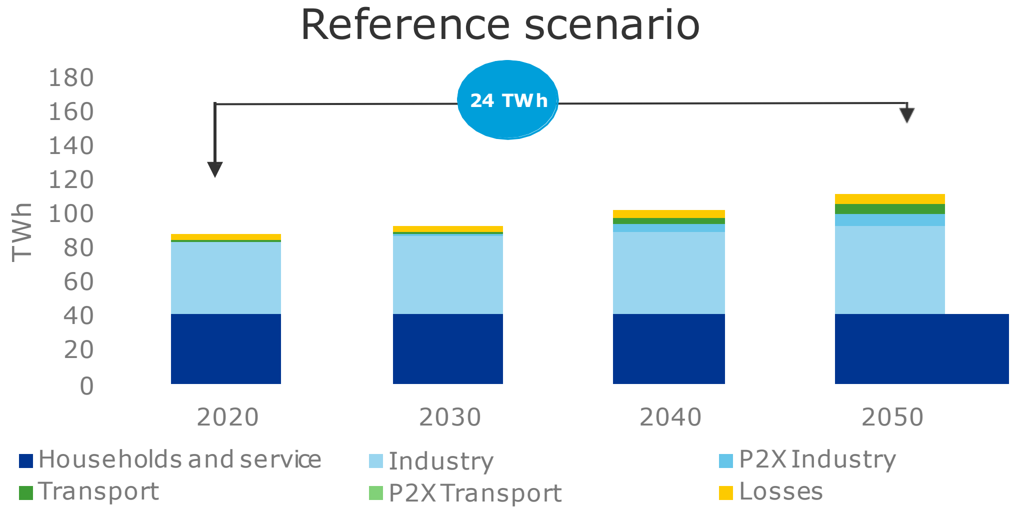
Development trajectories for electricity demand in Finland under two scenarios





Scenario assumptions

- Finland will meet its carbon emission targets for 2035, which entails carbon neutrality.
- Total electricity demand increases from 87 TWh in 2019 to 135 TWh in 2050.
- The large increase in electricity is driven by increased electrification of industry, particularly from new industries and electrification of energy feedstock used in existing industry, as well as the electrification of transport and household heating.



Scenario assumptions

- The reference scenario follows Norwegian Water and Energy Directorate's (NVE) Nordic electricity market forecast from 2020-2040. We have assumed the growth trajectory from 2030 to 2040 to continue to 2050.

Finland – Key sector demand outlook

Industry

- The industry segment contributed close to 50 % of the total electricity demand in Finland in 2019.
- Electrification of energy carriers with the aim to reduce emissions, coupled with growth in new industries, may increase industry demand by 40 TWh by 2050
- A carbon price is essential for this driving this transition and facilitating technology development, including electrification of high temperature processes.
- Replacement of coal with hydrogen as the reduction feedstock in the metal industry can stimulate electricity demand. Chemical industry and iron industry (10 and 7 TWh in 2050).

Households and service

- Households and service industry contributed to an energy demand of 41 TWh in 2018.
- Heat pumps continue gaining market share for heating in both segments and are expected to replace a majority of current oil and other fossil fuel heating together with small shares of direct electric heating and district heating.
- The net impact on electricity demand is however estimated to be marginal (2 TWh in 2050), as demand growth from heat pumps is offset by the improved efficiency compared to direct electric heating. In addition, further energy efficiency gains and climate change have negative impact on heating demand.

