Nordic Energy Research

TRACKING NORDIC CLEAN ENERGY PROGRESS

The crucial decade for climate action

The Nordic countries have a common vision of becoming the most integrated and sustainable region in the world. Achieving carbon neutrality is a critical lever for this vision, with the transition of the energy system playing a key role in the pathway forward.

This report, **Tracking Nordic Clean Energy Progress 2025**, highlights key achievements, such as the increased adoption of renewable energy and advances in electrification, while also identifying areas where further efforts are needed.

A unique feature of this report is its consolidation of the most recent and comprehensive Nordic energy statistics into a single resource. By providing updated data on emissions, energy consumption, and the transition to renewable energies, it serves as a reference tool for policymakers, researchers, and stakeholders working towards a sustainable energy future.

As we navigate this crucial decade for climate action, the findings in this report offer valuable insights into the Nordic region's progress and the challenges ahead – supporting informed decision-making and fostering continued collaboration towards shared climate goals.

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CEO, Nordic Energy Research

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About this publication

The Nordic countries have some of the most ambitious energy and climate policies in the world.

In 2019, Denmark, Finland, Iceland, Norway, and Sweden signed a joint Declaration on Nordic Carbon Neutrality, committing to make the Nordic countries carbon neutral, in line with the COP21 Paris Climate Agreement. To support this commitment, Nordic Energy Research commissioned the Nordic Clean Energy Scenarios study. The aim of the study was to identify and help prioritise, through scenario modelling, which necessary actions to pursue before 2030 and to map potential long-term pathways to carbon neutrality.

This report tracks the overall level of emission reductions in Denmark, Finland, Iceland, Norway, and Sweden and the drivers required to achieve a carbon-neutral Nordic energy system. The report evaluates progress towards Nordic carbon neutrality and compares their progress.

- Power Sector
- Flexible Energy System
- Carbon Accounting
- Road Transport
- Grid infrastructure
- Nordic Progress
- Heat Sector
- Energy Storage
- Industry & Power-to-X
- Heavy Transport

Glossary

CCS	Carbon Capture and Storage
CO_2	Carbon dioxide
COP21	United Nation's 21st Climate Change Conference in Paris in 2015.
COP28	United Nation's 28th Climate Change Conference in Dubai in 2023.
DH	District Heating
ESG	Environmental, Social, and Governance
EV/BEV/PHEV	Electric vehicle/battery electric vehicle/plug-in hybrid electric vehicle
GHG	Greenhouse gas: CO2, CH4, N2O, and fluorinated-gases (F-gases)
H_2	Hydrogen
IEA	The International Energy Agency
LULUCF	Land Use, Land-Use Change and Forestry
NCES	Nordic Clean Energy Scenarios
PtX	Power-to-X
RD&D	Research, Development and Demonstration
RE/RES/VRES	Renewable Energy/Renewable Energy Sources
VRES	Variable renewable energy sources such as wind and solar

Glossary

$MtCO_2$/$MtCO_2e$	Megaton of carbon dioxide (CO_2) / Megaton CO_2 equivalent used to compare different GHGs.
MW/GW/TW	Megawatt/Gigawatt/Terawatt
MWh/TWh	Megawatt-hour/Terawatt-hour
PJ	Peta Joule
TJ	Tera Joule

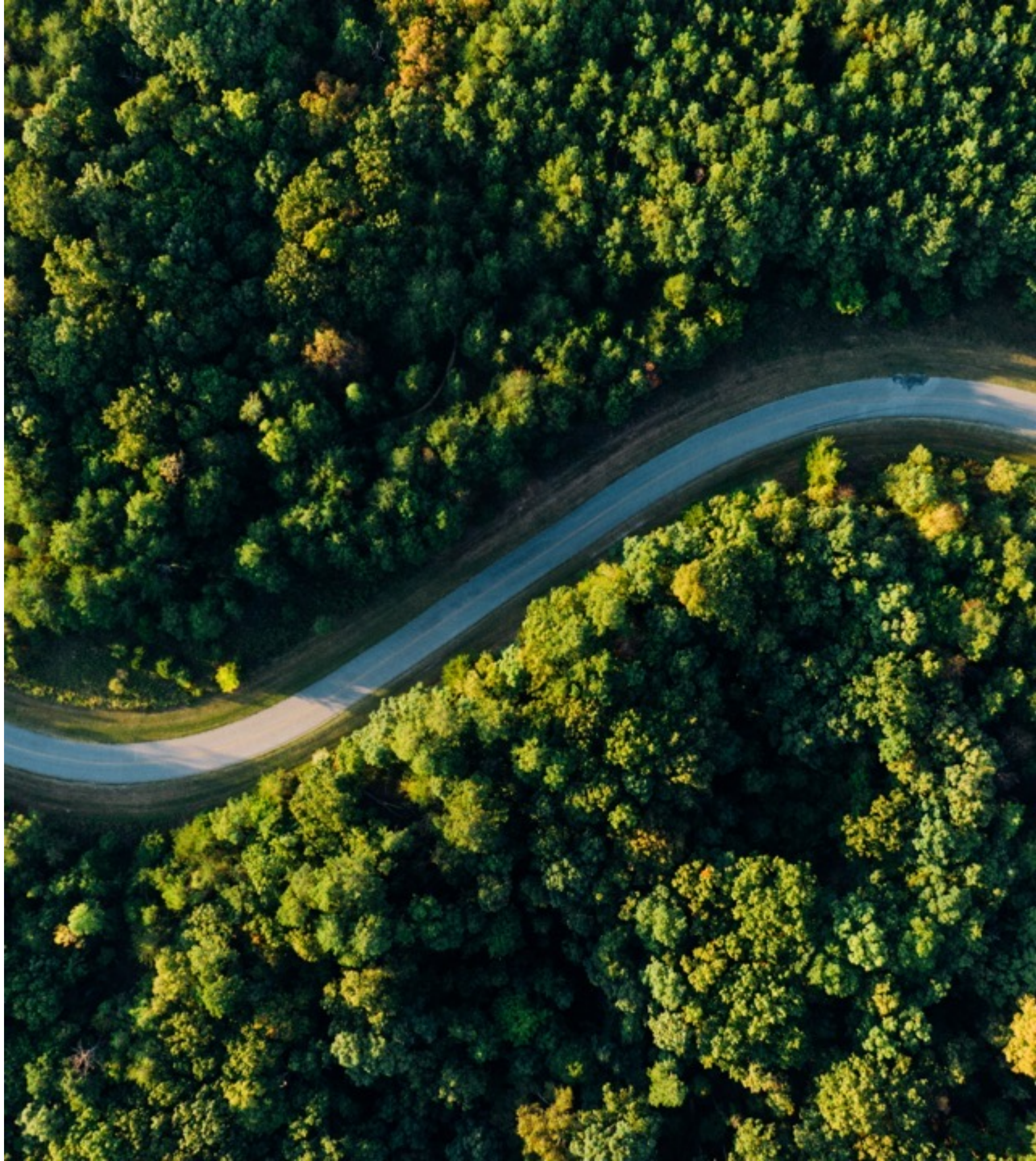
01

Introduction

Key takeaways from the Nordic Clean Energy Scenarios

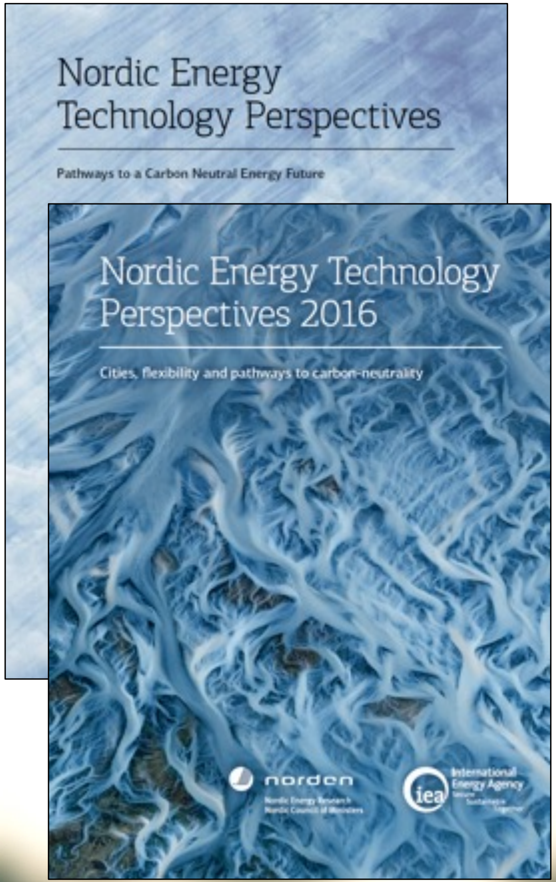
Progress at a glance

This report tracks emission reductions and key drivers for achieving a carbon-neutral Nordic energy system, assessing progress across Denmark, Finland, Iceland, Norway, and Sweden. It builds on the 2021 Nordic Clean Energy Scenarios study, which outlined four potential pathways to carbon neutrality and provided guidance on priority actions. Since 2021, the energy landscape has evolved significantly, underscoring the need to revisit the study's insights. In this context, we highlight five key takeaways that remain central to the Nordic energy transition:



Five key takeaways from the 2021 Nordic Clean Energy Scenarios study

1. Direct electrification is at the core of all decarbonisation strategies.
2. The Nordic region holds significant potential for producing Power-to-X (PtX) for export, as well as for driving industrial growth within the region.
3. To achieve net-zero emissions, technologies and strategies enabling negative emissions will be essential.
4. Our view on biomass has changed: we recognise that biomass is a finite resource and should be reserved for high-impact applications that Maximise value in the green transition, such as synthetic fuels for hard-to-abate sectors.
5. Nordic collaboration is crucial for the energy transition, and through green energy exports, the Nordic countries can accelerate the broader European green transition.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Pathways to a Carbon Neutral Energy Future
Nordic Energy Technology
Perspectives 2016
Cities, flexibility and pathways to carbon-neutrality
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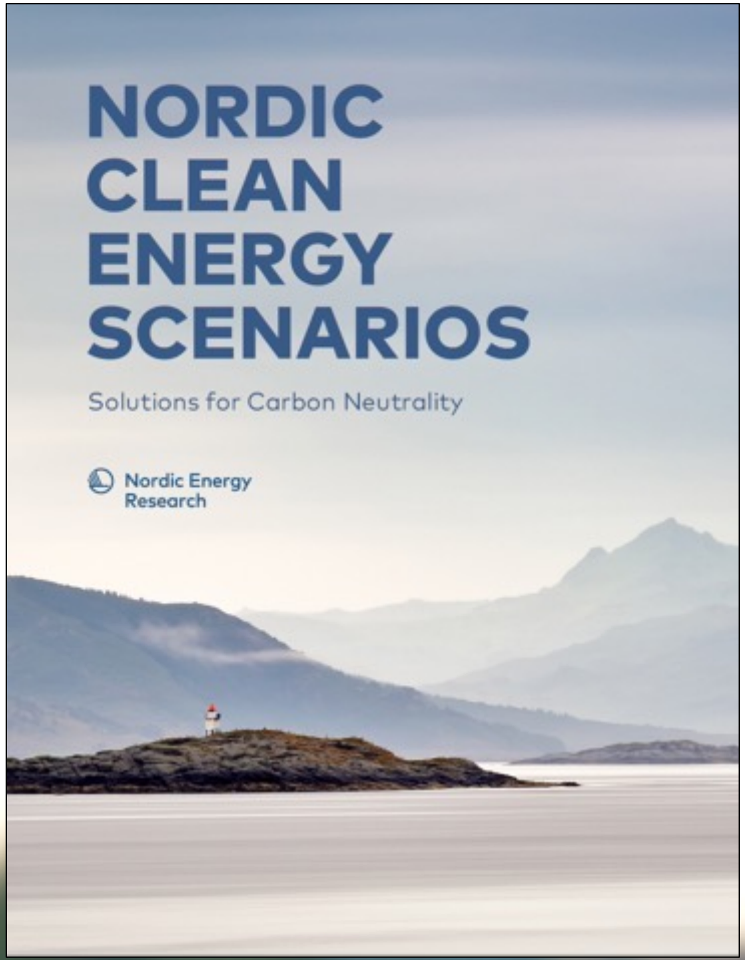
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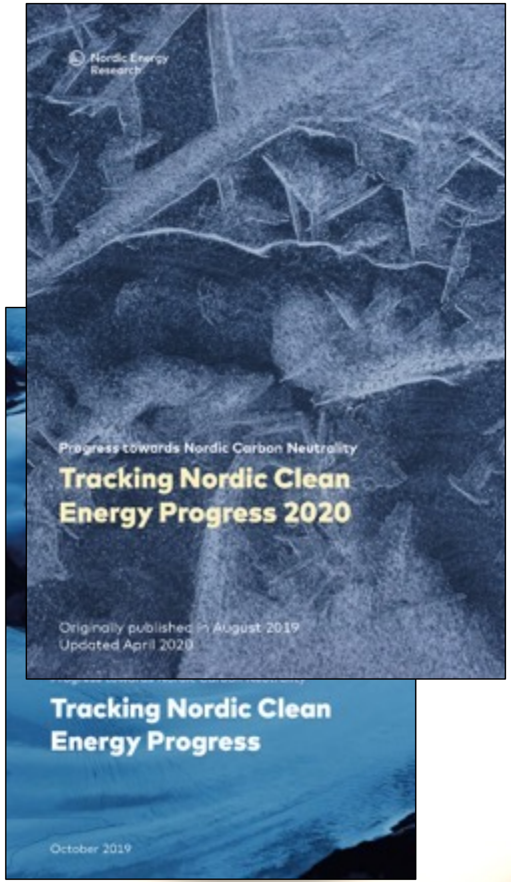

Progress towards Nordic Carbon Neutrality
Tracking Nordic Clean
Energy Progress 2020
Originally published in August 2019
Updated April 2020
Tracking Nordic Clean
Energy Progress
October 2019

Learnings from the past three years

1. There is no conflict between energy security and the green transition—on the contrary, the green transition strengthens energy security.

2. Energy security is not only about the volume of imported fuels; it also depends on resilient value chains for technologies vital to the green transition.

3. Strengthening system flexibility through measures like demand response and energy storage is a key opportunity to accelerate the green transition and increase resilience and energy security at the same time.

4. We must accelerate the pace of the transition to meet our climate goals.

Are we on track?

- Not on track - Insufficient steps
- Greater effort is required but critical steps are being addressed
- On track - Sufficiently promising efforts and impact

The colours red, yellow, and green indicate progress achieved today towards reaching Nordic carbon neutrality in 2050. Three different perspectives are considered in the estimation of progress:

Measurable and timely progress – Is a measurable progress towards the target of the driver in question visible in statistical data? Is the gap between the present situation and the target for 2050 decreasing annually with a speed that suggests that the Nordics will be able to achieve the target in time?

Technical solutions – Do the key technical solutions exist? If the key technical solutions exist then what remains is to a higher degree within our control, namely improving efficiency, organisation, and pricing/market. If key technical solutions have not yet been developed and demonstrated full-scale, then there is a higher risk of not achieving the necessary in due time.

Mix of initiatives – Initiatives critical for the transformation vary depending on the maturity and type of the critical elements for each driver. They may span from legislation such as minimum energy performance standards to RD&D, from market pricing to data services etc. A mix of strong initiatives activating a variety of stakeholders and change agents is expected to lend greater momentum to the green transition.

Power Sector

Emissions from the power sector are decreasing at a good pace, even with rising electricity consumption. Additionally, electricity generation is becoming increasingly renewable.

Flexible Energy System

The response following the Ukraine war has shown our resilience, but actions are still needed. Negative power prices highlight the challenges in integrating wind and solar energy.

Carbon Accounting

Nordic forest carbon sinks have decreased since 2010, offsetting other emissions reductions.

Road Transport

There has been significant progress in the road transport sector, with a notable increase in EVs for both cars and vans.

Grid infrastructure

There is no aligned strategy for H2/PtX, and the recommendations from the NCES report have not be followed yet.. While electricity exchange has been successful, there are future concerns.

Nordic Progress

Overall, the rate at which CO2 is decreasing is promising. However, non-CO2 emissions are lagging, and emissions from LULUCF are moving in the wrong direction.

Heat Sector

Direct electrification is key to decarbonising the heat sector, with the residential sector shifting from fossil fuels to district heating and clean electricity.

Energy Storage

The Nordic countries efficiently use large hydro reservoirs for energy storage, but to meet future demands for flexiblity, they need significant investments in batteries and hydrogen-based fuels.

Industry & Power-to-X

The sector struggles with decarbonisation, requiring significant updates to industrial processes and a shift to less carbon-intensive solutions, hindered by the cancellation of many big green investments and PtX projects.

Heavy Transport

There is promising development in green technology for trucks. However, air travel continues to grow, leading to an increase in emissions.

02

Nordic Progress at a Glance

Transformation towards a sustainable future

Many sectors lag behind

The Nordic countries have reduced CO_2 emissions from fossil fuels and industry by 30% since 1990. In that sense, we are on track.

The overall GHG emissions decreased between 1990 and 2010. However, since then, the increasing LULUCF emissions have to some degree countered the reductions in CO_2 emissions from fossil fuels and industry, leading to a diversion from our track.

Finland, Iceland and Norway have set earlier target years for climate neutrality and/or emission reductions and need further initiatives to achieve their respective targets in time.

Denmark and Sweden have chosen later target years (2050 and 2045 respectively) for their climate neutrality and emission reductions and are on track to reach them..

Targets for Nordic Climate Neutrality

In 2019, the Nordic countries signed a joint Declaration on Carbon Neutrality, committing to making the Nordic countries carbon neutral, in line with the COP21 Paris Climate Agreement. All Nordic countries are aiming for climate neutrality with different target years and varying additional overall targets.

Targets for Nordic Climate Neutrality

Table 02.1: Nordic climate targets

Country	Target year for climate neutrality	LULUCF* included	Carbon credits allowed	Emission reduction targets on the way to climate neutrality	Based on
Denmark	2050	Yes	No	GHG –70% by 2030	KEFM
Finland	2035	Yes	No	GHG excl. LULUCF –60% by 2030, -80% by 2040, -90% by 2050	YM
Iceland	2040	Yes	No	GHG excl. LULUCF –40% by 2030	Government IS
Norway	2050	Yes	Yes	GHG excl. LULUCF - 55% by 2030	Regjeringen
Sweden	2045	Yes**	No**	GHG excl. LULUCF –85% by 2045	Krisinformation

* LULUCF: Land Use, Land Use Change, and Forestry.
** Sweden's forest carbon sinks are very large, and their negative emissions re calculated only partially in the overall target. Sweden's climate goals technically allow credits, but LULUCF sinks should be enough to provide the remaining 15% of the GHG reductions.

Total emission reductions not on track

Nordic CO2 emissions from fossil fuels and industry are decreasing with at pace modelled in the NCES project.

However, the total GHG emissions have decreased more slowly between 2010-2020 than between 2000-2010 due to reduced forest carbon sinks, and are currently not on the trajectory to reach the national targets.

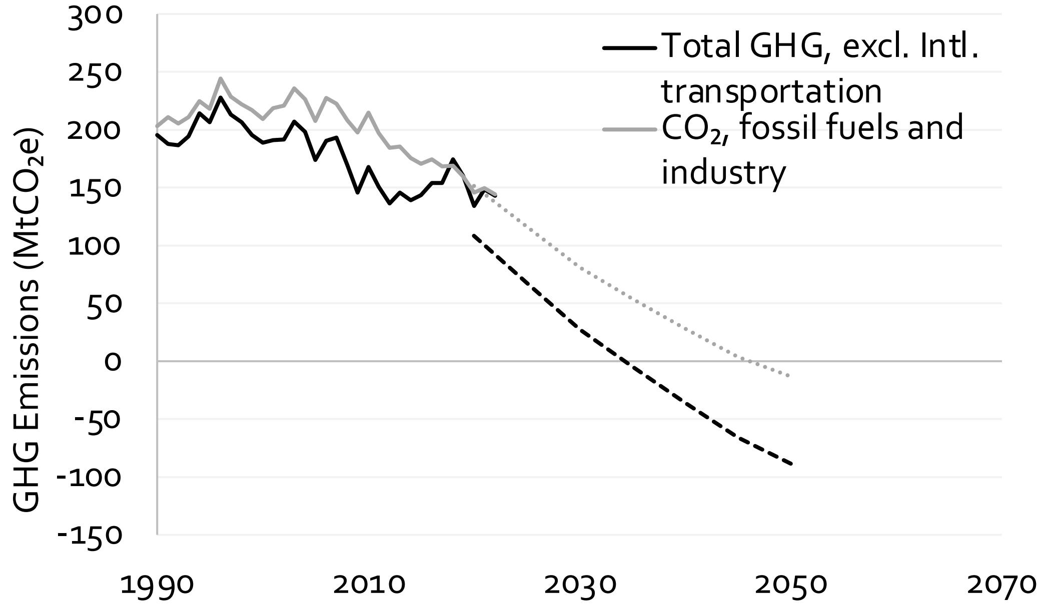


Figure 02.1: Nordic GHG emissions: left table: observed data right table: estimated emission reduction target based on on national targets (total GHGt) or NCES scenario moddeling (CO2 fossil fuels and industry)

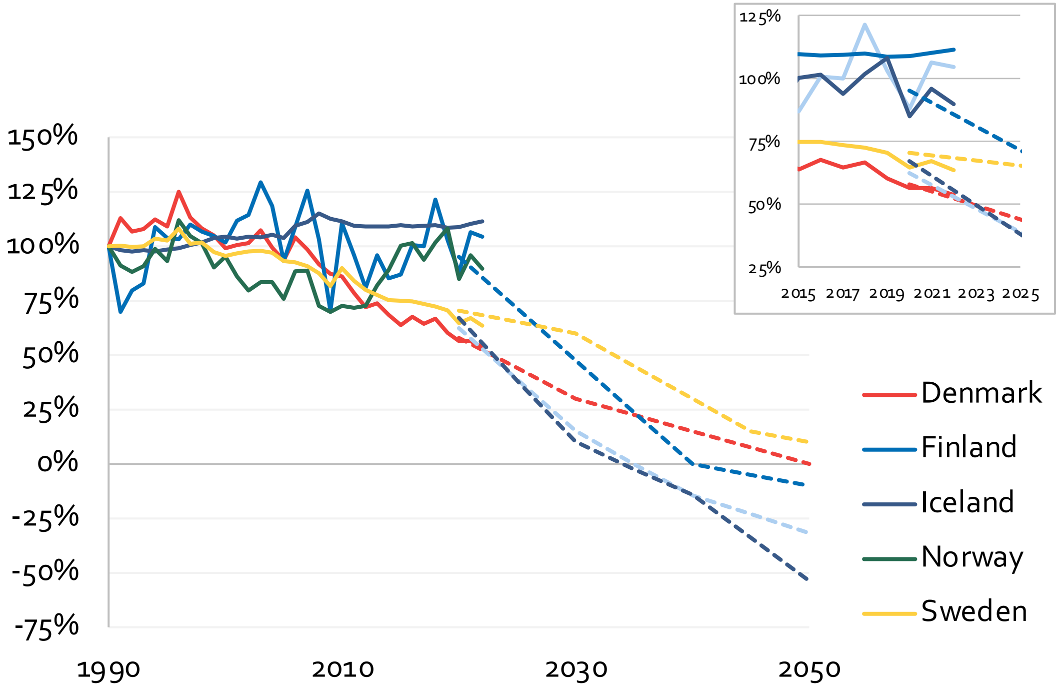
Data sources: Denmark's Integrated National Energy and Climate Plan, Finland's Integrated Energy and Climate Plan, Iceland's Climate Action Plan 2020, KLIMAKUR 2030, Sveriges integrerade nationella energi- och klimatplan, The Swedish climate policy framework, Hiilineutraali suomi 2035 - Skenaariot ja vaikutusarviot, National Inventory Report - Emissions of greenhouse gases in Iceland from 1990 to 2018, REPORT ON POLICIES, MEASURES AND PROJECTIONS - Projections of Greenhouse Gas emissions in Iceland til 2035, Meld. St. 13 (2020–2021) Report to the Storting (white paper); Norway's Climate Action Plan for 2021–2030, EEA; Trends and projections in Europe 2019

Progress towards Nordic climate neutrality

Looking at historical developments in emissions in the Nordic countries, they have been falling relative to 1990 levels. The dashed lines indicate the estimated target pathways from 2020 to the respective target years of each country. Additional targets listed in the previous slide are included in the estimates.