Transport

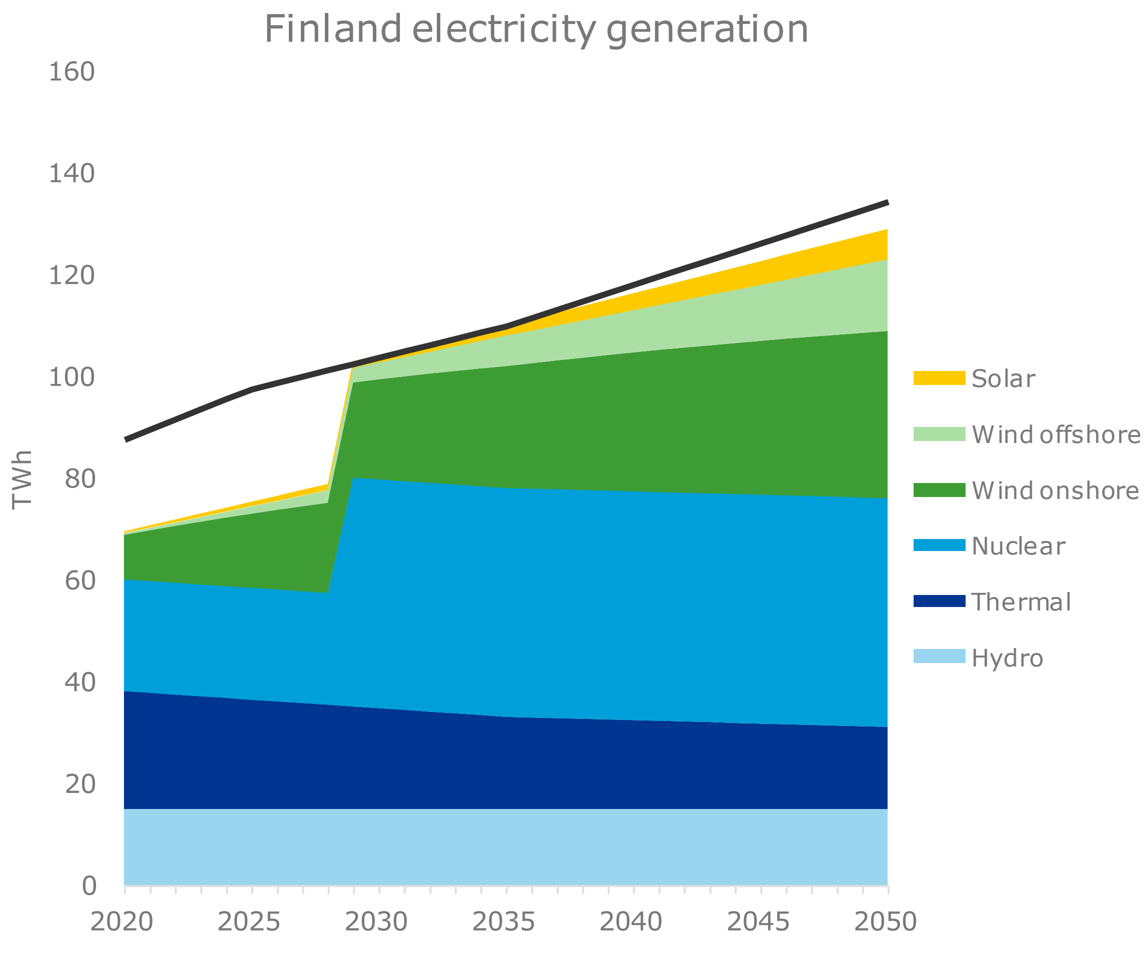
- Electrification of transport is still limited to railway (0.6 TWh in 2019) and personal vehicles (0.3 TWh in 2019).
- Electrification of the transport sector is expected to grow significantly (up to 2 Mn EVs in 2045) over the years as it offers a low-cost solution for reducing national emissions. This dynamic is also aided by the fact that's EVs will be cost competitive within 2030.
- The electricity demand is based on the targets referenced in the Action program for carbon-free transport published by the Ministry of Transport. The study estimates that transport sector would consume electricity totalling 3TWh in 2030 and 10TWh in 2045.

Power-To-X

- Even though the technology offers great demand side flexibility, the uptake of production capacity will largely be limited to what is needed to feed sectors that require hydrogen to reduce carbon emissions.
- High investment and storage costs are main barriers, which are assumed to decrease but still remain relatively high for most sectors towards 2050.

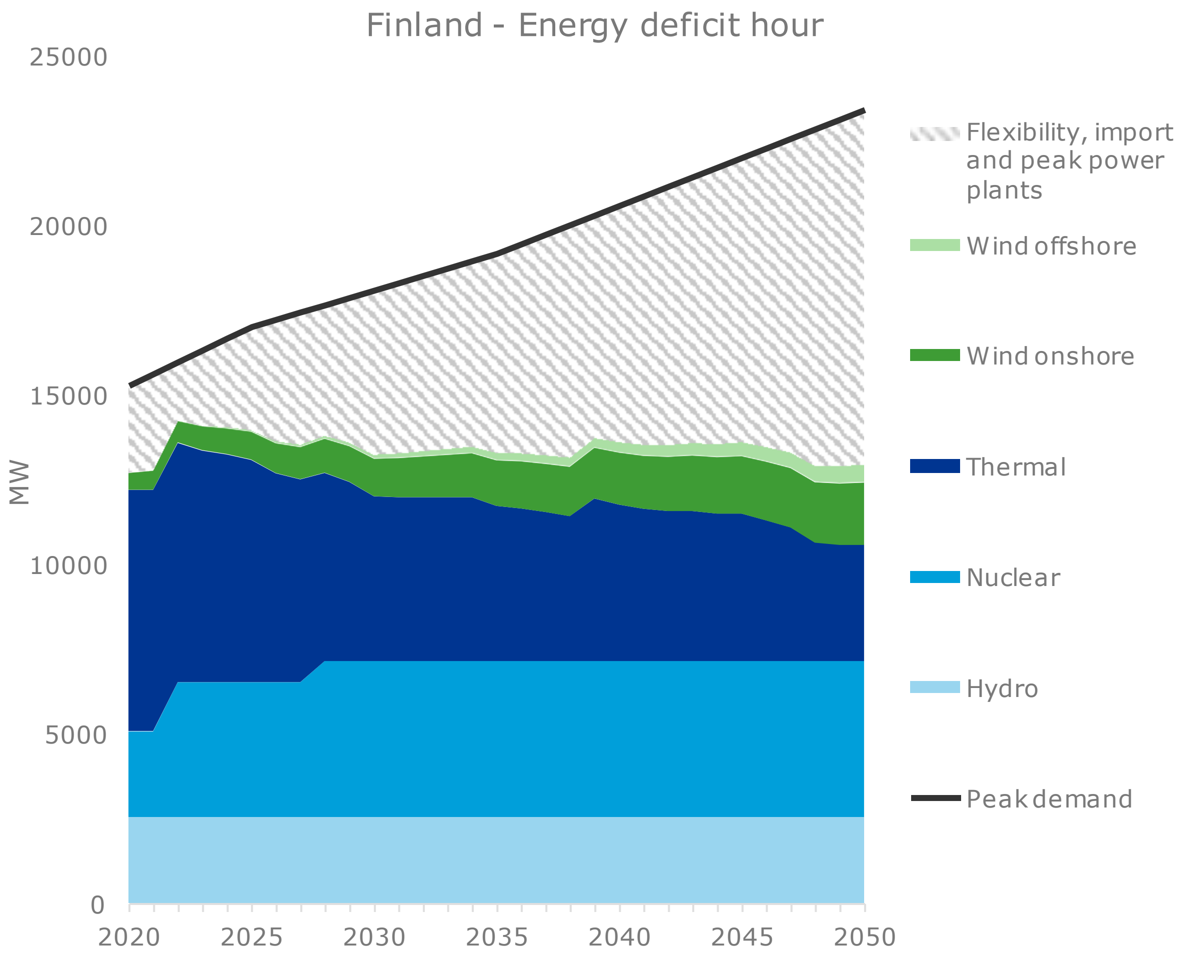
1) https://www.iea.org/reports/putting-co2-to-use