Norway, Finland, and Iceland have the most ambitious target years (2030-2040), but are not yet on their GHG reduction target pathways.

Sweden and Denmark are aiming for carbon neutrality in 2045 and 2050, respectively, and are both on track to reach those longer-term targets.



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Large CO_2 emission reductions from fossil fuels and industry

Nordic CO2 emissions from fossil fuels and industry increased until the early 2000s and have steadily decreased since, due to a wide range of energy and climate policies. In 2022, a 30% decrease compared to 1990 in Nordic CO2 emissions from fossil fuels and industry was achieved, as shown in Figure 02.3.

The country picture is more nuanced: Norway has reduced CO2 emissions from fossil fuels and industry per capita by 8% compared to 1990 levels, but not the country's overall CO2 emissions. This is because of a quite significant growth of population.

In Iceland's case, the CO2 emissions from fossil fuels and industry rose, both overall and per capita, to a large extent because of a growth in carbon intensive industry.

Denmark left behind a carbon-heavy power and heat sector, succeeding in reducing CO2 emissions from fossil fuels and industry per capita by 53% in 2022 compared to 1990 levels. Sweden and Finland both follow close behind with 49% and 42% reductions, respectively.

	Denmark	Finland	Iceland	Norway	Sweden	Nordics
1990	10,3	11,3	8,7	8,1	6,7	8,8
2022	4,8	6,5	9,9	7,4	3,4	5,2
Reduction	-53%	-42%	13%	-8%	-49%	-41%

Table 02.2: CO2 emissions from fossil fuels and industry in tons per capita in the Nordic countries, 1990 and 2022 levels.

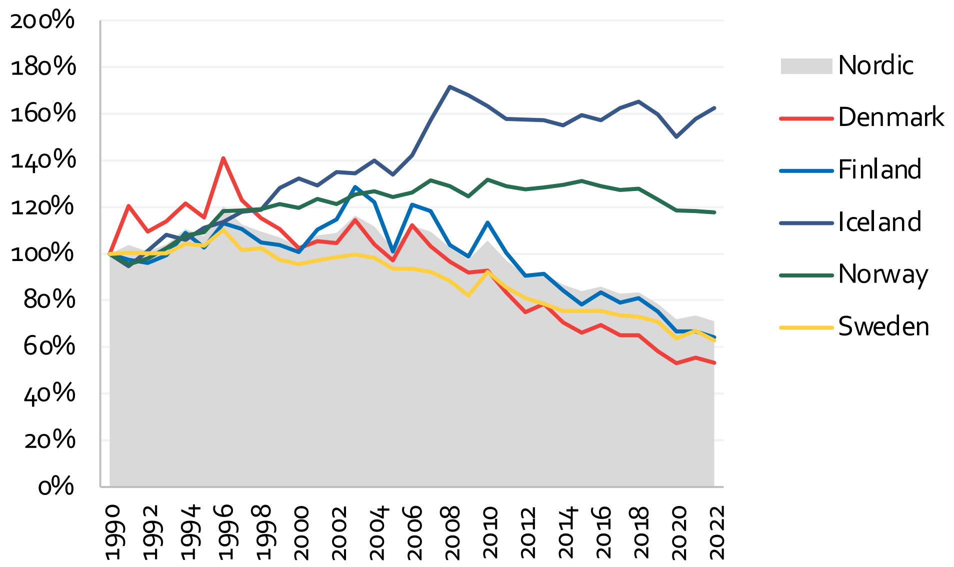


Figure 02.3: Development in CO2 emissions from fossil fuels and industry in the Nordic countries relative to 1990 levels.

Data sources: Denmark's Integrated National Energy and Climate Plan, Finland's Integrated Energy and Climate Plan, Iceland's Climate Action Plan 2020, KLIMAKUR 2030, Sveriges integrerade nationella energi- och klimatplan, The Swedish climate policy framework, Hiilineutraali suomi 2035 - Skenaariot ja vaikutusarviot, National Inventory Report - Emissions of greenhouse gases in Iceland from 1990 to 2018, REPORT ON POLICIES, MEASURES AND PROJECTIONS - Projections of Greenhouse Gas emissions in Iceland til 2035, Meld. St. 13 (2020–2021) Report to the Storting (white paper); Norway's Climate Action Plan for 2021–2030, EEA; Trends and projections in Europe 2019

Data source: Eurostat.

Largest emission reductions in the power and heat sector

In the Nordics, the largest CO2 reductions have been in the power and heat sectors (-25 MtCO2 from 1990 to 2022) and other fuel combustion (-23 MtCO2 from 1990 to 2022). Other fuel combustion is mainly from the heating but includes a range of smaller CO2 sources as well.

Nordic road transport emissions peaked in 2008 and have reduced since. In 2022, these emissions were 7% below 1990 levels.

Industrial CO2 emissions (fuel use and processes) also peaked in the early 2000s and have declined since. In 2022, these emissions were 11% below 1990 levels.

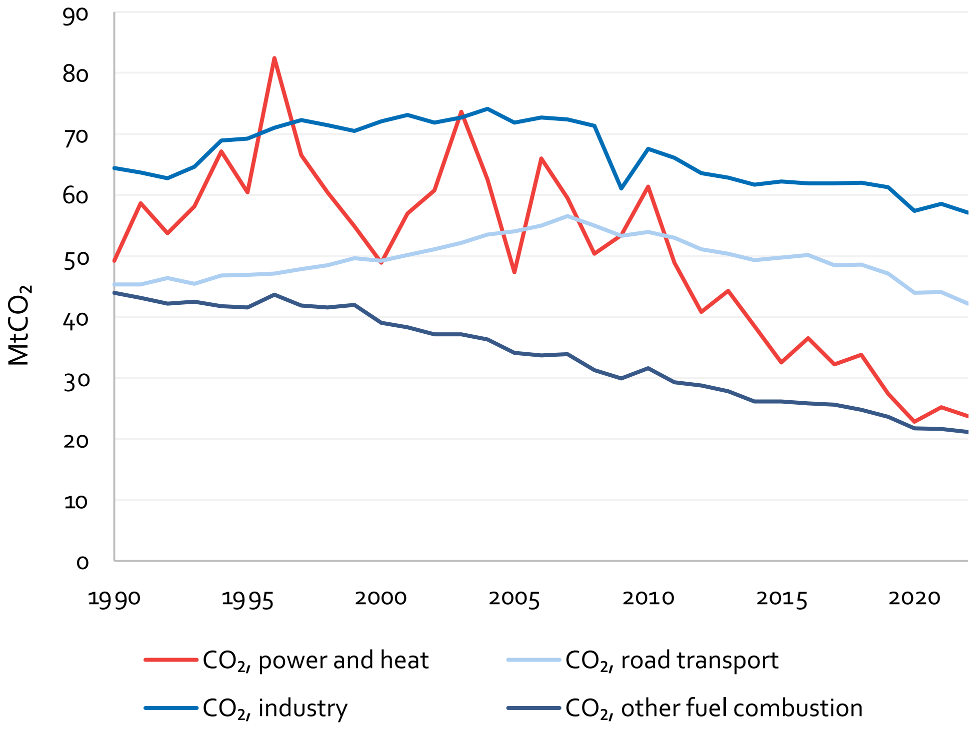


Figure 02.4: CO2 emissions by main sector. *Data source: Eurostat.*

Emissions decoupling from energy consumption

Since 1990, the Nordic countries have achieved a 30% reduction in CO_2 emissions by 2021. Despite this reduction, both gross and final energy consumption in the Nordics have increased by 13% and 16%, respectively, since 1990.

The energy consumption in Iceland between 1990-2021 has doubled, which can be attributed to the country's success in attracting energy-intensive industries that seek to benefit from its green electricity. Norway's energy consumption increased by 31%, while Denmark's and Sweden's increased by only 7% each. Finland's energy consumption increased by 18%.

Meanwhile, populations across the Nordic countries have grown since 1990, meaning that the increase in energy consumption per capita has not necessarily followed the same upward trend. This suggests that while overall energy consumption has risen, the efficiency and sustainability of energy use per individual may have improved.

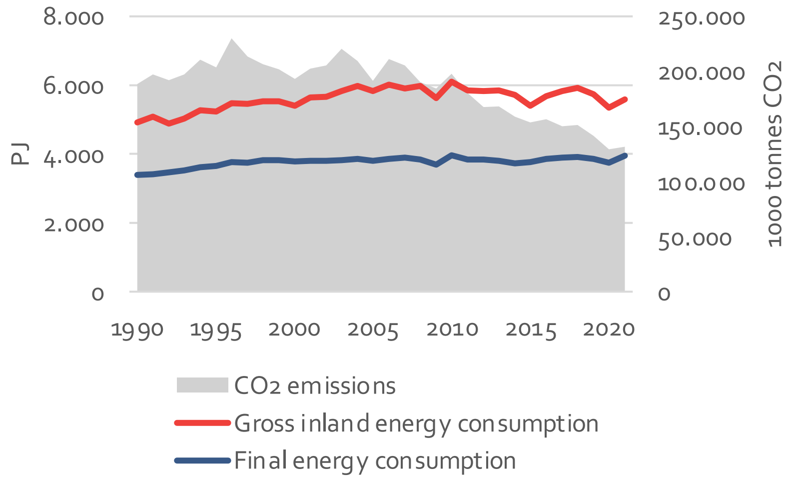


Figure 02.5: Nordic energy consumption and CO_2 emissions.

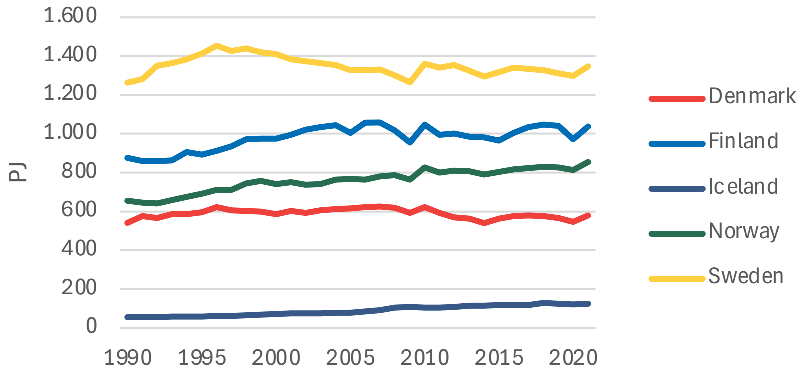


Figure 02.6: Final energy consumption per country.

Data source: Eurostat.

Share of renewable energy in consumption increases

Over the last ten years, on average, the five Nordic countries have increased the share of renewable energy in their final energy consumption by 12%. All five Nordic countries have seen significant increases in the utilisation of renewable energy.

Sweden leads the charge in share of renewable energy from the gross final energy consumption with a 17% increase, closely followed by Denmark at 16%. Finland isn't far behind with a 14% rise, while Norway and Iceland also make significant strides with 11% and 6% increases, respectively.

This increase highlights the Nordic region's commitment to sustainable energy solutions, racing well ahead of the average European increase of 5 percentage points in the period 2012-2022.

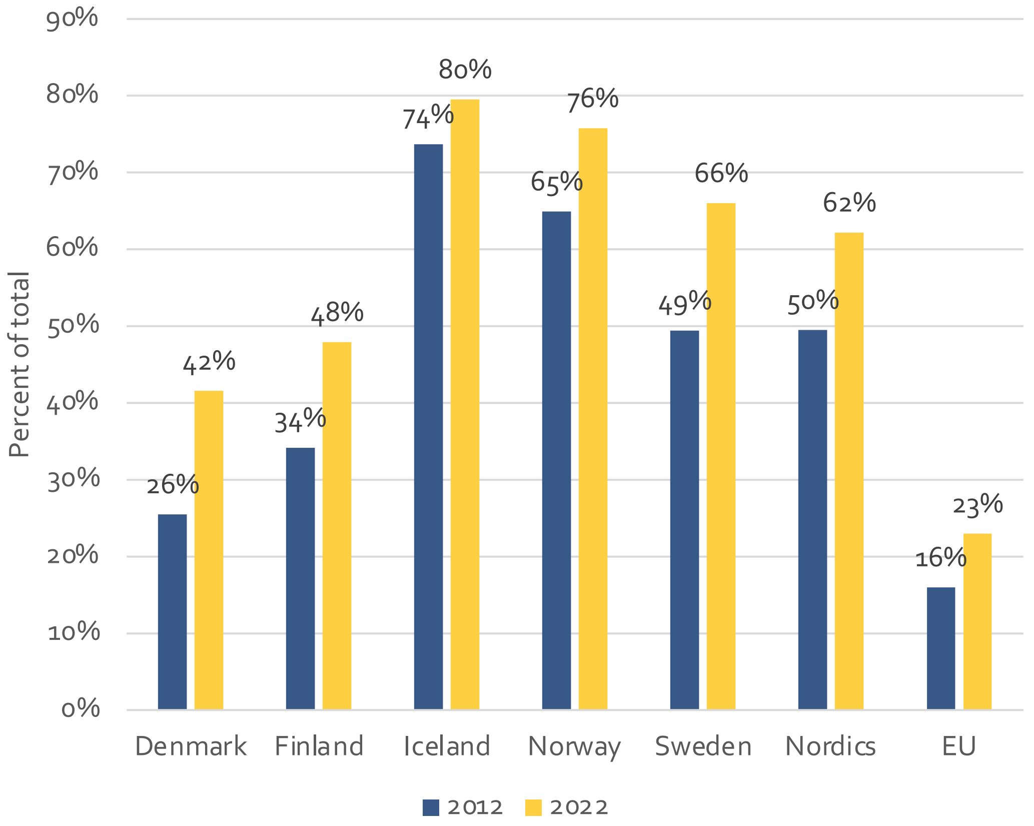


Figure 02.7: Share of renewable energy of the gross final energy consumption.

Data source: Eurostat.

Increased renewable energy production

Since 1990, the Nordic countries have made remarkable strides in boosting their renewable energy (RE) production. Denmark has led the way by tripling its production of renewable energy, while Iceland has impressively doubled its own. Finland has seen a 1.5-fold increase in its RE production, and Sweden has achieved a substantial 95% rise. Norway, too, has made significant progress with a 39% increase. These achievements underscore the region's strong commitment to sustainable energy and its leadership in the global shift towards greener power sources.

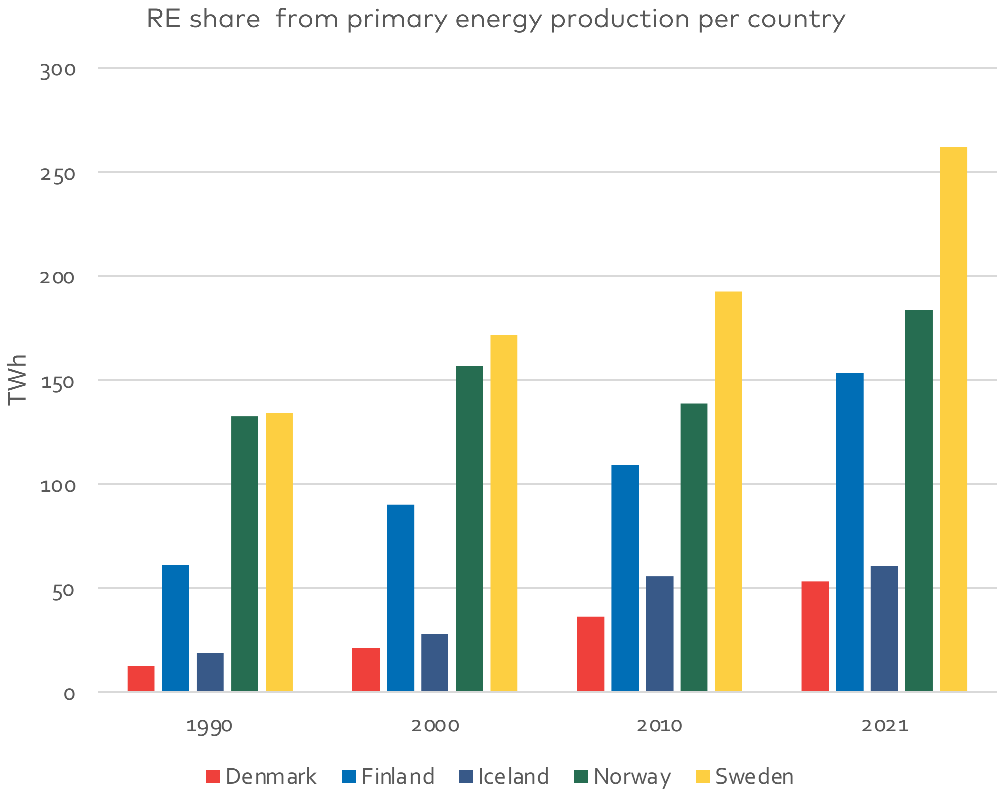


Figure 02.8: Renewable energy production per country.

Data source: Eurostat.

In the spotlight: The Climate Alliance

DK2020 Initiative: Aligning Danish Municipalities with the C40 Framework for Climate Action Planning

The DK2020* initiative marks a significant milestone as it represents the first adaptation of the C40 standard to smaller cities. This adaptation facilitates the development of ambitious climate action plans that are in line with the Paris Agreement. All 98 municipalities in Denmark are participating in this initiative, with 96 municipalities having already established their climate action plans. The DK2020 initiative provides technical assistance to Danish municipalities, guiding them on their path to becoming CO2-neutral and climate resilient by 2050. This initiative is a collaborative effort between Realdania, Local Government Denmark (KL), and the five Danish regions.

*The Climate Alliance is the new name of the previously called DK2020 programme.

Source: Concito, 2024

03

The Power Sector

We are on track!

On track to achieve decarbonisation goals

The Nordic power sector is on track to achieve its ambitious decarbonisation goals, demonstrating significant progress in reducing carbon emissions. This ongoing transformation is driven by a strong commitment to sustainable energy practices and innovative technologies.

A key factor in this success is the high utilisation of renewable energy sources (RES). The Nordic countries have harnessed their abundant natural energy resources, such as wind, hydro, geothermal and biomass, to generate clean electricity. This not only reduces reliance on fossil fuels but also enhances energy security and resilience.

The Nordic region's power systems are increasingly integrating renewable energy at a high capacity, showcasing the effectiveness of advanced grid management and storage solutions. This integration ensures a stable and reliable power supply.

Overall, the Nordic power sector's progress towards decarbonisation serves as a model for other regions, highlighting the potential of renewable energy to drive a sustainable and low-carbon future.

Decreased emissions from power and heat

Denmark has made remarkable strides in reducing CO2 emissions from power and heat, achieving a 75% reduction since the 1990s.

Finland saw its CO2 emissions peak in the early 2000s, but has since cut them by 50%, with a 34% reduction since 1990.

Norway and Iceland have maintained nearly fossil-free power generation since 1990, though Norway has seen a slight increase in emissions due to increased waste incineration capacity.

Meanwhile, Sweden has successfully reduced its power and heat emissions by 30% since 1990.

These achievements highlight the Nordic region's commitment to sustainable energy and climate action.