Finland - Forecasting generation for a low carbon scenario



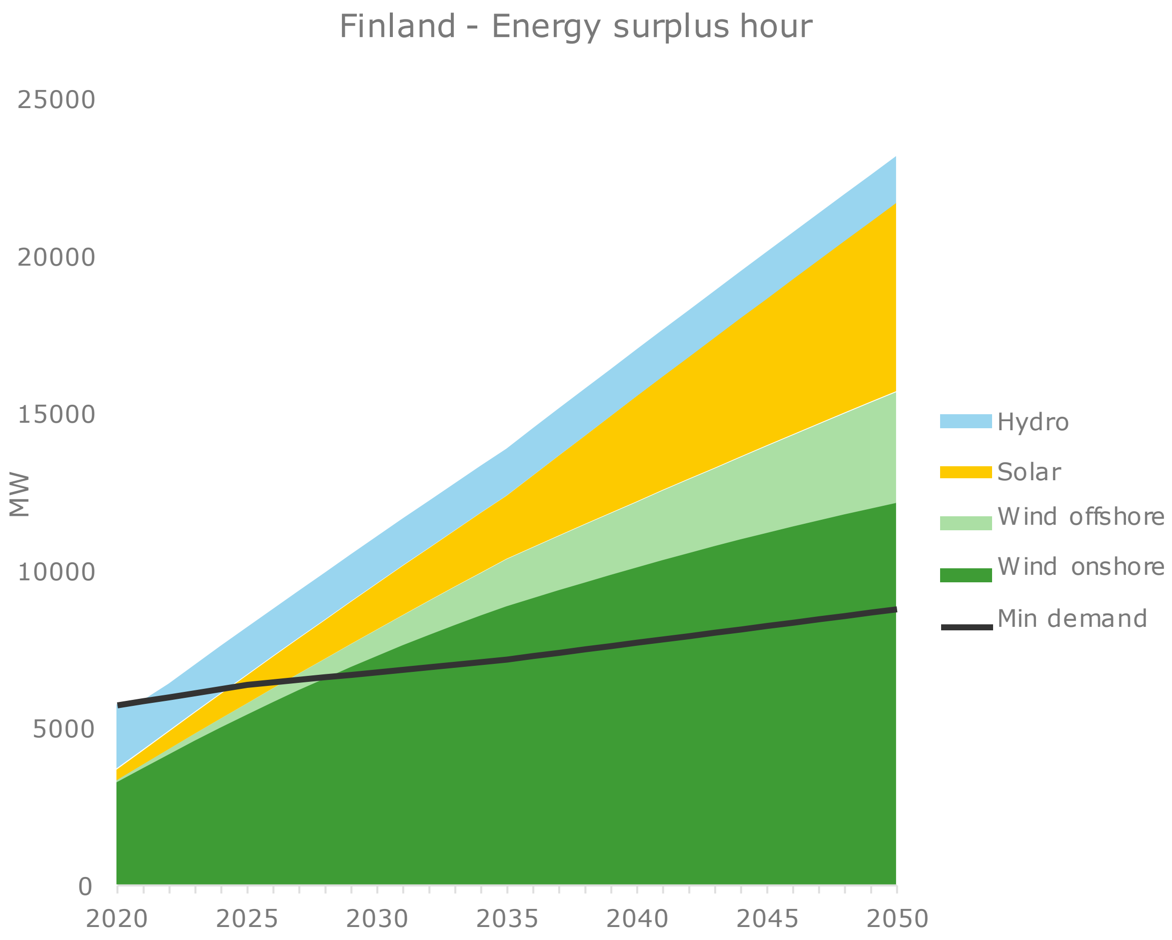
- Finland is expected see a substantial increase in electricity generation, but will still remain a net importer of electricity. In this scenario total electricity generation will increase from approximately 87TWh in 2019 to 135TWh by 2050.
- Finland currently has four nuclear power plants. Two new nuclear plants are expected to be in operation before 2030; Olkiluoto 3 (1600 MW) in 2022, and Hanhikivi 1 (1200 MW) in 2028. This will double the nuclear generation to 45 TWh. Life-extending investments will be necessary for the current plants to operate until 2050.
- Wind power is expected to increase to 47 TWh in 2050, playing a dominant role in the Finnish electricity mix. Towards 2050 the share of offshore generation will gradually increase to 30%.
- Solar power will increase to 6 TWh.
- Finland has an installed hydropower capacity of around 3 GW, which is expected to remain constant.
- Thermal generation will have a small decrease. The Finnish government is committed to phase out coal within 2030, and parts of this is expected to be replaced by biomass.

Finland – System Adequacy Assesment – Energy deficit hour



- The figure shows possible development of a deficit hour for Finland. As electricity demand increases Finland will increasingly rely on imports and flexibility solutions like demand side flexibility and battery energy storage in hours with low wind generation and high electricity demand.
- Demand side flexiblity includes flexible EV charging and electric heating, shifting consumption from deficit hours to surplus hours, and demand reduction from industial consumers when the power price reaches ceratin limits.

Finland – System Adequacy Assesment – Energy surplus hour



- Like in the other Nordic countries, there will potentially be hours with surplus electricity generation in Finland when wind and solar generation is high and electricity demand is low.
- Demand side flexibility and battery energy storage systems will be important to absorb surplus electricity that is not exported.
- Flexible demand activated when there is surplus generation and prices are low will help balance the system and increase the capture price for wind power. Power-to-x is not a separate category in the Finnish electricity demand scenario, but it is assumed that parts of the electricity demand can be shifted from deficit hours to surplus hours based on price signals.

6.2

Methodology

Sources forming the basis for the low carbon scenario analysis

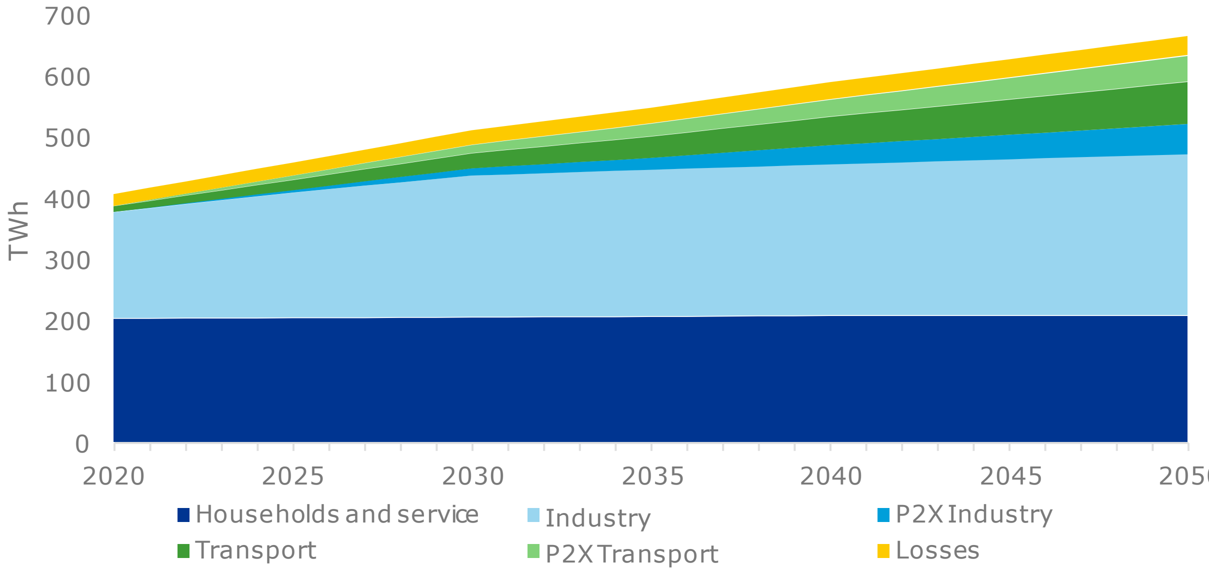
The electricity demand and production forecast in this report is built on external reports. All the national reports are in compliance with the respective country meeting their national emission targets. The reports below have been key to informing our datasets for electrification in the Nordics.