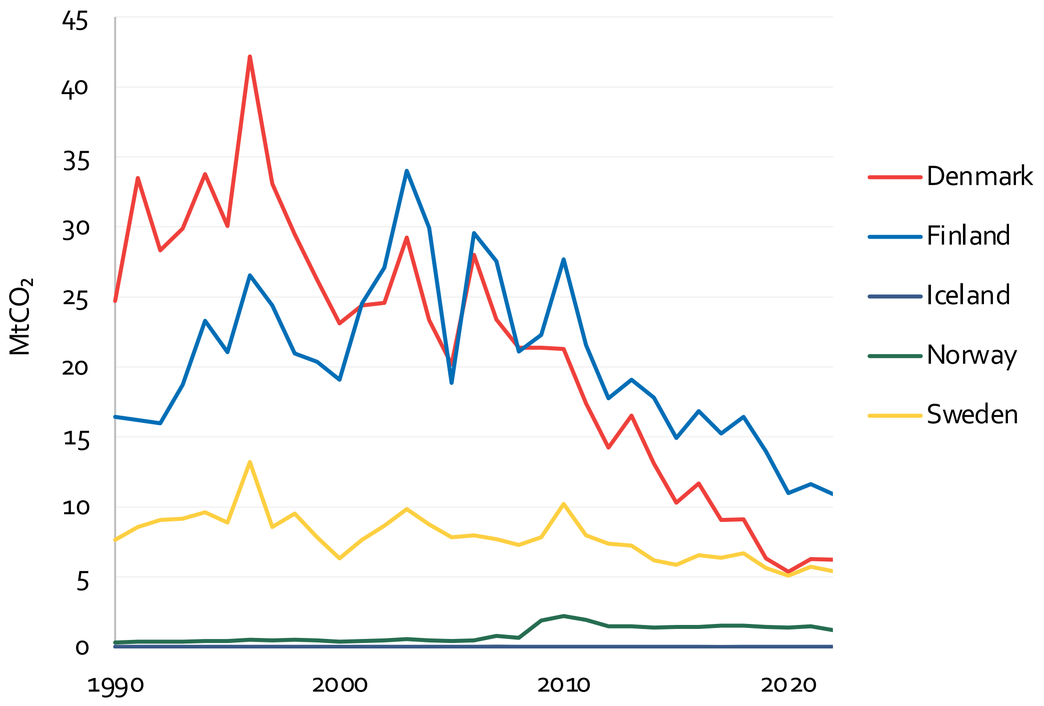


Figure 03.1: CO2 emissions from power and heat generation per country.

Data source: ESTAT, 2024

Increasing electricity consumption

Electricity consumption in the Nordic countries has shown a slight upward trend over the past few decades. From 1990 to 2023, the overall electricity consumption in the region increased by 18%.

Iceland stands out with a remarkable threefold increase in its electricity consumption since 1990, primarily due to the increasing activity in the aluminium smelting industry.

Norway also saw a significant rise in electricity consumption, with a 31% increase since 1990. Finland and Denmark followed with increases of 29% and 15%, respectively. Sweden is the only Nordic country to have reduced its electricity consumption, achieving a 6% decrease since 1990.

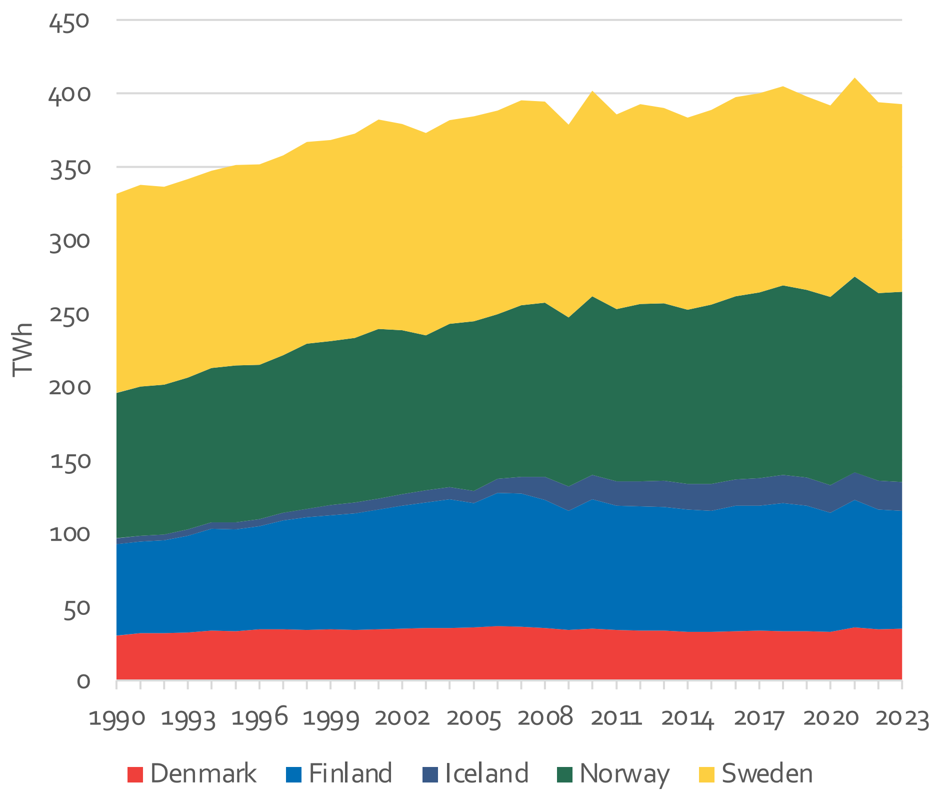


Figure 03.2: Gross electricity consumption by country.

Data source: World energy balance, IEA, 2024

Fossil based electricity generation replaced by renewables

Over the past decade, the Nordic electricity generation has seen a significant reduction in fossil fuel-based generation, coupled with a substantial rise in wind energy generation. Additionally, there has been notable growth in hydro and biomass contributions.

This shift towards renewable sources has been accompanied by a steady increase in overall electricity generation within the Nordic countries.

Electricity consumption in the Nordic countries has been on the rise, reflecting the region's growing energy needs. However, this increase in consumption is paralleled by a significant growth in energy exports. From 1990 to 2023, the Nordics have seen their energy exports double.

The declines in electricity consumption in 2020 and 2022 can be attributed to different factors. In 2020, the COVID-19 pandemic led to widespread lockdowns, reduced industrial activity, and changes in daily routines, all of which contributed to lower electricity usage. In 2022, the developing war in Ukraine caused a surge in electricity prices, prompting consumers and businesses to cut back on their electricity consumption to manage costs.

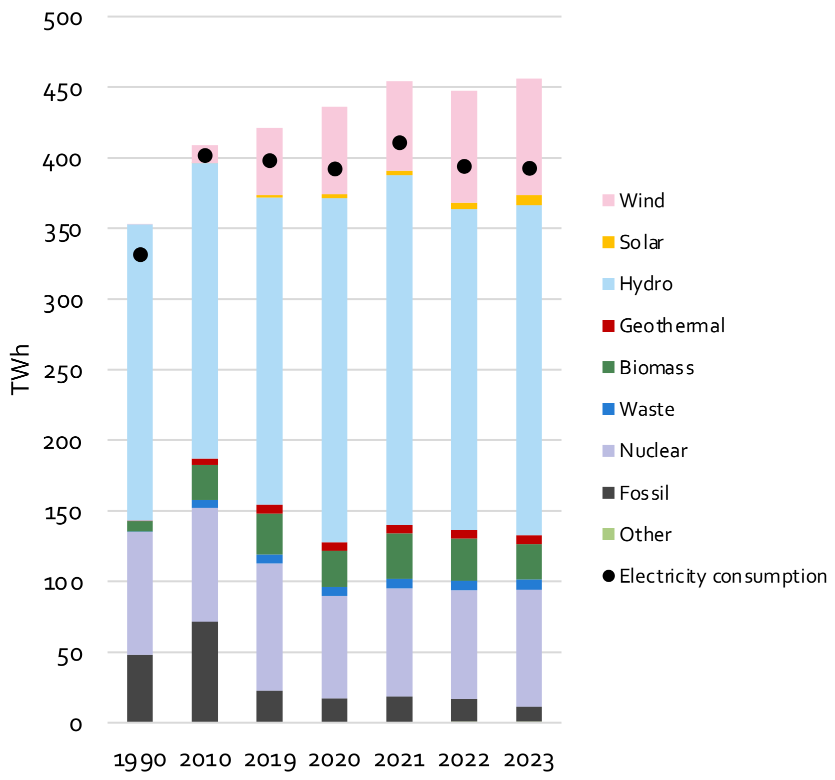


Figure 03.3: Electricity generation in the Nordics by source. The black dots indicate the amount of electricity consumed within the Nordic countries.

Data source: IEA

Changing electricity generation mix

In the last decade:

Denmark: Fossil fuel generation plummeted from 52% to 16%, with wind power soaring from 32% to 54%.

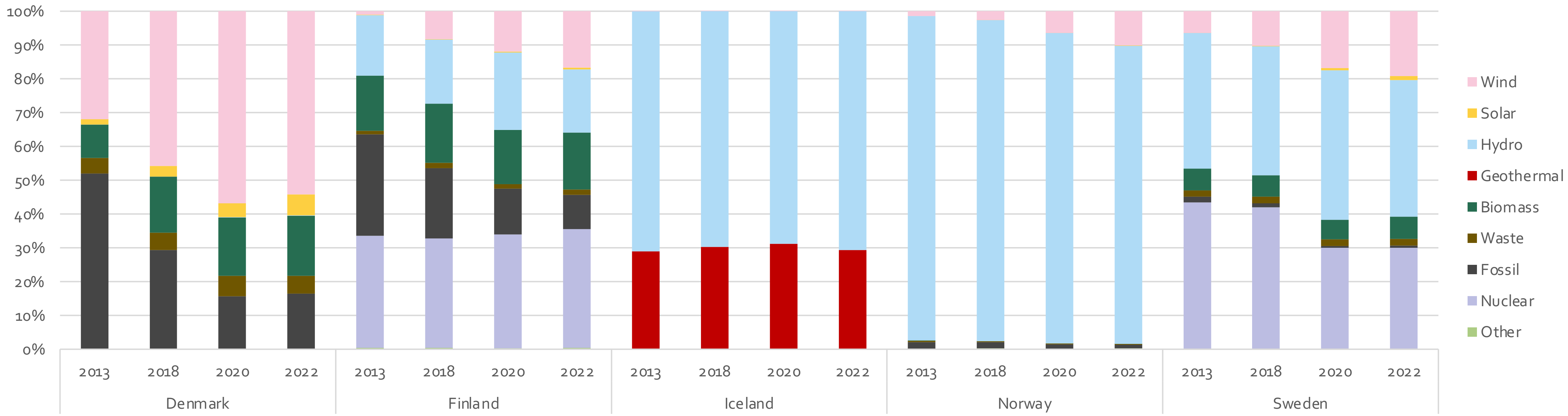
Finland: Fossil fuel use fell from 30% to 10%, and wind power climbed from 1% to 17%.

Iceland: Hydro power accounts for 71% of generation in 2022, with the remaining 29% from geothermal sources.

Norway: Wind power increased from 1% to 10%, with hydro power dominating at over 88% in 2022.

Sweden: Nuclear power's share dropped from 43% to 30%, while wind power surged from 6% to 19%.

Figure 03.4: Electricity generation per country by source



Data source: IEA

Fossil free electricity production is 96%

In 2023, the share of renewable energy in the Nordic power generation reached 78%, excluding nuclear power, which contributes an additional 18% to the energy mix.

Hydro power generates 51%, followed by significant contributions from wind with 18% and biomass with 6%. Power generation from solar and geothermal amounts to 2% and 1%, respectively.

Power generation from fossil fuels has been significantly reduced, now accounting for just 2%. This shift underscores the Nordic region's commitment to advancing into a more sustainable power generation future.

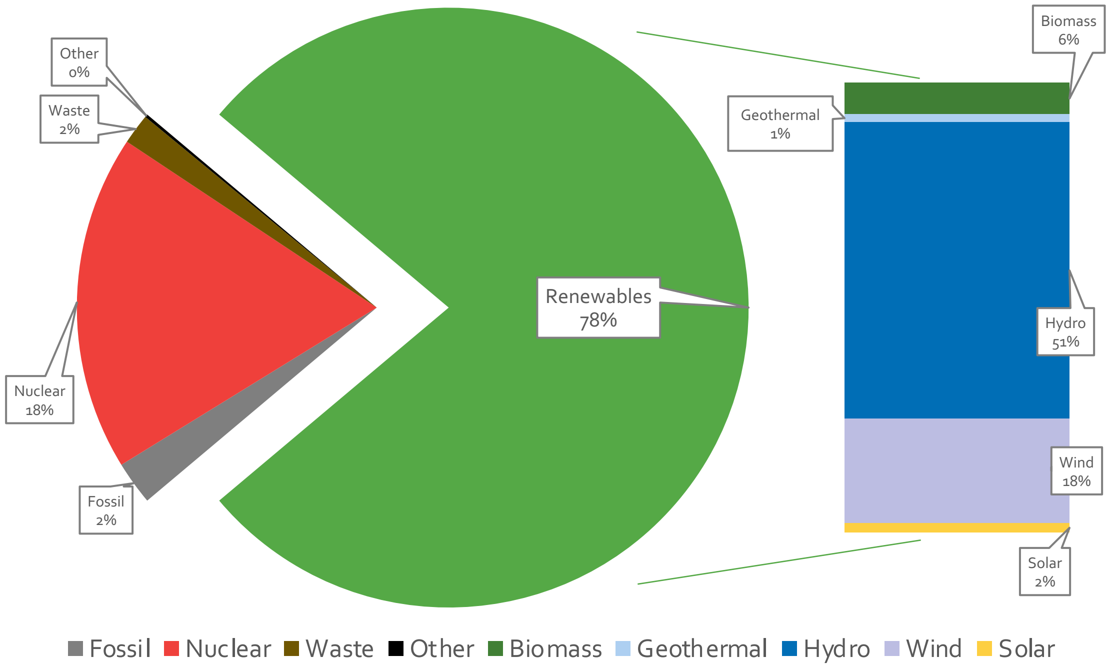


Figure 03.5: Share of renewables in power generation, 2023

Data source: IEA

Growth in installed capacity

In the period between 2000-2023, the installed power capacity in the Nordics has increased by 49 % from just above 90 GW to almost 140 GW.

This growth is driven by additions of wind and solar capacity while non-renewable capacity has plummeted from around 37 GW to 27 GW in 2023.

Other renewable capacity, which increased from 4 GW to 10 GW, is a mix between biomass, renewable municipal waste, geothermal energy and biogas.

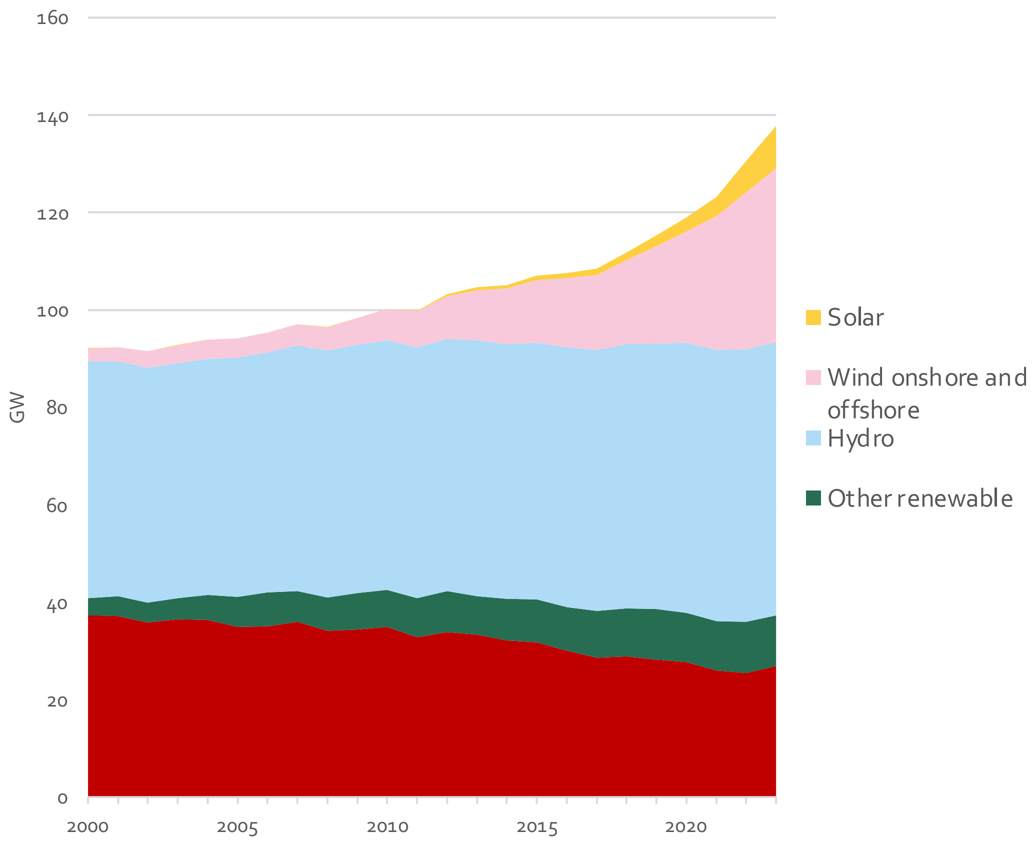


Figure 03.6: Development in installed power capacity in the Nordics

Data source: IRENA

In the spotlight: Hywind Tampen

Hywind Tampen, Norway the world's first floating wind farm has a capacity of 94.6 MW. The wind farm is powering Equinor's Snorre and Gullfaks fields (oil and gas fields in the North Sea, Norway). The wind farm is located about 140 kilometres from the shore and has a water depth between 260-300 meters. The turbines are mounted on floating concrete structures with a common anchoring system.

Hywind Tampen began power production in the third quarter of 2022 and is fully operational as of August 2023. This project generates 384,000 MWh of electricity annually, offsetting 200,000 tons of carbon dioxide (CO2) emissions each year.

The project, developed by Equinor, is currently owned by several companies with the following ownership stakes: Equinor (41%), DEA Norge (9.83%), ExxonMobil Exploration and Production Norway (9.83%), Inpex Idemitsu Norge (9.83%), OMV (Norge) (9.83%), Petoro (9.83%), and Var Energi (9.83%).

Source: Equinor, Power Technology

04

The Heat Sector

Heating for a warmer tomorrow

Slow progress in residential sector

Direct electrification is a key element of all decarbonisation strategies in the heat sector, yet the pace at which it is being implemented remains a concern. In the residential sector, fossil fuel consumption is decreasing, while the use of district heating, electricity, and renewable energy sources is increasing. However, these shifts are not occurring swiftly enough to meet the necessary decarbonisation targets. While this trend highlights the growing importance of sustainable energy solutions, it also emphasises the need for a more accelerated transition to ensure a greener, more energy-efficient future.

Households consume more electricity

Since 2008, total residential energy consumption has grown by 7%, which is less than ideal from a climate perspective. The share of electricity and district heating usage has increased by 16%, which is positive and reflects the growing reliance on cleaner energy sources. However, the uptake of renewables and waste has been relatively modest, rising by just 5%. Fossil fuel consumption has fallen by 45%, marking a significant shift. Fast forward to 2021, and the Nordic residential energy landscape has changed: fossil fuels now make up just 6% of total consumption, while electricity dominates at 48%. District heating accounts for 31%, and renewables and waste contribute 16%.

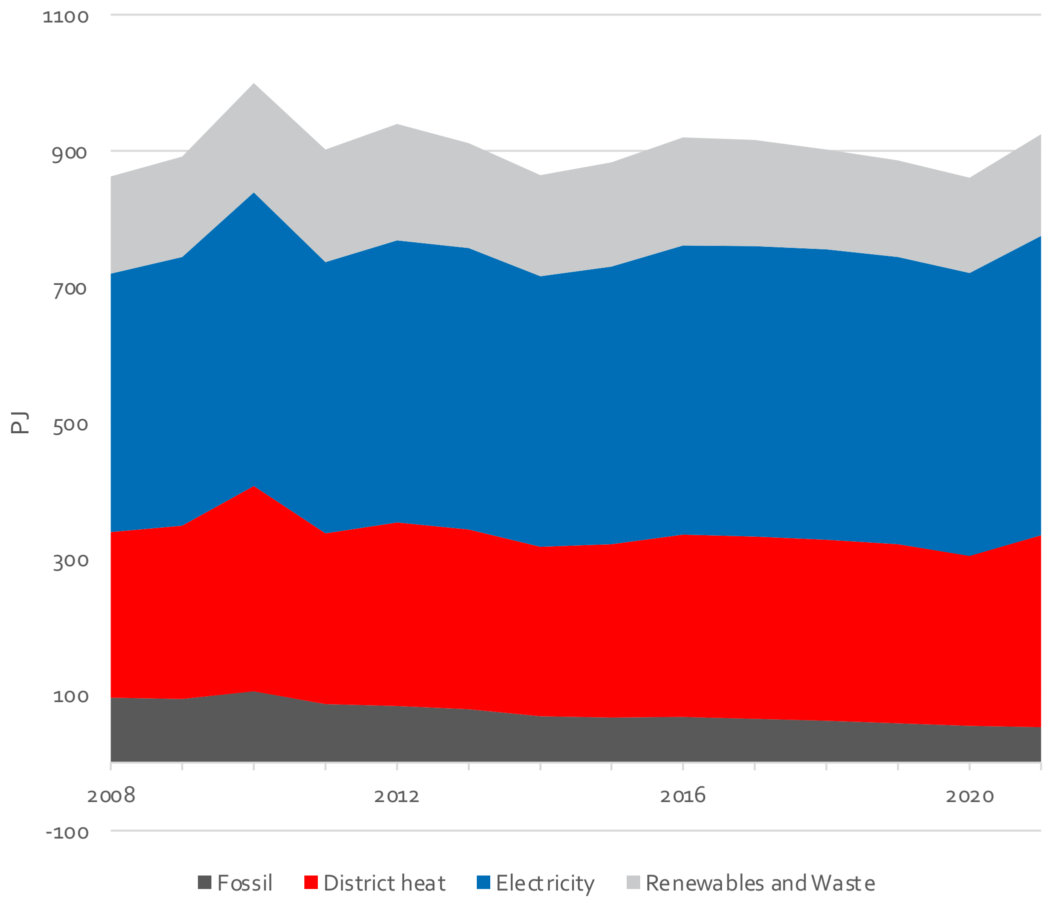


Figure 04.1: Final energy consumption in the Nordic residential sector.

Note: Energy consumption for transport is excluded
Data source: World Energy Balances, IEA

Increasing sale of heat pumps

In the Nordics:

The Nordics have seen a significant surge in heat pump sales (fig. 04.3), with an overall increase of 42% from 2021 to 2022. This growth is particularly pronounced in Sweden and Finland, where sales soared by 61% and 52%, respectively. Denmark and Norway also experienced growth, although on a smaller scale, with increases of 20% and 25%, respectively.

International perspectives:

Global sales of heat pumps grew by 11% in 2022, driven by increased policy support and high natural gas prices. Europe saw a record 40% increase, particularly in air-to-water models. In the U.S., heat pump sales surpassed gas furnaces, while China's market remained stable. Currently, heat pumps meet around 10% of global heating needs, but this must rise to 20% by 2030 to meet climate goals. To achieve net zero emissions by 2050, annual sales need to grow by over 15%. Prioritising installations in multistorey buildings and enhancing energy efficiency retrofits are essential for continued growth.

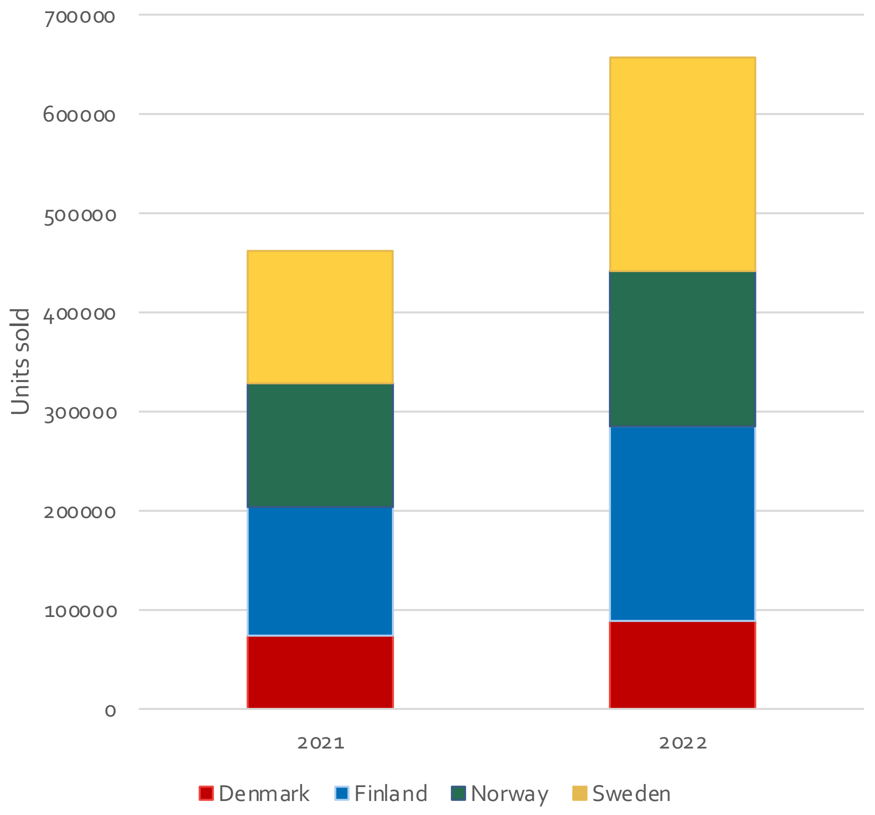


Figure 04.2: Sales of heat pump units (*air-to-air or air-to-water). Note: No available data for Iceland.

Data source: European Heat Pump Association (EHPA)

Source: IEA (2023), Global heat pump sales continue double-digit growth, IEA, Paris, Link, Licence: CC BY 4.0

In the spotlight: The Swedish heat pump success

For single-family houses, some form of electric heating (including heat pumps) is the most common heating method. As early as 2019, 1.2 million single-family houses (equivalent to 60 percent of such houses) used a heat pump, and this number has grown since then.

Why is this the case? The reason lies in a well-organised support system, which makes it easy for homeowners to both install green heating systems and improve the energy efficiency of their homes.

Boverket, the Swedish National Board of Housing, Building, and Planning, offers households financial support of up to 30,000 SEK for material costs related to energy efficiency and green heating measures. This means households can receive a maximum of 60,000 SEK in total or up to 50% of total material costs. Additional support schemes are also available to cover labor costs.

This support system is easy to access via Boverket's homepage, which also provides links to free municipal energy efficiency experts. These experts can advise homeowners on the most suitable technical solutions for their specific needs and also on all support schemes available.

Source: DBDH

In the spotlight: HOFOR heat pumps

HOFOR is a utility company located in Copenhagen, Denmark. It is set to invest billions in large-scale heat pumps to further reduce Copenhagen's reliance on biomass and fossil fuels. Their demonstration heat pump in Sydhavnen has successfully utilised seawater and wastewater as heat sources, paving the way for future projects.

Currently, 85% of Copenhagen's district heating is CO2-neutral. However, HOFOR aims to enhance this by installing collective electric heat pumps powered by green energy from wind turbines. These pumps will harness surplus heat, seawater, and wastewater to provide district heating, significantly boosting sustainability.

By 2033, up to ten heat pumps with a combined capacity of 300 MW will be operational across Copenhagen. This initiative will reduce the use of fossil fuels and biomass, contributing significantly to Copenhagen's goal of becoming climate-positive by 2035. The transition to electric heat pumps will also enhance the flexibility of the energy system, allowing the use of green power when available.

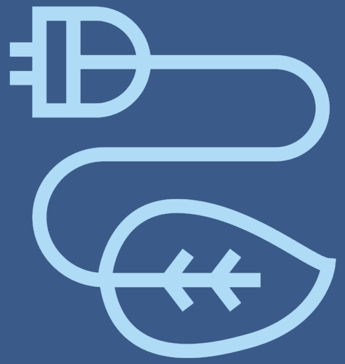
Source: DBDH

Photo: State of Green

05

A flexible Energy System

Managing a system with high share of wind and solar



Increasing need for flexibility

Onshore wind and PV gained momentum in 2022 due to high electricity prices and supply security concerns. However, regular negative power prices reveal the challenges of integrating wind and solar energy.

The surge in power prices during 2021 and 2022 also made the market more responsive than ever. The events following the start of the war in Ukraine highlighted Nordic resilience, but also underscored the need for further action to ensure flexibility and resilience in the Nordic energy system.

In response, countries, companies, and municipalities are now developing carbon accounts, including Scope 3 emissions, and setting requirements for sub-suppliers. Environmental, Social, and Governance (ESG) considerations are likely driving these changes.

Large increase in hours with negative prices

Electricity market prices can become negative during periods when electricity production exceeds consumption. In these instances, producers must pay to feed electricity into the grid, while consumers are paid to use it.

The number of hours with negative electricity prices in the Nordic countries has risen from fewer than 100 to nearly 1,000 hours annually. This increase is largely due to the rapid expansion of wind and solar generation capacity, which often benefit from other revenue streams that reduce their incentives to react to price signals. Their growth has outpaced the development of flexibility measures needed to balance the grid.

Negative price hours create business opportunities for implementing flexibility solutions. The estimated value of these hours has grown from a few million euros to almost 50 million euros. However, this still represents only about 0.4% of the total market volume.

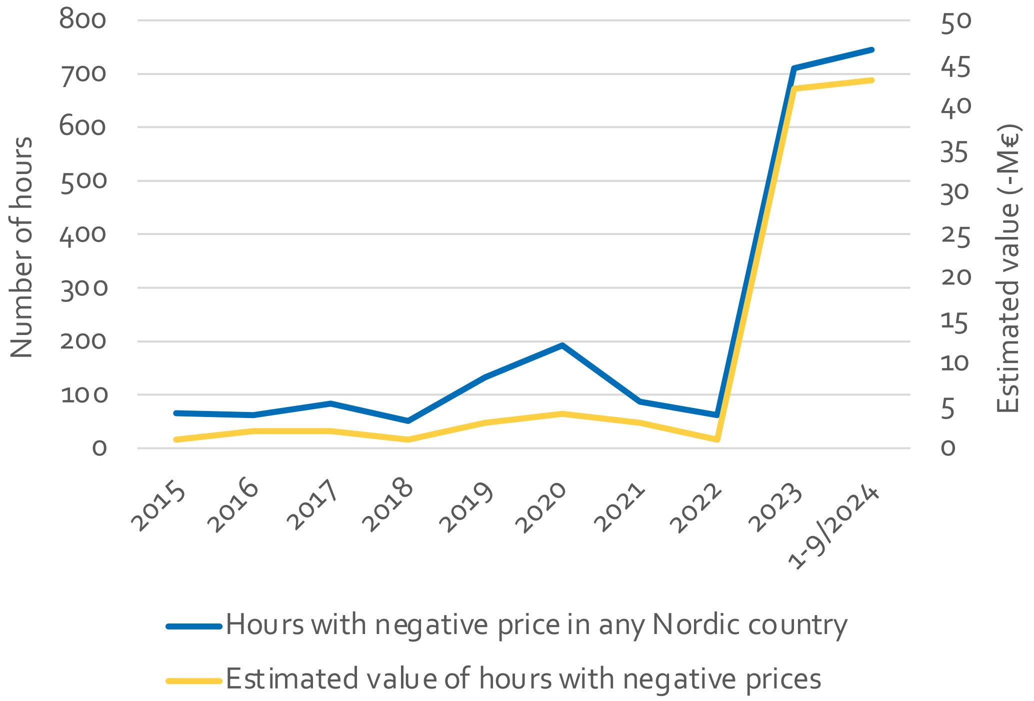


Figure 05.1: Number (left axis) and estimated value (right axis) of hours with negative electricity prices.

Data source: Price data from ENTSO-E. Estimated value calculated from hourly prices and total load. This method assumes that all electricity goes through the markets overestimating the value.
Note: The market event with –500 EUR/MWh prices in Finland in 2023 cleaned from the figure.

New trend: sky high electricity prices

Simultaneously the number of hours with high electricity prices has risen significantly.

Before 2021, there were only a few hours with prices exceeding 200 €/MWh, but this has become regular occurrence in 2023 and 2024.

oAverage of 90 hours in Nordic countries in 2023 simultaneously, the number of hours with high electricity prices has risen significantly. Before 2021, there were only a few hours with prices exceeding 200 €/MWh, but these became much more frequent during 2021 and 2022 due to the energy crisis. Although the number of such hours has decreased since then, they still occur regularly, with 90 hours recorded in the Nordic countries in 2023 and 50 hours in the first nine months of 2024.

oAverage of 50 hours in the first 9 months of 2024

The years 2021 and 2022 were particularly exceptional, marked by very high electricity prices.

Similar trends are observed with prices over 100 €/MWh and 300 €/MWh.

	2015	2016	2017	2018	2019	2020	2021	2022	2023	1-9/24
Denmark	0	2	0	2	0	5	620	4034	117	48
Finland	0	2	0	12	0	3	342	2549	117	118
Norway	0	2	0	2	0	0	206	3301	49	13
Sweden	0	2	0	2	0	3	457	2574	89	38

Figure 05.2: Number of hours with prices over 200 EUR/MWh

Data source: ENTSO-E

Increasing flexible electricity demand

Policies aiming for peak demand reduction and recent high prices have increased price response and demand-side management according to Nordic Transmission System operators, though there are no common metrics to measure the development.

Statnett, Norway, found 3% demand reduction during high-price hours in households in their 2019 study. The flexibility market in Norway has developed significantly since and EuroFlex flexibility market opened on the 1st of January 2024 providing short- and long-term demand reduction and load shifting.

Svenska Kraftnät, Sweden identified a 5% reduction in demand during high price peaks compared to projections in their 2023 study

Finland: A recent market analysis estimated that the volume of price-elastic demand bids has increased from the level of 1000 MW in 2021-2023 to the level of 2000 MW in 2024 [Litmanen, 2024].

In the spotlight: Euroflex

Euroflex is a local flexibility market in Norway aimed at managing electricity demand during peak periods. It involves grid companies like BKK, Elvia, and Glitre Nett, who buy flexibility services to either reduce consumption or boost production. Initially focused on the Agder region, Euroflex has now expanded to include Oslo, enhancing grid stability and efficiency by utilising consumer flexibility. (Nodes)

The Euroflex flexibility market is already open and will open for trading on the NODES platform in late 2024, with Elvia and Glitre Nett opening their entire license areas for trading, representing over 1.2 million electricity customers. The initiative is seen as a significant step towards utilising spare grid capacity and supporting Norway's NetZero targets. (Nodes)

Figure: Nodes

06

Energy Storage

Harnessing the Power of Batteries
and Thermal Storage Solutions

More flexible storage needed

The Nordic region benefits from large hydro reservoirs that provide excellent and cost-effective energy storage options, which are already being efficiently utilised.

Meeting growing future flexibility needs with a changing energy mix will require supplementing hydro reservoirs with batteries or hydrogen-based fuels.

While the use of battery storage is on the rise, the current installed capacity remains relatively insignificant compared to hydro storage. To fully harness the potential of renewable energy, significant investments in battery and hydrogen storage technologies are essential. This will ensure a resilient and sustainable energy system capable of meeting the region's ambitious climate goals.

Important roles for batteries in the Nordics

Despite an extensive hydro storage capacity in the Nordic region, batteries can still play an important role in the electricity system for several reasons:

- **Fast response times**: Batteries can respond almost instantly to fluctuations in electricity demand or supply, making them ideal for short-term grid balancing and frequency regulation, where quick adjustments are critical.
- **Distributed energy storage:** Unlike centralised hydro reservoirs, batteries can be deployed closer to consumers, at homes, businesses, or within local grids. This helps improve energy reliability and reduces transmission losses.
- **Support for intermittent renewables**: With the increasing share of solar and wind power in the Nordic energy mix, batteries can store excess energy generated during peak production times and release it when renewable generation is low, further enhancing grid stability.
- **Peak load shaving**: Batteries can help reduce peak electricity demand by storing energy during off-peak hours and supplying it during high-demand periods, alleviating pressure on the grid and minimising the need for additional power generation.

The Nordic countries are expected to have almost 1800 MW of installed battery capacity by 2030, not including batteries in electric vehicles.

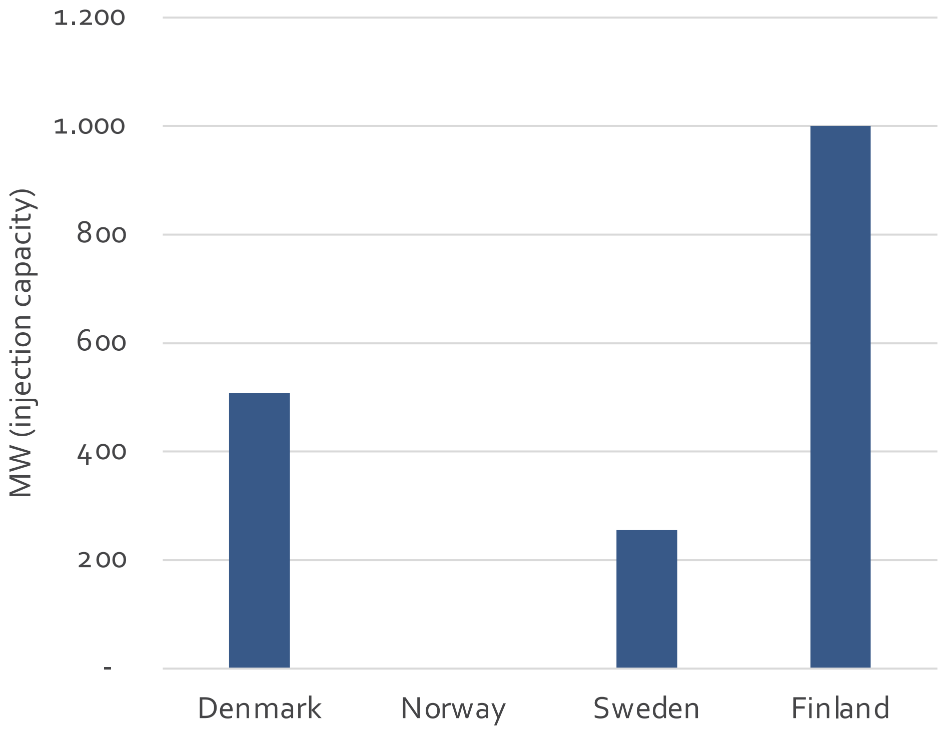


Figure 06.3: Expected battery capacity in the Nordics by 2030, not including batteries in electric vehicles. Megawatts measure the rate at which energy is injected into or drawn from the grid at any given moment

Data source: ENTSO-E ERAA2023 and Analyseforudsætninger til Energinet

Battery storage globally

According to the Announced Pledges Scenario* from the International Energy Agency (IEA) the battery storage capacity worldwide will increase from approximately 1% of the total power capacity as of 2023 to 6% and 12% in 2030 and 2050, respectively. This would mean that the total battery storage capacity would increase from about 90 GW to 4400 GW globally.

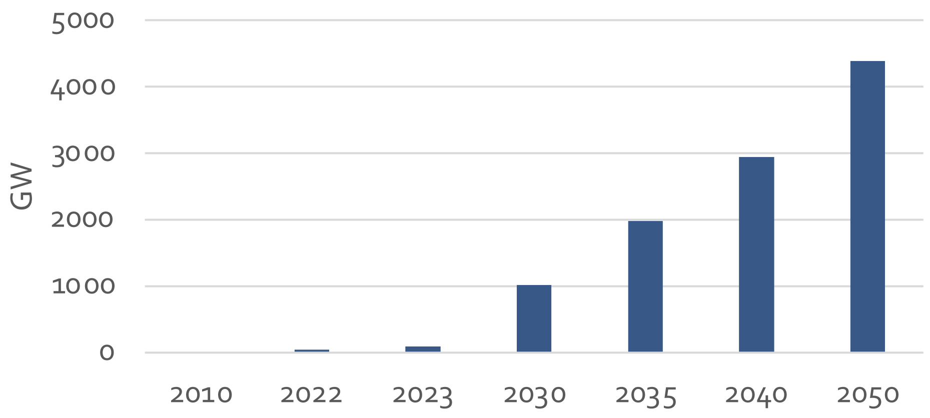


Figure 06.1: Battery storage capacity, based on announced pledges, IEA.

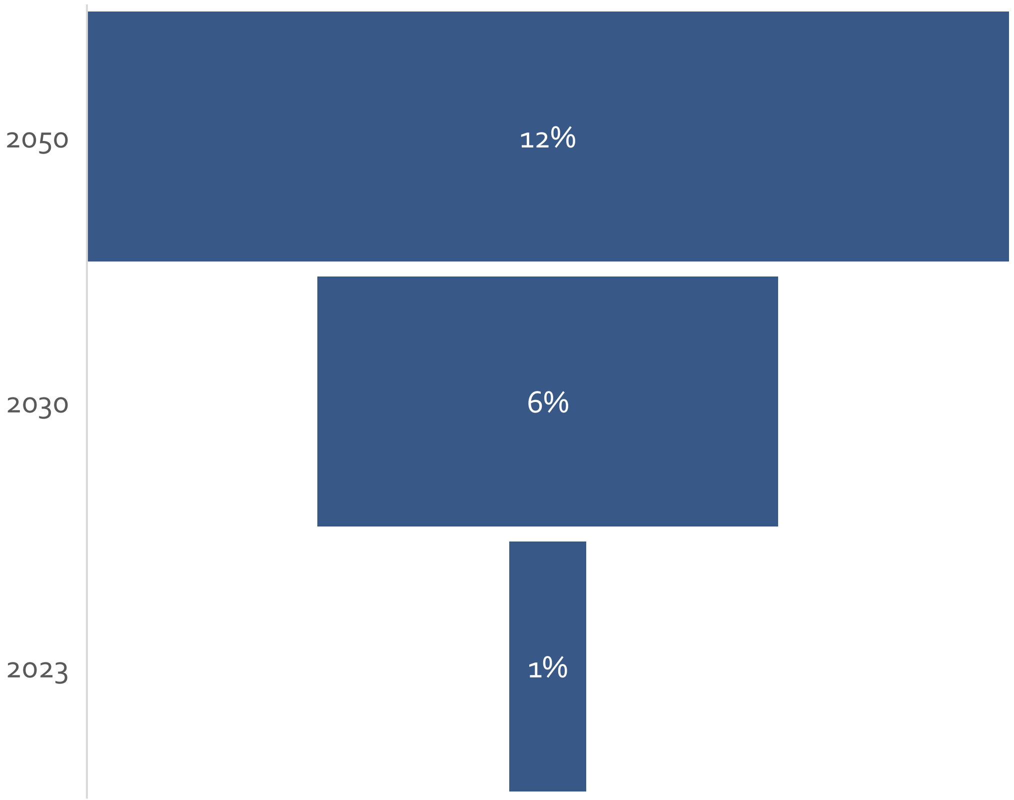


Figure 06.2: Share of battery storage capacity out of total power capacity, IEA.

* The Announced Pledges Scenario explores the outcomes if all national energy and climate commitments, including net zero targets, are fully achieved on schedule.