Defining Scenarios For Electricity Demand

Core Scenario – Low carbon:

- **This scenario will be aligned with the decarbonisation aspirations in place in each Nordic market**, in which electrification will play a key role in driving carbon emission reductions. **In short, the aim with this scenario is to showcase electrification as one of the most important enabler for a low-emission society.**
- This scenario is based on data sourced from external reports that are aligned with Nordic market decarbonisation aspirations – notably those listed on slide 11.

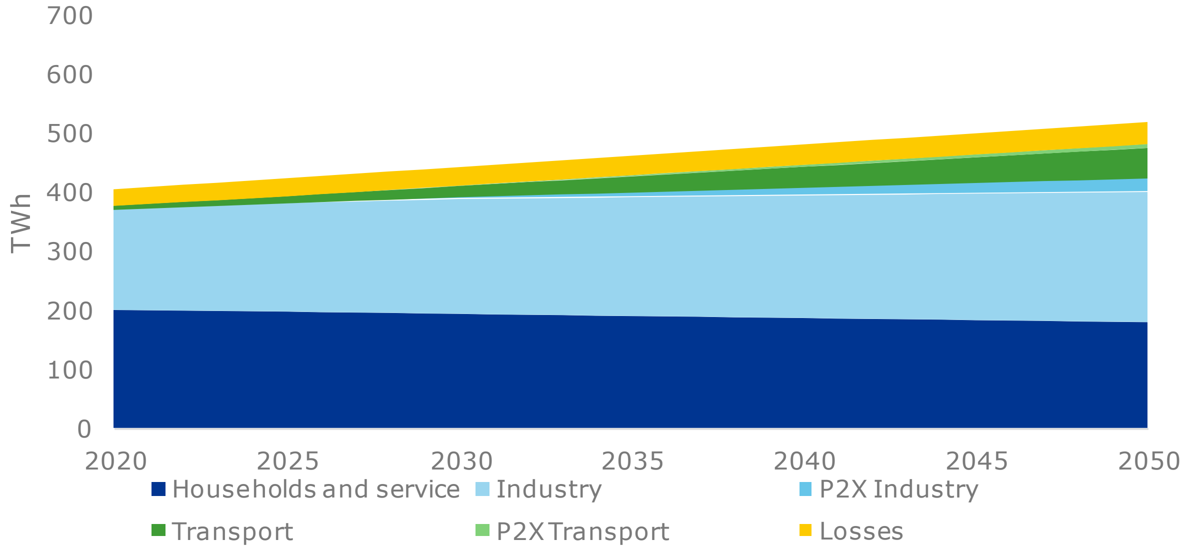
Nordics – Low carbon scenario demand, TWh



Comparison Scenario – Reference scenario

- The reference scenario follows Norwegian Water and Energy Directorate's (NVE) Nordic electricity market forecast from 2020-2040. The scenario is aligned to national studies for 2020. We have assumed the growth trajectory from 2030 to 2040 to continue to 2050.
- This scenario still includes a growth in Nordic electricity demand, but to a lower extent than the low carbon scenario.
- **This scenario will act as a comparison to our main low carbon scenario.**