Energy storage

Finland, Norway and Sweden have a substantial energy storage capacity of approximately 125 TWh, thanks to their large hydro reservoirs. To put the Nordic hydro storages into perspective, the energy storage capacity of 100 million electric cars is approximately 5 TWh (assuming 50 kWh per car).

This vast storage is essential for balancing the fluctuations in renewable energy generation.

With existing interconnections to the UK, Germany, the Netherlands, Poland, and the Baltics, the Nordic region already serves as a key energy storage provider for the rest of Europe.

Many Nordic hydropower plants are upgrading their control systems to improve its responsiveness. By installing advanced automation and digital monitoring systems, operators can better control water flow and turbine operations.

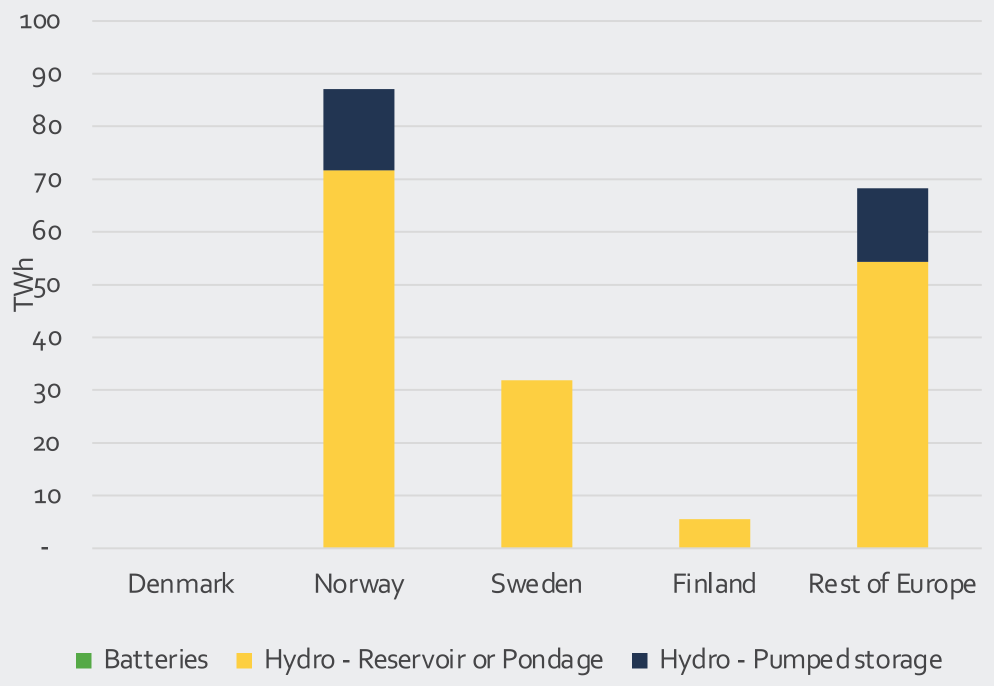


Figure 06.4: Energy storage capacity volumes in Europe compared to Denmark, Norway, Seden and Finland. Terawatt-hours measure the total amount of energy stored or consumed over a period of time.

Data source: ENTSO-E ERAA2023 and Analyseforudsætninger til Energinet

In the spotlight: Battery storage cases

Battery energy storage is essential for the Nordic region's energy transition, enhancing grid stability and reliability. Batteries can provide crucial backup power, regulate grid frequency, and support energy markets, demonstrating their importance in creating a resilient and sustainable energy infrastructure. As the Nordics continue to invest in battery storage, they pave the way for a secure and efficient energy future.

Denmark

The energy company EWII is locating a 30 MW/43 MWh battery energy storage system next to the high voltage transformer station at Hasle, Bornholm. For a start, the battery will be supplying ancillary services to Energinet, but the battery can also supply Bornholm with electricity for one hour, in the case the island is isolated because of cable failure.

Finland

OX2 has sold its 50MW/110MWh battery energy storage project in Uusnivala, Finland, to the L&G NTR Clean Power Fund. The project will help regulate grid frequency and stability and participate in energy arbitrage in wholesale markets.

Sweden

The Elektra Energy Storage Project, Sweden’s largest battery storage project, is now fully operational. Located in Landskrona, southern Sweden, the project will provide ancillary services to help balance the grid for Landskrona Energi.

Source: Green Power Denmark, OX2, RES group Sweden

Photo: Axpo, RES group Sweden

In the spotlight:
Largest cavern heat storage in the world

Vantaa Energy in Finland started the construction of the largest underground thermal energy storage in the world. It will have a volume of 1.1 million m3 and capacity of 90 GWh, approximately 5% of Vantaa's annual DH demand.

The deepest section of the storage will be 140m below the ground level and high hydrostatic pressure enables very high storage temperatures up to 140 degrees Celsius.

The storage is charged with excess heat from a nearby waste incineration plant and with electric boilers during low price hours in the Finnish market area. Electric boilers with heat storage will likely become a new major source of flexibility for the electricity sector.

The discharge power of the storage will be 200 MW, which is roughly half of the winter base load of the whole city of Vantaa. This allows more flexible operation of the district heating grid and helps avoid start-ups of fossil units.

Storage investments in general require cheap charging and enough full cycles throughout the year to be profitable. Vantaan Energia is planning to achieve this through multiple charging methods, increased flexibility in operation, and varying power prices in Finland.

The estimated cost is 200 million euros and the construction is planned to start in spring 2025.

Source: Vantaan Energia

Photo: Axpo, RES group Sweden

07

Carbon Accounting

Balancing emissions with Nature´s assets

More flexible storage needed

Nordic CO2 emissions from fossil fuels and industry have decreased by 30% between 1990 and 2022 and are on track when compared to the modelled emissions in the NCES project.

Nordic overall GHG emissions decreased from 1990 to 2010, but the increasing LULUCF emissions have countered the reductions from CO2 emissions from fossil fuels and industry from 2010 to 2022.

Emissions from international transport are increasing, but those are not part of national targets.

Nordic countries are starting several pilot projects for carbon capture and storage, such as Mammoth Direct Air Capture plant in Iceland and Northern Lights project in Norway.

Nordic GHG emissions by source

Nordic CO2 emissions from fossil fuels and industry are on track with compared to the modelled trajectory in the Nordic Clean Energy Scenarios project.

However, LULUCF emissions have increased above the previous assumptions and consequently put Nordic countries above the GHG emission trajectories.

Emissions from international aviation and shipping are increasing, but they are not included in national targets as these sectors have their own sectoral international emission reduction agreements.

Other GHG emissions, such as CH4, are on a downward trend but these emissions are hard to mitigate, and their total amount is projected to reduce by only 60% from 1990 to 2050.

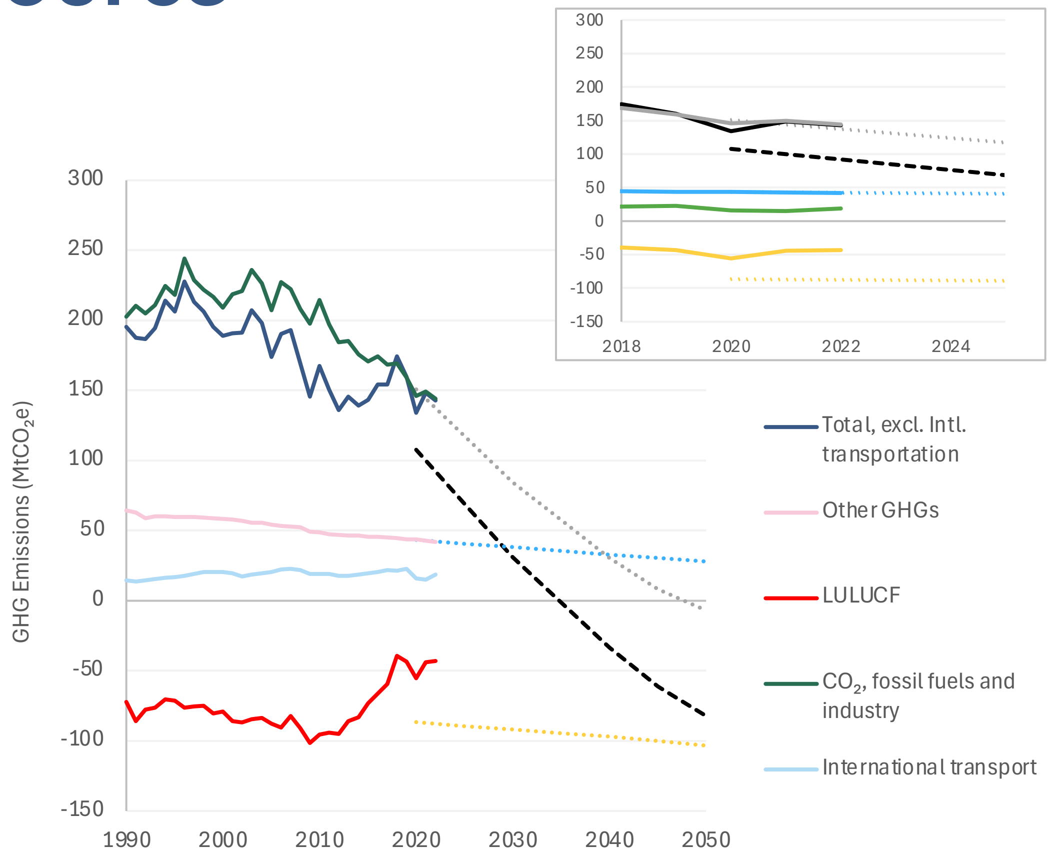


Figure 07.1: Nordic GHG emissions. Solid lines are statistical values, dashed line for estimated national target trajectories, dotted lines are assumptions or modelling results from NCES project.

Data sources: Denmark's Integrated National Energy and Climate Plan, Finland's Integrated Energy and Climate Plan, Iceland's Climate Action Plan 2020, KLIMAKUR 2030, Sveriges integrerade nationella energi- och klimatplan, The Swedish climate policy framework, Hiilineutraali suomi 2035 - Skenaariot ja vaikutusarviot, National Inventory Report - Emissions of greenhouse gases in Iceland from 1990 to 2018, REPORT ON POLICIES, MEASURES AND PROJECTIONS - Projections of Greenhouse Gas emissions in Iceland til 2035, Meld. St. 13 (2020–2021) Report to the Storting (white paper); Norway's Climate Action Plan for 2021–2030, EEA; Trends and projections in Europe 2019

Increasing use of biomass, reducing forest carbon sinks

Domestic biomass production in the Nordic countries has increased from 500 PJ in 1990 to 1050 PJ in 2022. The increasing use of forest energy has reduced the forest carbon sinks. In addition to domestic production, the import of bioenergy has increased from 4 PJ in 1990 to 170 PJ in 2022. This increase has had additional LULUCF impact outside Nordic countries. Forest carbon sinks would require policies to turn the trend, or additional emission reductions from fossil fuels and industry.

Data sources: Denmark's Integrated National Energy and Climate Plan, Finland's Integrated Energy and Climate Plan, Iceland's Climate Action Plan 2020, KLIMAKUR 2030, Sveriges integrerade nationella energi- och klimatplan, The Swedish climate policy framework, Hiilineutraali suomi 2035 - Skenaariot ja vaikutusarviot, National Inventory Report - Emissions of greenhouse gases in Iceland from 1990 to 2018, REPORT ON POLICIES, MEASURES AND PROJECTIONS - Projections of Greenhouse Gas emissions in Iceland til 2035, Meld. St. 13 (2020–2021) Report to the Storting (white paper); Norway's Climate Action Plan for 2021–2030, EEA; Trends and projections in Europe 2019

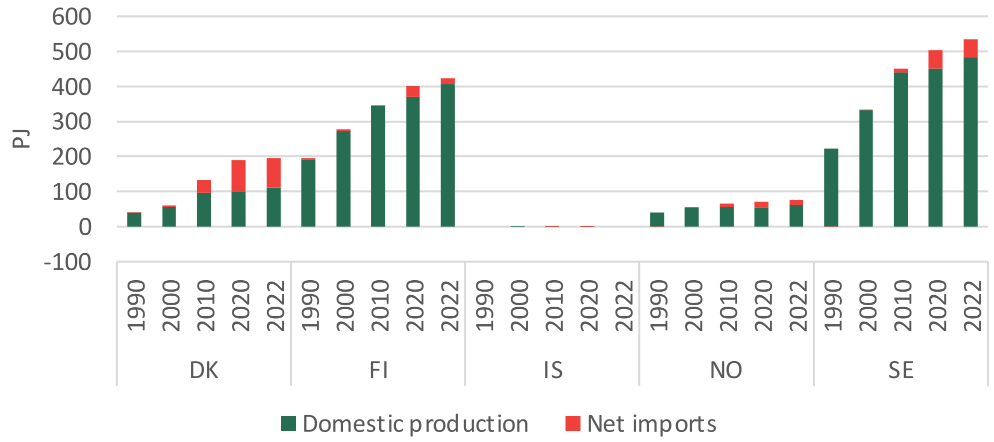


Figure 07.2: Bioenergy production and net imports.

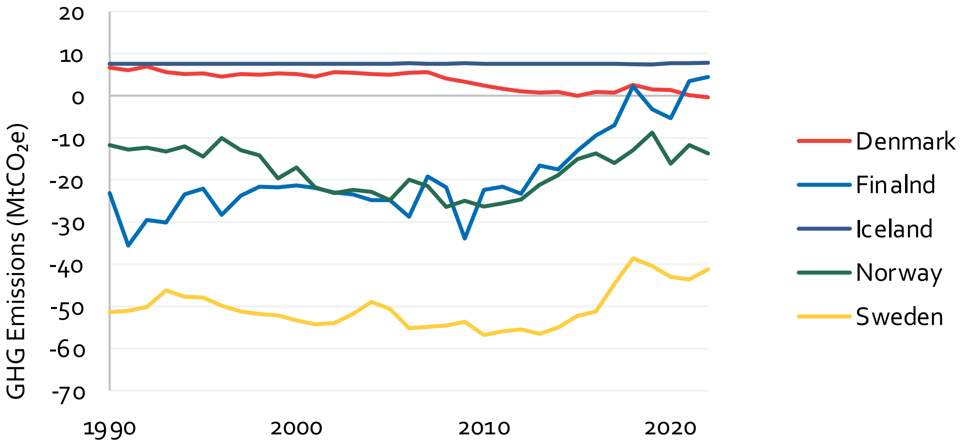


Figure 07.3: Emissions from LULUCF.

Increasing emissions from international transport

International transportation is not part of national targets but has international sectoral actions and targets instead.

Emissions from international aviation and shipping were increasing until the COVID-19 pandemic, which reduced the emissions in 2021, but the activity has increased since. Statistics are not yet available for 2024, but many airlines have reported on record amount of passenger.

The overall trend has been increasing in Sweden and Iceland, stable in Finland and Norway, and slightly decreasing in Denmark.

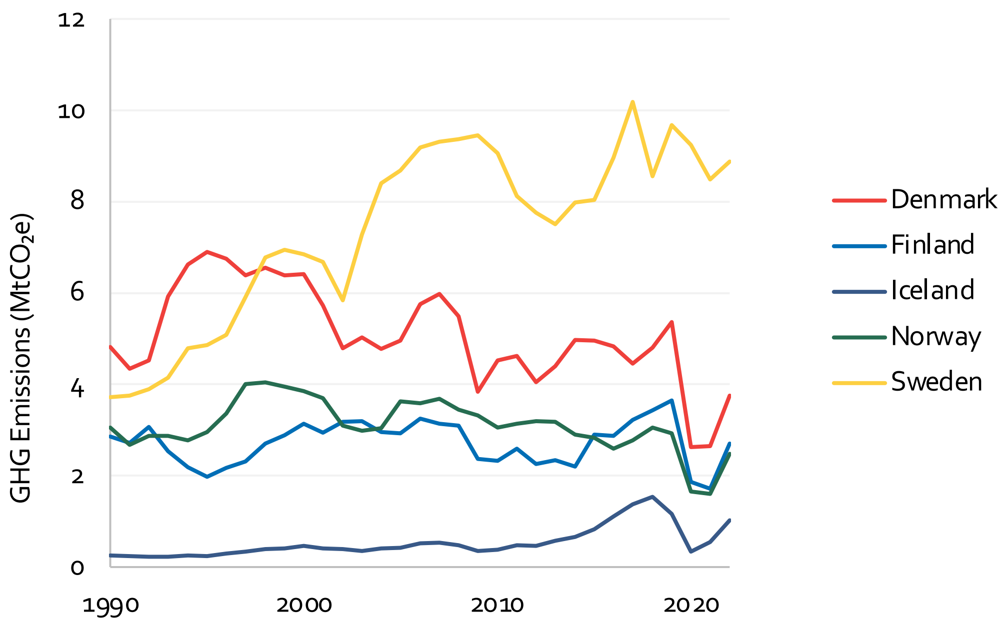


Figure 07.4: Emissions from international aviation and shipping.

Data sources: Denmark's Integrated National Energy and Climate Plan, Finland's Integrated Energy and Climate Plan, Iceland's Climate Action Plan 2020, KLIMAKUR 2030, Sveriges integrerade nationella energi- och klimatplan, The Swedish climate policy framework, Hiilineutraali suomi 2035 - Skenaariot ja vaikutusarviot, National Inventory Report - Emissions of greenhouse gases in Iceland from 1990 to 2018, REPORT ON POLICIES, MEASURES AND PROJECTIONS - Projections of Greenhouse Gas emissions in Iceland til 2035, Meld. St. 13 (2020–2021) Report to the Storting (white paper); Norway's Climate Action Plan for 2021–2030, EEA; Trends and projections in Europe 2019

In the spotlight:
The largest direct air capture plant in the World

In 2024, Climeworks launched the Mammoth direct air capture (DAC) plant in Iceland, which is capable of capturing up to 36,000 metric tons of CO_2 annually. This facility, ten times larger than its predecessor Orca, uses renewable geothermal energy to power its operations. Captured CO_2 is stored underground in basaltic rock formations, where it mineralises and is permanently sequestrated.

The Mammoth plant's modular design allows for scalability, with twelve of its planned 72 collector containers already installed. This phased approach allows a gradual ramp-up of operations and provides valuable insights for future projects. Climeworks aims to achieve megaton-scale carbon removal capacity by 2030 and gigatonne-scale by 2050.

Before the introduction of Mammoth, DAC plants were capturing approximately 10,000 metric tons of CO2 annually, as reported by the International Energy Agency (IEA). However, under the IEA's ambitious Net Zero Emissions by 2050 Scenario, the DAC technology has the potential to scale up significantly, with projections indicating the technology could capture nearly 65 million metric tons of CO2 per year by 2030. This dramatic increase underscores the critical role that DAC could play in global efforts to mitigate climate change and reduce atmospheric carbon levels.

Source: Cimateworks and SPGlobal

Photo: Climateworks

08

Industry and power- to-X

Direct and indirect electrification of industry and the use of PtX

More flexible storage needed

The Nordic industry is struggling with decarbonisation, as the Nordic GHG emissions from industry have remained almost unchanged over the past decade.

Reducing industrial emissions is challenging, and there has not been a sufficient decoupling between production levels and emissions. Consequently, industrial emissions increase with rising production. Breaking this connection requires substantial updates to industrial processes, which have not yet occurred on a large scale.

The Nordic industry has been growing with increasing speed since the 1990s, increasing the overall industrial energy consumption. However, this is countered by a decrease in the carbon intensity of industrial consumption. Additionally, the heat consumption in in the industrial sectors is drastically increase since 1990's.

It is crucial to switch to less carbon-intensive solutions while maintaining growth. While there are emerging hydrogen projects in the Nordics, recent delays and cancellations of several green investments, including power-to-X projects, hinder progress.

Industry energy consumption

Since 1990, industrial energy consumption has seen varied trends. Finland and Norway experienced increases of 19% and 11%, respectively, while Iceland's industry consumption skyrocketed by 250%. In contrast, Denmark and Sweden managed to reduce their industrial energy consumption by 11% and 5% in 2021.

All Nordic countries, except Norway, have reduced their fossil fuel usage in the industry sector. Norway's fossil fuel consumption has remained relatively stable, with an overall increase of 7% since 1990. Electricity consumption in industry has risen in all countries except Sweden, which achieved a 13% reduction. Notably, electricity accounts for 97% of Iceland's total industrial energy consumption.

Heat consumption has surged in Finland, Norway, and Sweden since 1990, while Denmark saw a more modest increase of about 18%. Unfortunately, there is no data available for Iceland's industrial heat consumption. Biofuel consumption has increased significantly across all Nordic countries, ranging from 30% to 70% since 1990, with Finland and Sweden being the largest consumers at 174 PJ and 200 PJ in 2021, respectively.

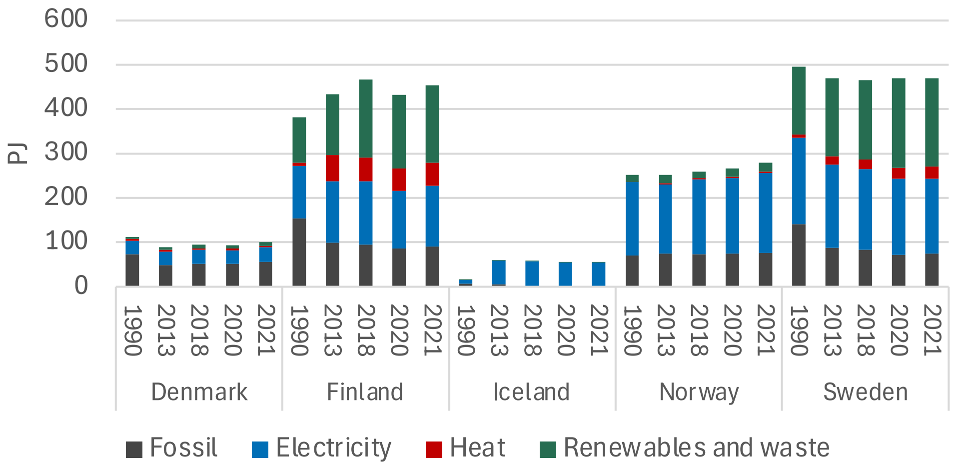


Figure 08.1: Industry total final consumption by source

Source:World Energy Balances IEA

Carbon intensity of industry energy consumption

Carbon intensity in industry consumption has decreased across all Nordic countries since 1990 except Norway, where it has seen a slight increase.

Iceland has made a remarkable reduction, bringing its carbon intensity down to 1 tCO2/TJ in 2022. This is a significant achievement compared to Denmark, which has the highest carbon intensity among the Nordic nations at 40 tCO2/TJ in 2022.

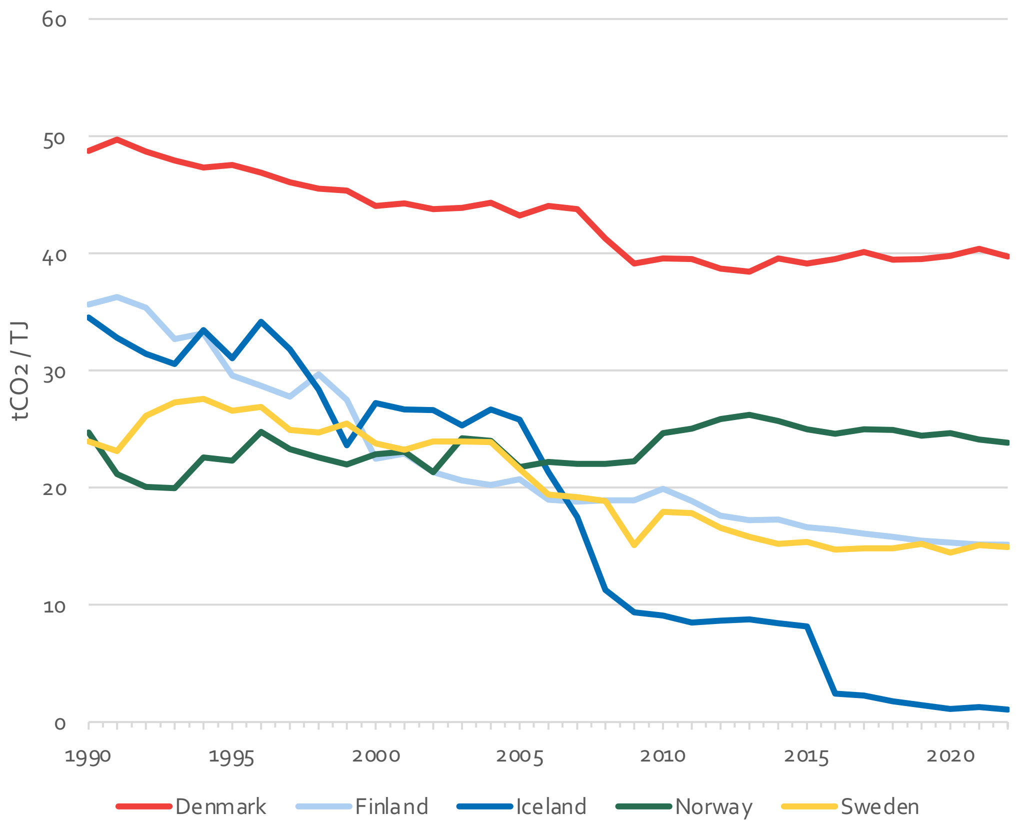


Figure 08.2: Industry total final consumption by source

Source: IEA

GHG emissions development in industry

Since 1990, industrial energy consumption has seen varied trends. Finland and Norway experienced increases of 19% and 11%, respectively, while Iceland's industry consumption skyrocketed by 250%. In contrast, Denmark and Sweden managed to reduce their industrial energy consumption by 11% and 5% in 2021.

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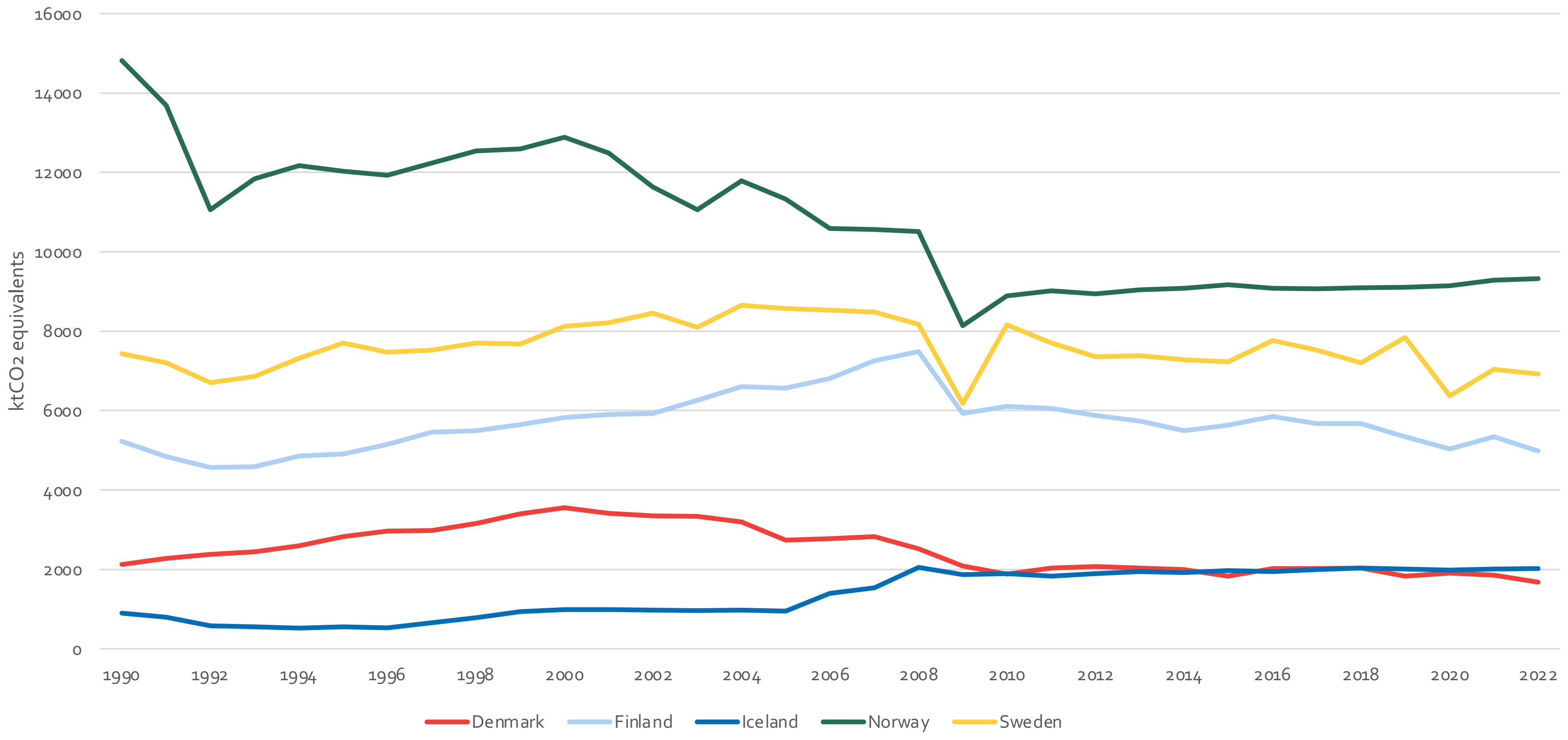


Figure 08.3: Greenhouse gas emissions in industrial processes and product use

Source: Nordic Statistics

In the spotlight:
Stegra's plant in Boden, Sweden

Stegra, formerly H2GS Boden AB, is set to build the world's first large-scale, low-carbon, hydrogen-based steel manufacturing plant in Boden, northern Sweden. This groundbreaking project, powered by renewable sources, aims to produce 5 million tonnes of high-quality steel annually by 2030, with production starting in 2025. The plant will utilise a hydrogen-based direct reduction process combined with electrified downstream facilities, significantly reducing CO_2 emissions by up to 95% compared to traditional steelmaking methods.

The innovative approach replaces coal with hydrogen, produced on-site using Europe's largest electrolyser powered by renewable energy. This process will primarily emit water and heat instead of CO_2, marking a significant environmental breakthrough. The project also emphasises circularity, ensuring minimal waste and maximum resource efficiency. This positions the plant as a pioneer in low-carbon steelmaking in Europe and globally.

From a productivity standpoint, the project leverages established technologies on a large scale, enhancing Sweden and Finland's research and development capabilities in green steel manufacturing. It supports the Swedish steel industry's transition to more sustainable methods, contributing to the post-fossil fuel era.

Source: NIB

Photo: Stegra

Insight into "Nordic Hydrogen Valleys - value chain mapping across the region"

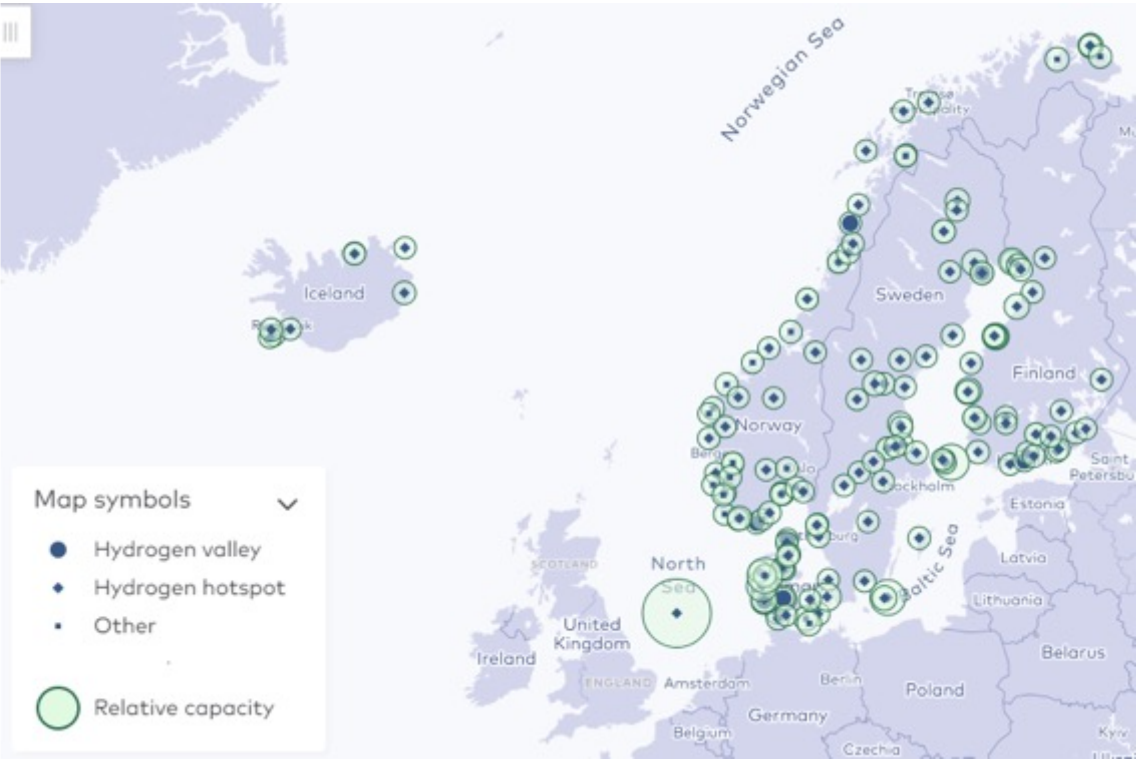
The Nordic Hydrogen Valleys project by NER focused on fostering the growth of Nordic hydrogen valleys, facilitating the exchange of knowledge among Nordic stakeholders, and highlighting Nordic strengths in hydrogen value chains. This was accomplished by establishing definitions for hydrogen valleys and hotspots, mapping hydrogen projects throughout the Nordic region, and categorising them based on specific criteria.

The criteria fospecificr hydrogen valleys include:

1. covering a geography in at least one Nordic country,
2. covering at least two steps of the hydrogen value chain (production, distribution, use),
3. having a hydrogen production capacity exceeding 500 tonnes per annum (tpa),
4. supplying hydrogen to at least two different end-use sectors, and
5. having at least reached the feasibility phase (feasibility study).

Nordic hydrogen hotspots are projects that do not qualify as hydrogen valleys but fulfill criterion 1 and at least two of criteria 2–5.

Denmark, Finland , Iceland, Norway and Sweden* has 162 hydrogen projects. Together, these projects aim for a total planned hydrogen production capacity of 7,221 kilotonnes per annum (ktpa). Among these projects, 123 are classified as hydrogen hotspots. Hydrogen hotspots encompass both direct and indirect uses of hydrogen, such as producing fuels or chemicals. These hotspots alone account for 5,986 ktpa of the planned hydrogen production capacity.



Source: Nordic Hydrogen Valleys-value chain mapping across the region, NER

Country	Total number of H2 projects	Total planned H2 production capacity (ktpa)	Number of hotspots	Planned H2 production capacity of hotspots (ktpa)
Denmark	29	3 748	18	2 822
Finland	36	1 126	39	1 126
Iceland	9	112	9	112
Norway	50	711	24	414
Sweden	38	1 524	37	1 512

Figure 08.4: Nordic hydrogen projects. Hydrogen projects in Greenland and the Faroe Islands are not referenced here. Source: interactive digital tool, NER

Plans for an extensive H2 grid

The European Hydrogen Backbone initiative consists of over 30 infrastructure operators who aim to accelerate the European decarbonisation by defining the critical role of the hydrogen. Their current plan is based on a range of production facilities, storages, consumers, and hydrogen grid.

The European Investment Bank estimates that the total investment needs could be up to 500 billion euros by 2050. However, the recent economic uncertainty and a period with higher interest rates, have delayed and halted several projects significantly delaying the overall progress.

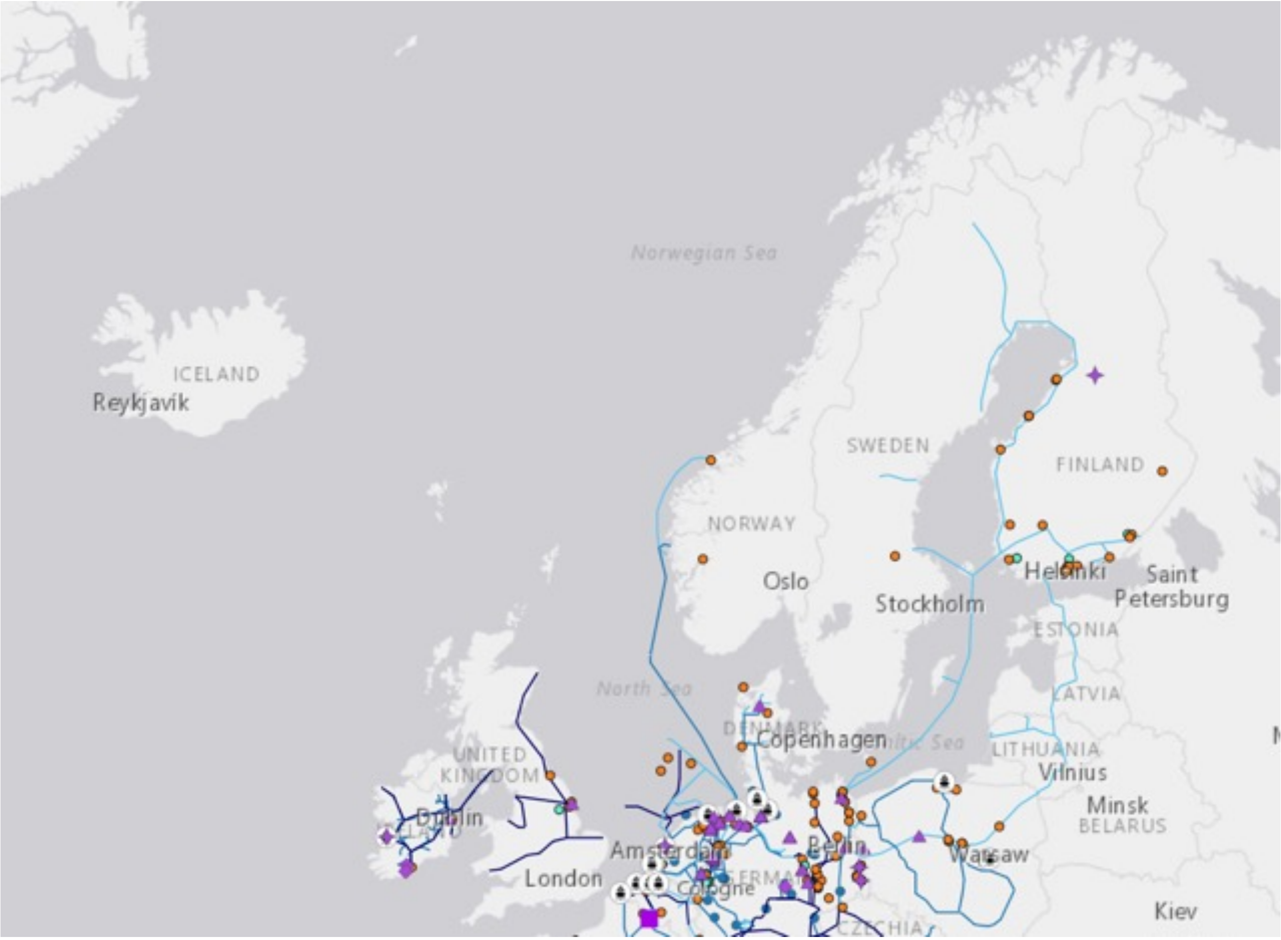


Figure 11.4: European hydrogen backbone.

09

En Route to Greener Road Transport

The rise of electric vehicles

Road transport is electrifying

Road transport is making significant strides in reducing CO_2 emissions, driven by the increasing adoption of electric vehicles for both cars and vans. This shift towards electrification is crucial for a greener future.

Additionally, embracing sustainable habits such as walking, Cycling, and using public transportation can further amplify these efforts. In the Nordic countries, there was an increased use of cars during COVID-19, but post-pandemic, there has been a notable reduction as people return to more eco-friendly transportation options.

Emissions from road transport

Sweden has ambitious target of reducing its emissions from the transport by 70% by 2030 compared to 2010. In 2022, Sweden was 36% below 2010 level and progress seems good.

Denmark, Finland, and Norway have also managed to peak their road transport emissions around 2010 and the emissions have on a reducing trajectory despite large annual variability.

Iceland's road transport emissions are small compared to other Nordic countries, but steadily increasing.

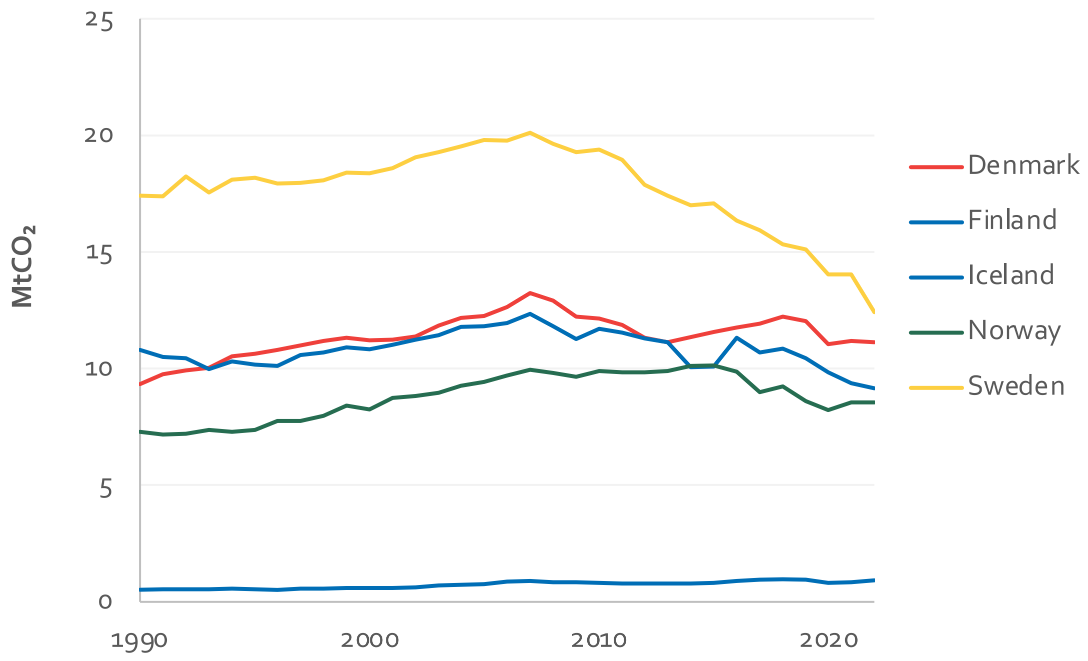


Figure 09.1: CO_2 emissions from road transport

Source: Estat

Electric cars and the road ahead

The number of electric vehicles (EVs) in the Nordic countries has increased tremendously between 2010 and 2023. As of 2023, there are over 2 million EVs across the five countries, corresponding to 15% of all cars in the Nordics.

Norway leads with approximately 900000 EVs, followed by Sweden with around 560000, Denmark with about 310000, Finland with 224,000, and Iceland with 44000.