Nordics – Reference scenario demand, TWh



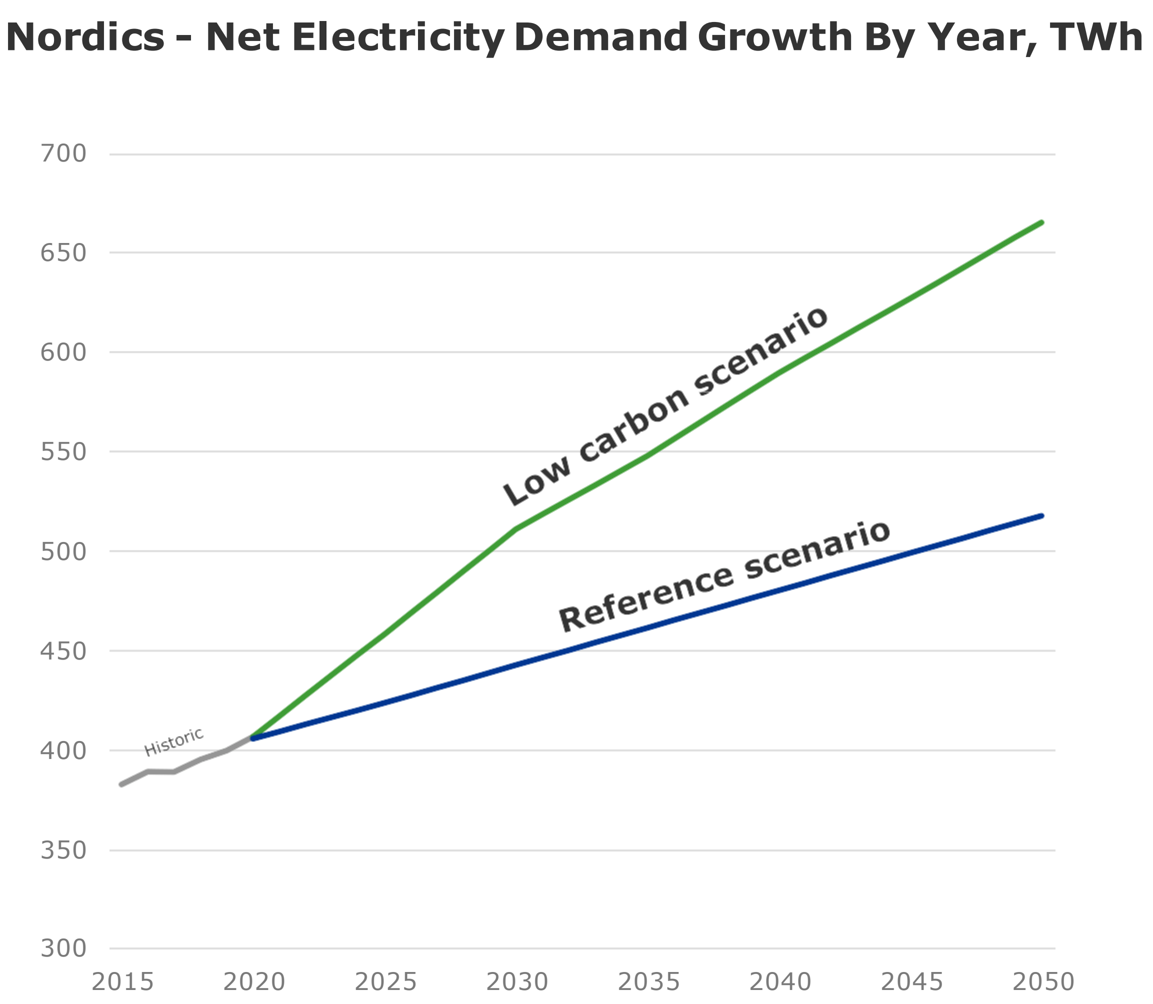
Key parameters in the low carbon scenario

The low carbon scenario dataset is derived from decarbonisation and electrification roadmaps for Norway, Sweden, Denmark and Finland. These have culminated in a country-level outlook for electrification by sector, which in turn feeds into our regional power demand outlook.

Notably, this scenario will be driven by high levels of electrification penetration across sectors – culminating in power demand trajectories to which we will develop corresponding power generation scenarios.

Below we outline some of the parameter prerequisites in our low carbon scenario:

- All the Nordic countries will meet their individual climate goals and ambitions:
  - **EU:** 40 % reduction by 2030
  - **Norway**: net zero emission by 2050
  - **Sweden**: zero net greenhouse gas emission 2045
  - **Denmark**: Reducing carbon emissions by 70% by 2030
  - **Finland**: carbon neutrality by 2035, carbon negative soon after 2035.



Gudmund Bartnes
Gudmund.Bartnes@dnv.com
+47 997 44 267

www.dnvgl.com

SAFER, SMARTER, GREENER