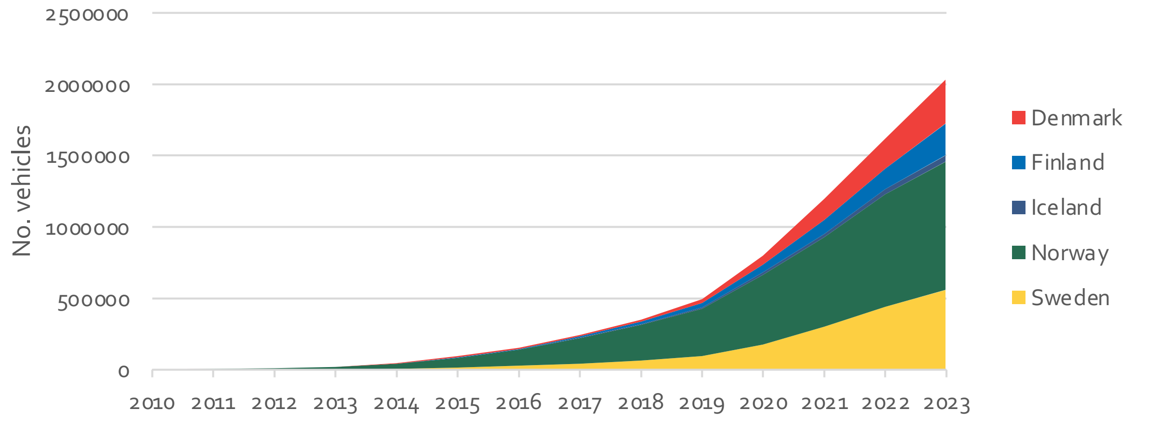


Figure 09.2: Growth in EV car stock by country

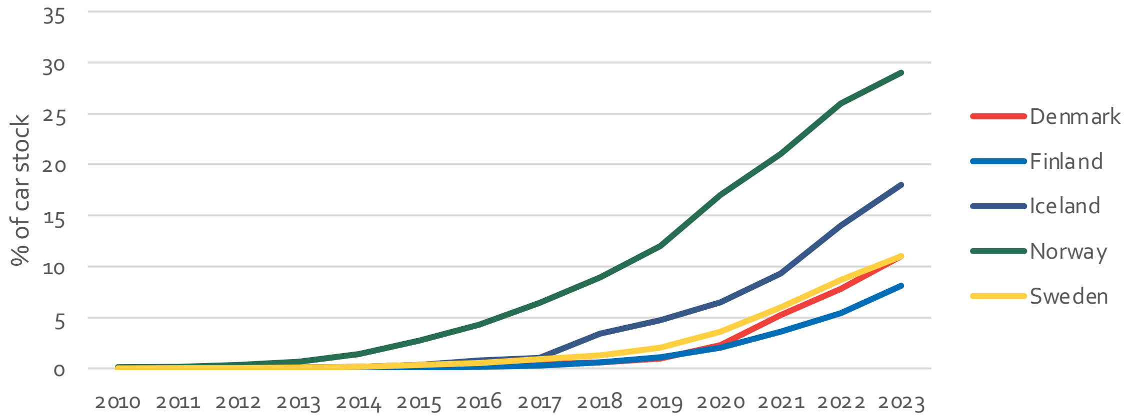


Figure 09.3: Share of EV car stock by country

Source: [IEA]

Note: Electric vehicles include plugin hybrid vehicles (PHEV) too.

The Nordic region has seen a significant increase in the number of Battery Electric Vehicles (BEVs) and Plug-in Hybrid Electric Vehicles (PHEVs), particularly since 2019. By 2023, the stock of BEVs reached approximately 1.3 million, while PHEVs totalled around 750000. In contrast, the stock of Fuel Cell Electric Vehicles (FCEVs) remains relatively small, with about 600 vehicles across the Nordics in 2023.

While both BEV and PHEV sales were increasing until 2021, BEV sales have continued to grow (reaching 327000 sales in 2023), whereas PHEV sales have declined (93000 sales in 2023). FCEV sales remain quite insignificant.

BEV: Battery Electric Vehicles solely run on electricity.
FCEV: Fuel Cell Electric Vehicles running on hydrogen.
PHEV: Plug-in Hybrid Electric Vehicles with a gas tank and larger battery.

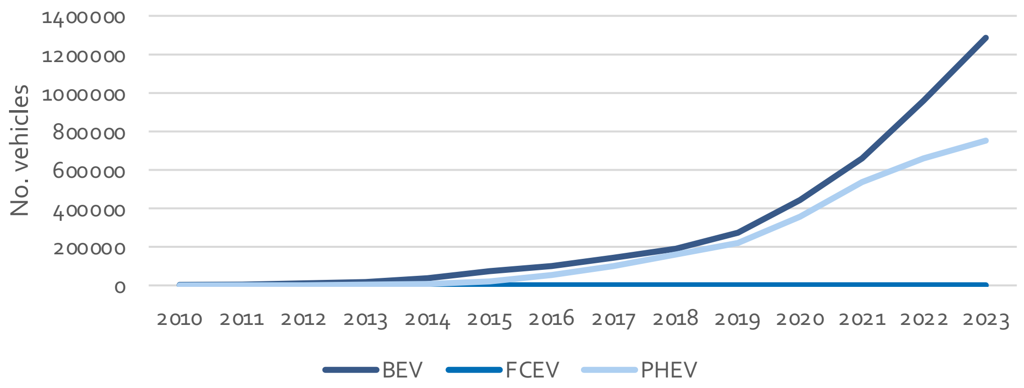


Figure 09.4: Growth of EVs by types of electrical motor

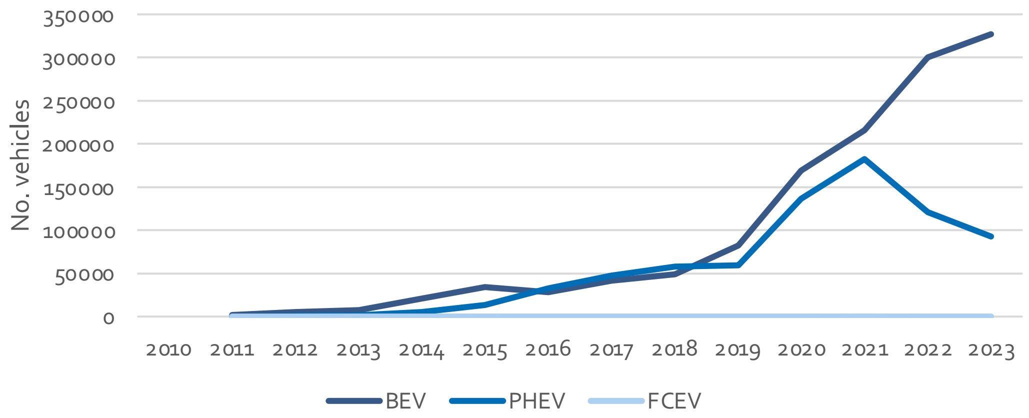


Figure 09.5: Sales of EVs by powertrain

Source: IEA

Electric car sales in the Nordics

In all Nordic countries the popularity of EVs have increased drastically over the last five years.

In 2023, more than 50% of all cars sold in the Nordics were electric. In Norway this is as high as 93%.

EV sales in Norway took off already in 2014 and the other Nordic countries followed later in 2018-2020. The early start in Norway is likely due to government subsidies.

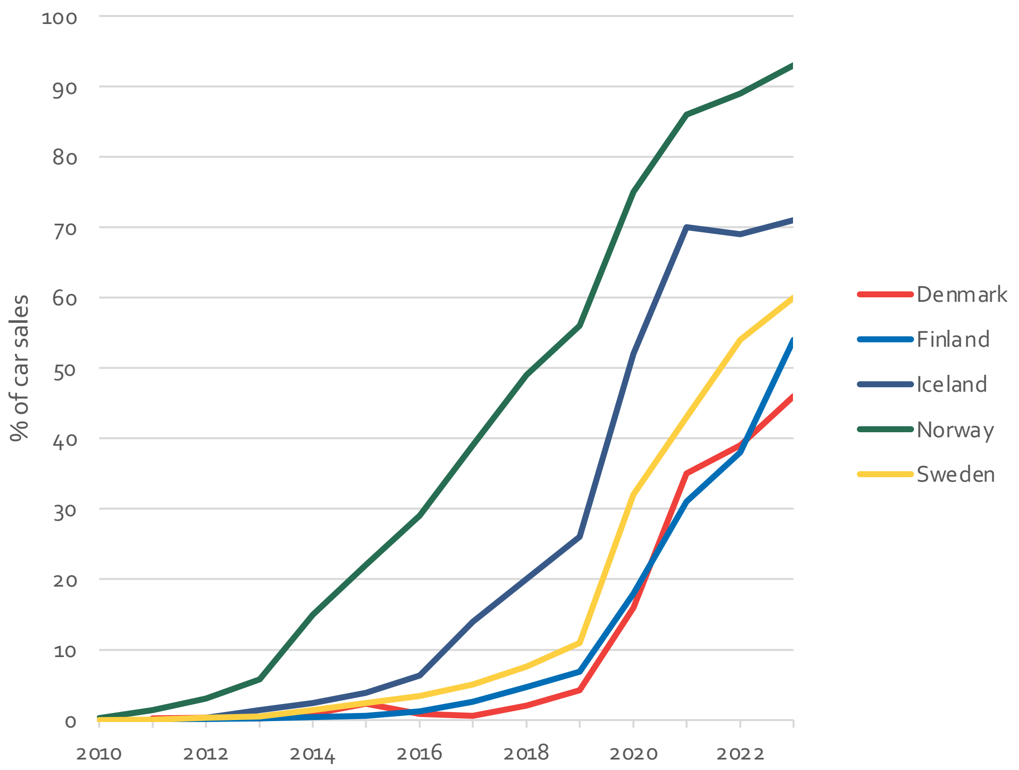


Figure 09.6: Share of EV car sales by country

Source: IEA

Electric vans driving the future

The development of the electric van stock in the Nordic region has seen a remarkable increase over the past few years, with a particularly sharp rise since 2021.

By 2023, the total number of electric vans reached approximately 65,000.

Norway leads the way, accounting for 48% of the region's electric vans, followed by Sweden with 33%. Denmark and Finland hold 14% and 5% of the stock, respectively.

Note: There is no data for electric vans in Iceland

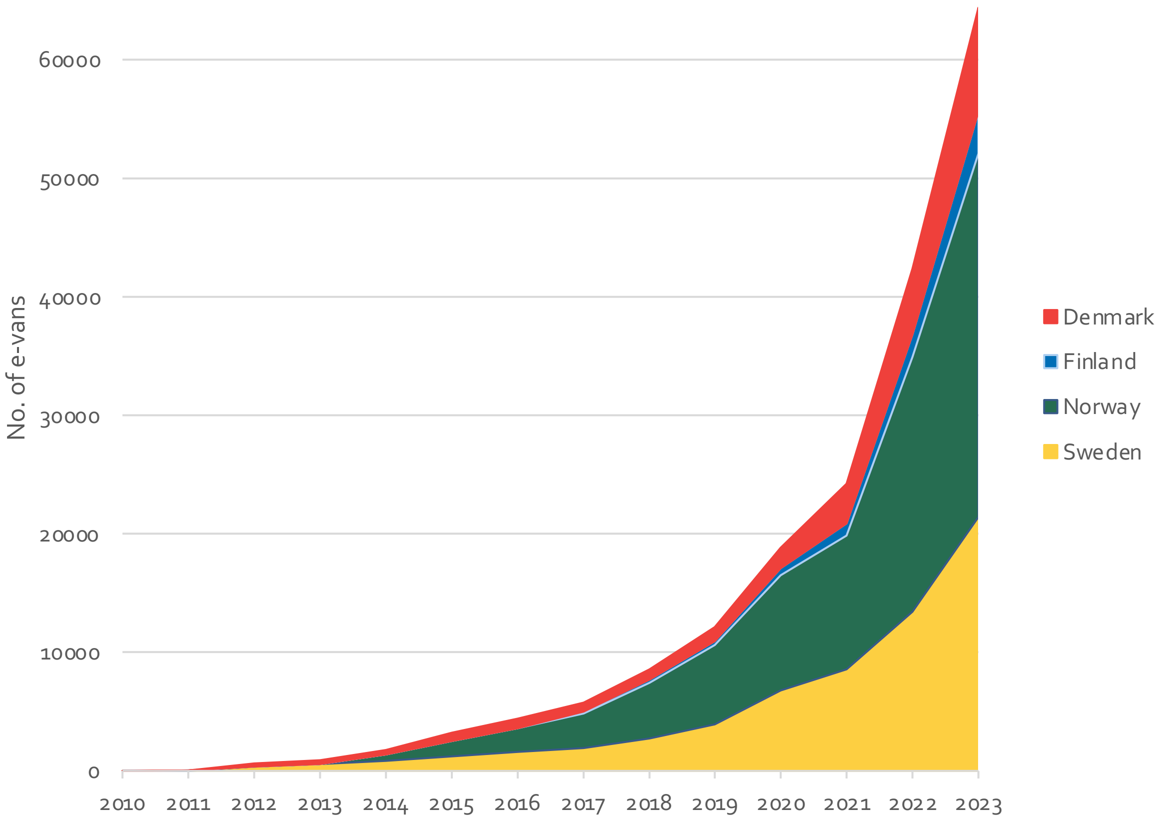


Figure 09.7: Electric vans stock in the Nordics

Source: IEA

Cars or public transportation?

Behavioural changes are important when reducing the emissions from transport sector. Increasing use of public transportation, cycling, and walking reduces the emissions and can improve the health.

The long-term trend in the use of cars versus public transportation seems to be decreasing in Sweden and growing in Denmark and Finland.

The share of cars increased in all Nordic countries during COVID-19 and few years more are needed to be able to assess if this had long-term impacts.

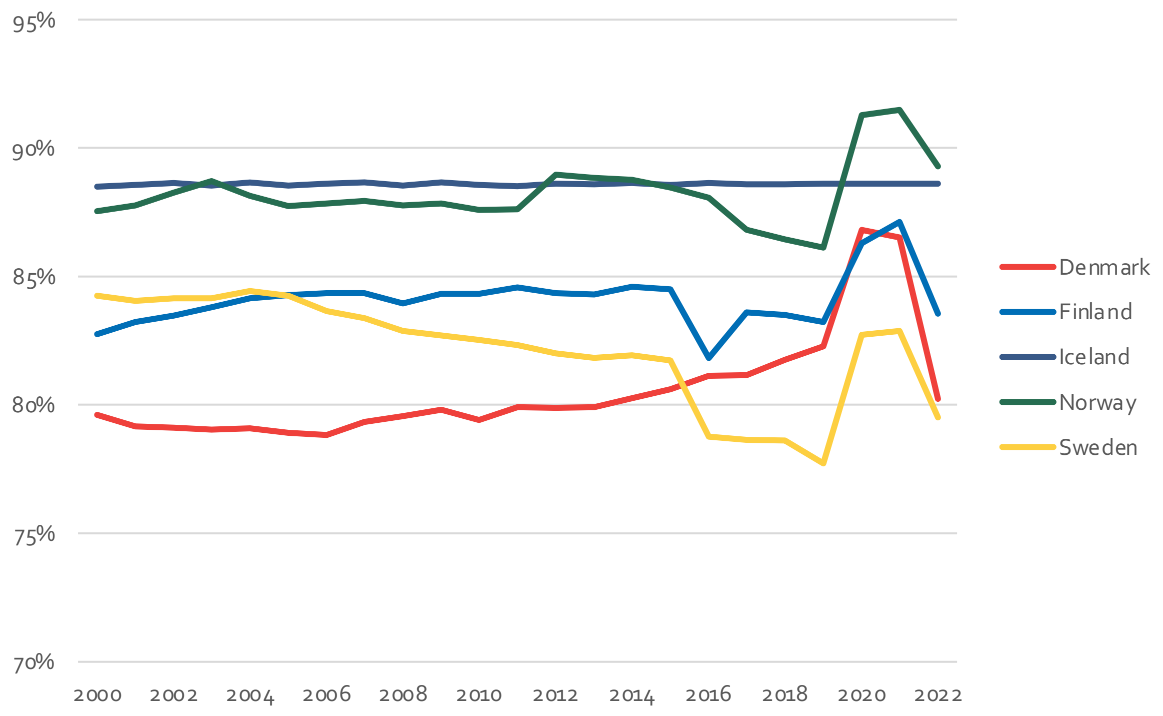


Figure 09.8: Share of inland* transportation travelled by cars

Source: Estat

*Inland: Eurostat statistics of inland transportation includes cars, trains, buses and trams. Airplanes, boats, walking, bicycling, etc. are not included. The figure shows the share of cars, and the remaining share would cover the public transportation.

Note: The shares of transport modes are difficult to estimate, and the statistics have in continuities e.g. in 2016 for Sweden and Finland without an apparent reasons.

In the spotlight: Valmet Automotive

Valmet Automotive operates the Uudenkaupungin autotehdas, Uusikaupunki Finland, which is a significant player in the EV industry. The facility is known for its comprehensive services in EV manufacturing, including the production of electric cars and vans.

Valmet Automotive has also expanded its operations to include battery systems, with a dedicated battery plant in Uusikaupunki that started large-scale production in 2021. This plant focuses on high-voltage battery systems, which are crucial for the electrification of vehicles.

Sources: Valmet-Automotive

Photo: Valmet-Automotive

10

Decarbonising heavy transport

Pioneering carbon-free shipping, heavy road transport and air travel

More flexible storage needed

The Nordic countries are decarbonising the emissions from trucks with biofuels and more recently with electrification. E-trucks reached already a 5% share from the sales of new trucks in Nordics in 2023.

The volume and emissions from international aviation and shipping have increased in the recent decades but saw a sudden drop during the COVID-19 pandemic. The most recent statistics indicate that the sector has returned to old trajectories in 2023 and 2024.

Electrifying trucks

The trend of developing electric trucks (E-trucks) has become increasingly prominent since 2020. This momentum has significantly accelerated over the past two years, with notable advancements and increased development activities in 2022 and 2023.

In 2023, the number of E-trucks in the Nordics grew, with the total stock reaching 2500 e-trucks.

The share of all new trucks has grown over 10% in Norway, that has set and is planning ambitious targets and support policies for e-trucks.

Other Nordic countries have smaller shares of e-trucks, but the trend is similar.

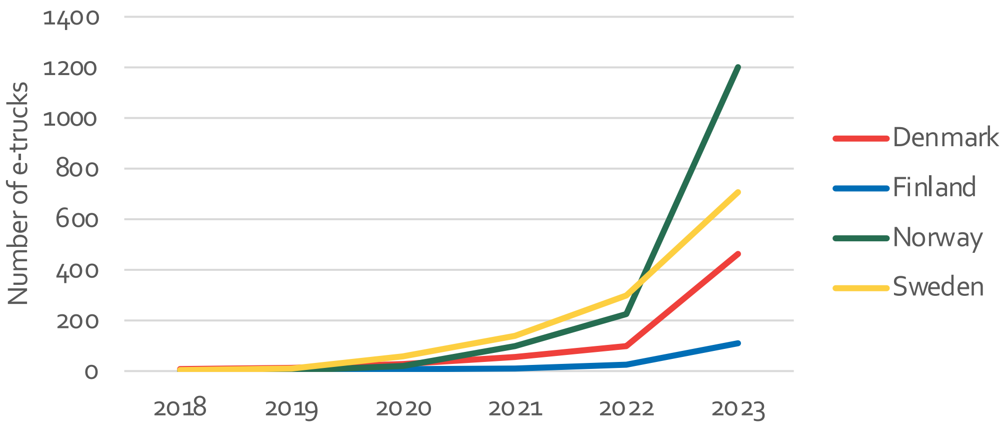


Figure 10.1: E-truck stock development.

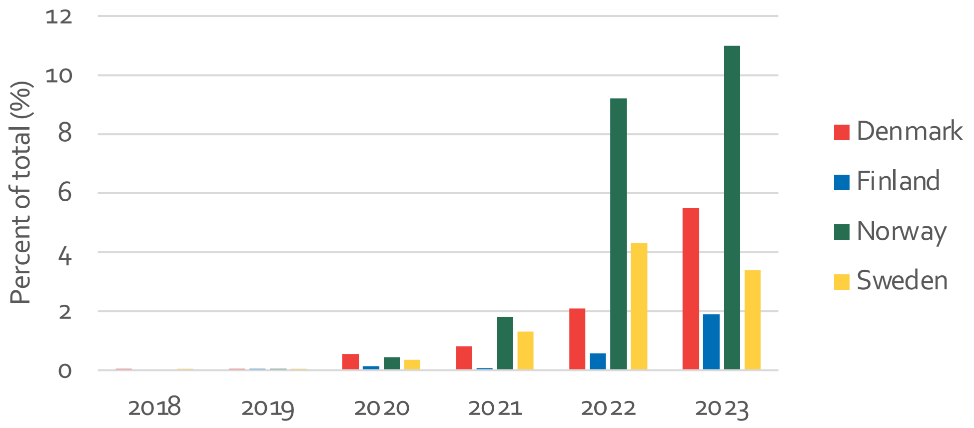


Figure 10.2: E-trucks sales share of total sales.

Source: IEA

In the spotlight: Hydrogen Trucks in Iceland

Five Icelandic companies have committed to purchase hydrogen-powered MAN hTGX freight trucks, marking a significant move towards sustainable transport. These heavy-duty trucks, weighing 44/49 tonnes, will be powered by hydrogen produced at the Hellisheiði Geothermal Power Plant by ON Power and distributed by Blær, the Icelandic Hydrogen Association.

This initiative brings together the truck manufacturer, importer, customers, and energy producers in one of Iceland's largest energy transition projects. ON Power, the sole hydrogen producer in Iceland, has been leading the way in the country's energy transition. Their hydrogen station, VON, has been producing hydrogen for transport since 2020, with an annual capacity sufficient for about 800 hydrogen passenger cars or five to seven large hydrogen trucks.

The project, negotiated by Iceland New Energy (Íslensk NýOrka) for 18 months, involves companies like BM Vallá, Colas, MS, Samskip Iceland, and Terra. Kraftur, representing MAN in Iceland, has secured 20 trucks for the next two years, with the first arrivals expected in spring 2025. A new hydrogen station is also being built to service trucks and passenger cars.

The introduction of these hydrogen trucks is expected to have a significant impact on reducing emissions in Iceland. With ranges up to 600 kilometres, these trucks are competitive with conventional diesel-powered trucks and will help save around 700 000 liters of diesel annually. This project is a major step towards a greener future in heavy transport, with hopes that more companies will adopt emission-free trucks.

Source: *ON, Iceland*

Passenger air transport

Annual flights within Nordic countries saw a consistent rise until the COVID-19 pandemic brought this growth to a sudden halt. The global health crisis caused significant disruptions in air travel, impacting the steady upward trend.

As the world gradually recovers, flight numbers are beginning to return to pre-pandemic levels. However, it will take a few more years to fully understand whether this resurgence will continue along the previous trajectory.

The impact of climate policies on this sector remains unclear due to the pandemic's disruption. As air travel stabilises, future data will be crucial in assessing the effectiveness of these policies in reducing emissions and promoting sustainable travel practices.

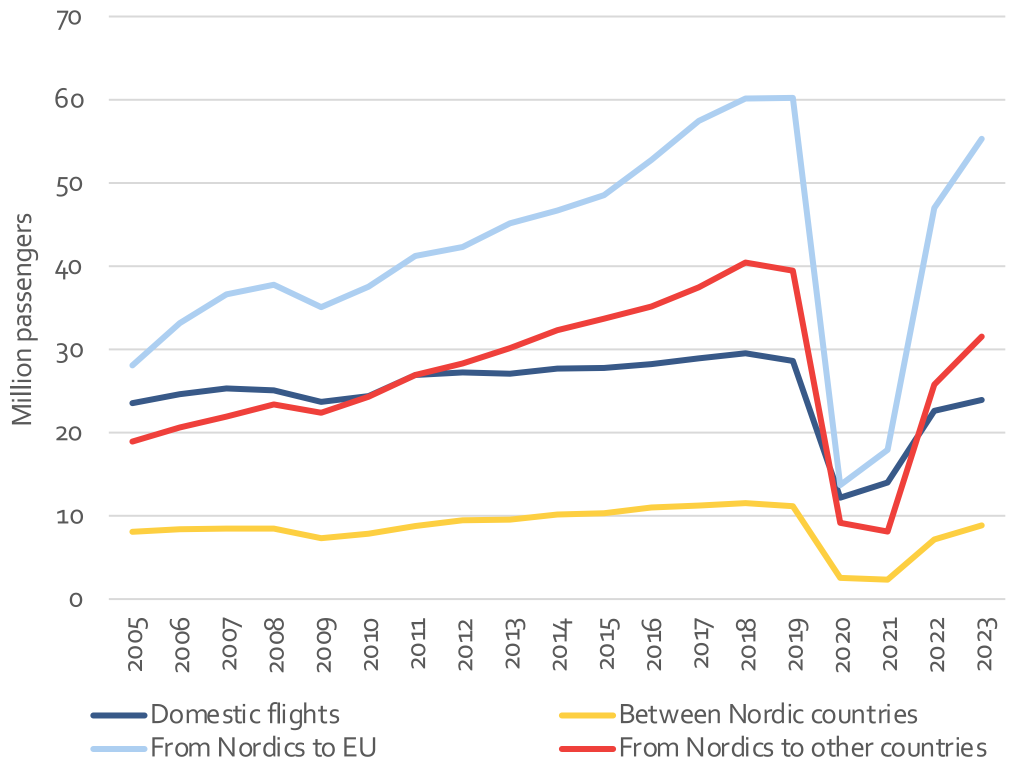


Figure 10.3: Nordic passenger aviation.

In the spotlight: Green Methanol from Kassø: A Step Towards Sustainable Shipping

In Kassø, Southern Jutland, one of Denmark's most advanced Power-to-X plants is set to revolutionise green fuel production. This facility will soon produce green methanol, which will be transported via the Port of Aabenraa to fuel AP Møller-Maersk's ships. The plant features an electrolysis unit using green electricity sourced from Northern Europe's largest solar park. This hydrogen is then combined with biogenic CO2 to create green methanol for Maersk's new methanol-powered vessels.

The electrolysis plant in Kassø has a capacity of 52MW and, when fully operational, will produce 42,000 Tonnes of green methanol annually. The plant's inauguration is scheduled for late 2024, marking a significant milestone in Denmark's green energy initiatives.

Maersk eagerly anticipates the arrival of Kassø's first batch of green methanol for the container ship Laura, expected by the end of the year. However, Maersk acknowledges that the 40,000 tonnes of e-methanol produced annually by the Kassø plant will only meet the yearly consumption of a single container ship. This highlights the immense scale of Maersk's ambition to have 25% of its fleet running on green fuels by 2030, necessitating a substantial increase in green fuel production both in Denmark and globally.

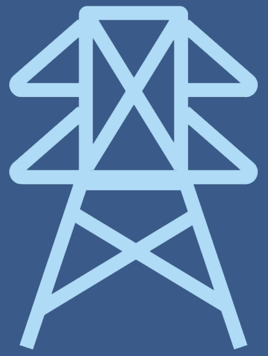
While the Kassø plant represents a significant step forward, it also underscores the broader challenge of scaling up green fuel production to meet the ambitious targets set by industry leaders like Maersk. The journey towards a sustainable maritime industry is underway, but achieving these goals will require concerted efforts and innovations across the globe.

Source: ON, Iceland

11

Grid infrastructure

Electricity trade and hydrogen infrastructure



Infrastructure is not keeping up

The clean energy transition requires very large investments in infrastructure, with estimates up to 600 billion euros/year in EU in this decade only (according to EEA).

Successful infrastructure investments require international cooperation on Nordic and European level.

The clean transition sets significant needs particularly on electricity, hydrogen, and CO2 infrastructures. The electricity grid requires investments and improvements, but the CO2 and hydrogen infrastructures need complete refurbishment.

Investments are progressing, but there has been some delays due to recent economic uncertainty, a period with higher interest rates, and social acceptance of construction projects.

Estimated value of electricity trade

The estimated value* of Nordic electricity exports was just under 1000 million euro per year from 2015 to 2020. High market prices in 2021 and 2022 increased the estimated revenues significantly.

The year 2023 and the first 9 months of 2024 had export values of 5000 million euros and 2500 million euros, respectively.

New interconnectors have increased the volume and value of trade. In addition, the European power systems face regular high prices increasing the value of Nordic exports.

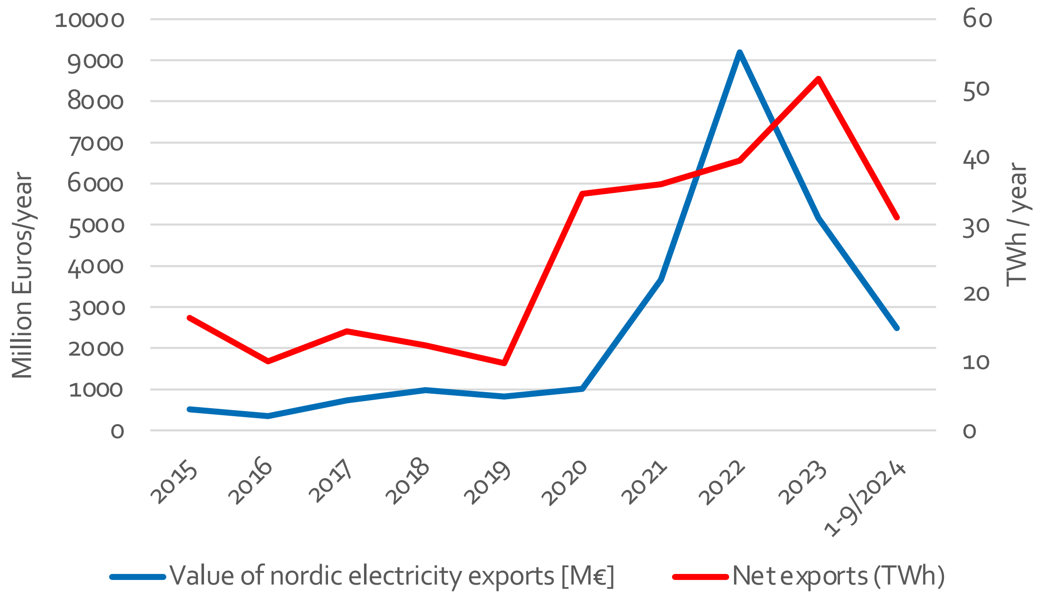


Figure 11.1: Estimated value* of the electricity trade. Data source: ENTSO-E transparency platform.

* Estimated value = scheduled transfers between market regions * area prices of exporting regions.

Annual electricity trade among the Nordics

The Nordic countries have significantly increased their net electricity exports to Central Europe, rising from 12 TWh/year between 2015-2019 to an impressive 40 TWh/year from 2020-2023.

Leading the charge, Sweden has emerged as the largest net exporter, contributing around 30 TWh/year. Meanwhile, Finland has significantly reduced its imports, dropping from 15 TWh/year (2015-2022) to just 3 TWh in 2023, thanks to the expansion of its nuclear and wind power capacities.

The share of net exports outside Nordic countries have increased when new interconnectors to Central Europe and the United Kingdom have been completed. Most notably, Norway's net exports are redirected from other Nordic countries to the United Kingdom and Central Europe.

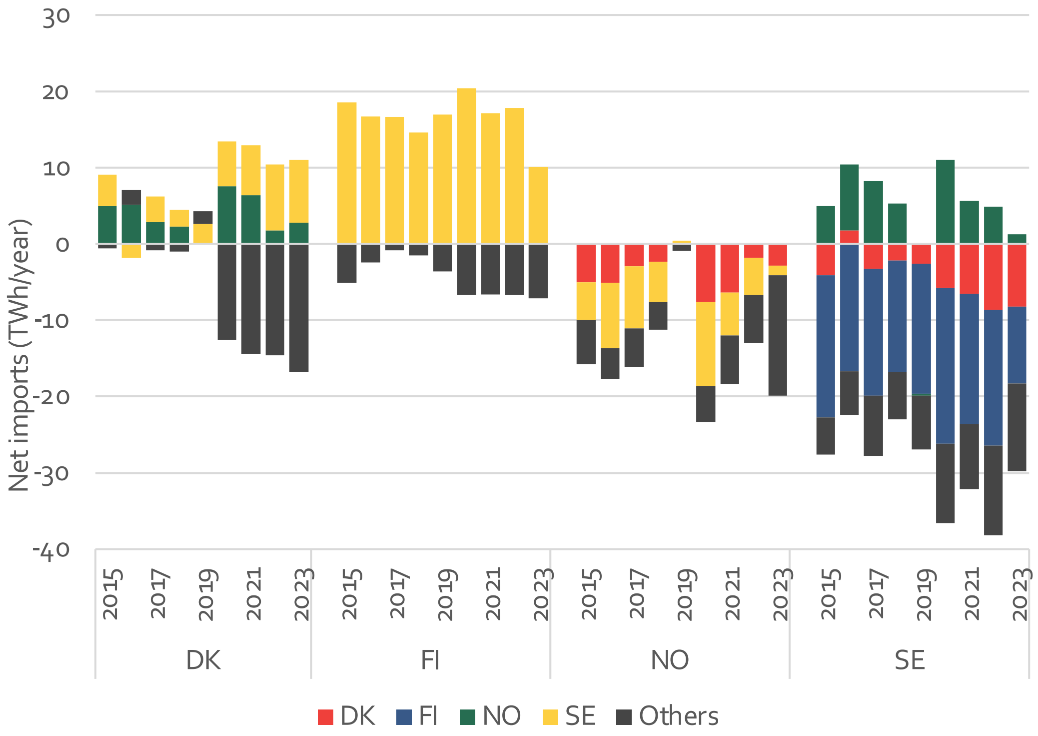


Figure 11.2: Nordic countries' annual electricity trade. Imports is indicated by positive numbers, and export is indicated by negative numbers. Data source: ENTSO-E transparency platform.

Estimated bottleneck revenues

Transmission companies collect bottleneck revenues when the connection between two countries is too weak, causing price differences.

The estimated bottleneck revenues* were 12500 million euros in 2022 and 4500 million euros in 2023.

Bottleneck revenues should be primarily used to make grid investments, but also to maintaining network security, reducing congestion costs, and offsetting tariffs for network users.

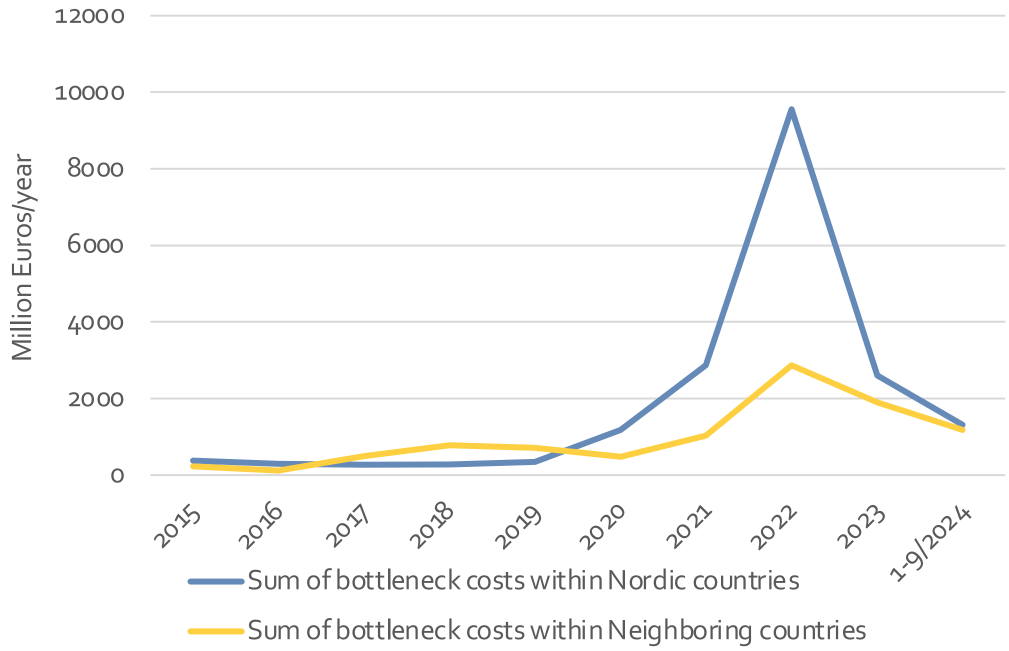


Figure 11.3: Estimated bottleneck revenues*. Data source: ENTSO-E transparency platform

*Estimated bottleneck revenue = scheduled transfers between market regions * difference in area prices

In the spotlight: Svenska kraftnät's Region Nord programme

Region Nord, formerly known as Fossil-Free Upper Norrland, is the name of the investment program created by Svenska kraftnät to enable the industrial energy transition in northern Sweden.

The program is also a pilot for Svenska kraftnät's new working approach, which aims to halve lead times so that a power line can be operational seven years after the start of the process, instead of the usual 14 years.

To succeed in the energy transition, new power lines and substations are needed to connect both industries and new wind power facilities on land and at sea.T he primary driver of the program is the industry's transition to fossil-free operations, but geographically adjacent investment projects are also included.

The program currently encompasses a total of 20 projects, divided into three main projects: Norrland Coast, Malmfälten, and Aurora Line.

Sources: Green Power Denmark, link 1 and link 2

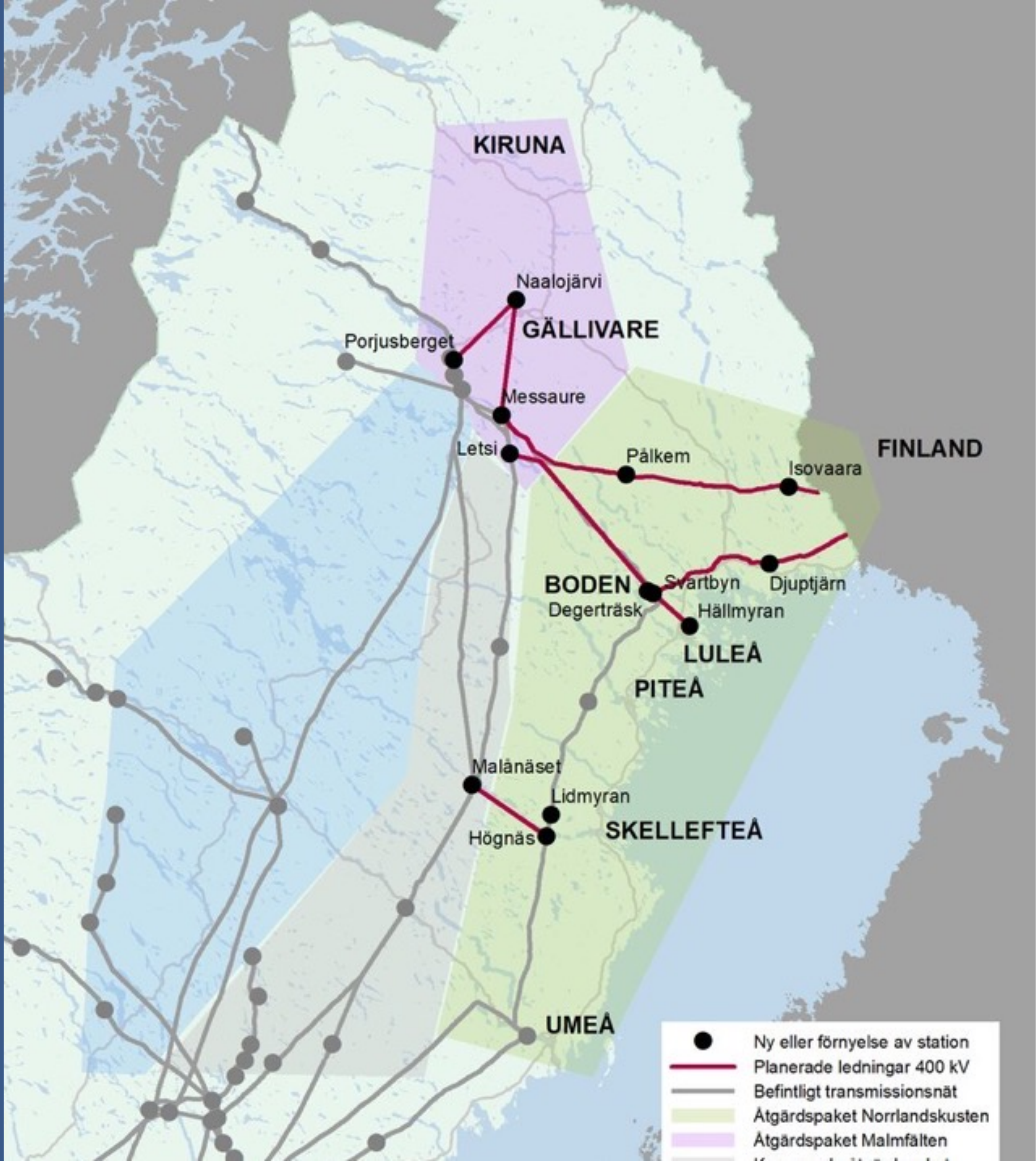


Photo: CO_2 tanks arriving Øygarden, Northern Lights.

Nordic cooperation on CO_2 infrastructure

In the Nordic Clean Energy Scenarios study, carbon capture and storage (CCS) was expected to take off around 2030, and the total volume of the CO_2 captured and stored was 8 $MtCO_2$/year in the Nordics in 2030.

Norwegian Northern Lights completed the first CO_2 receiving station in 2024. The first phase is aiming for 1.5 $MtCO_2$/year and the second phase to 5 $MtCO_2$/year

Four Nordic countries (Norway, Denmark, Finland, and Sweden) have agreed to collaborate on cross-border transportation and storage of CO_2.

The Northern Light's facility will receive part of the CO_2 from Nordics.

- Stockholm Exergi is converting a biomass-fired power and heat plant to be able to capture CO_2 with estimated volume of 0.8 $MtcCO_2$/year.
- Fortum Oslo Varme is planning to convert a waste incinerator plant to be able to capture CO_2 with estimated volume of 0.4 $MtCO_2$/year.

The CO_2 infrastructure is taking crucial technological and legislative steps, but the pace seems to be slightly slower than in the modelled scenarios.

12

Europe and the World

Comparison of the global and European perspectives with the Nordics

More flexible storage needed

The Nordic countries stand out globally for their high electricity consumption per capita, significantly exceeding both European and global averages. However, this is offset by a strong commitment to green energy, with a large portion of electricity produced from renewable sources like hydro, wind, and geothermal power, making their energy consumption much greener than in many other regions.

While many European countries and other parts of the world still rely on fossil fuels, contributing to higher CO2 emissions, the Nordics reduce their carbon footprint and set a global benchmark for sustainable energy. At the same time, energy efficiency measures should be prioritised to further reduce electricity consumption.

The Draghi report highlights that Europe's future competitiveness depends on transitioning to a low-carbon economy, moving away from imported fossil fuels and price volatility. The Nordic countries serve as a model of how sustainable energy practices can benefit both the environment and the economy.

Electricity consumption

Since the 1990s, electricity consumption per capita has surged across the globe, reflecting the intertwined nature of economic development and energy use. The world has seen a staggering 66% increase, Europe a more modest 12%, and the Nordics an impressive 48%. This rise in electricity consumption per capita mirrors the economic strides made, with advancements in technology, industrial growth, and improved living standards driving the demand for more power.

Fast forward to 2022, and the Nordics stand out with a significantly higher electricity consumption per capita compared to both Europe and the World. This isn't just a statistic; it's a testament to the region's robust economic health and high quality of life. Europe, while not matching the Nordics, still consumes twice the amount of electricity per capita as the global average, underscoring its own economic vigour and technological advancements.

In essence, the story of electricity consumption is one of progress and prosperity, highlighting how far we've come and the power we need to sustain our modern lifestyles.

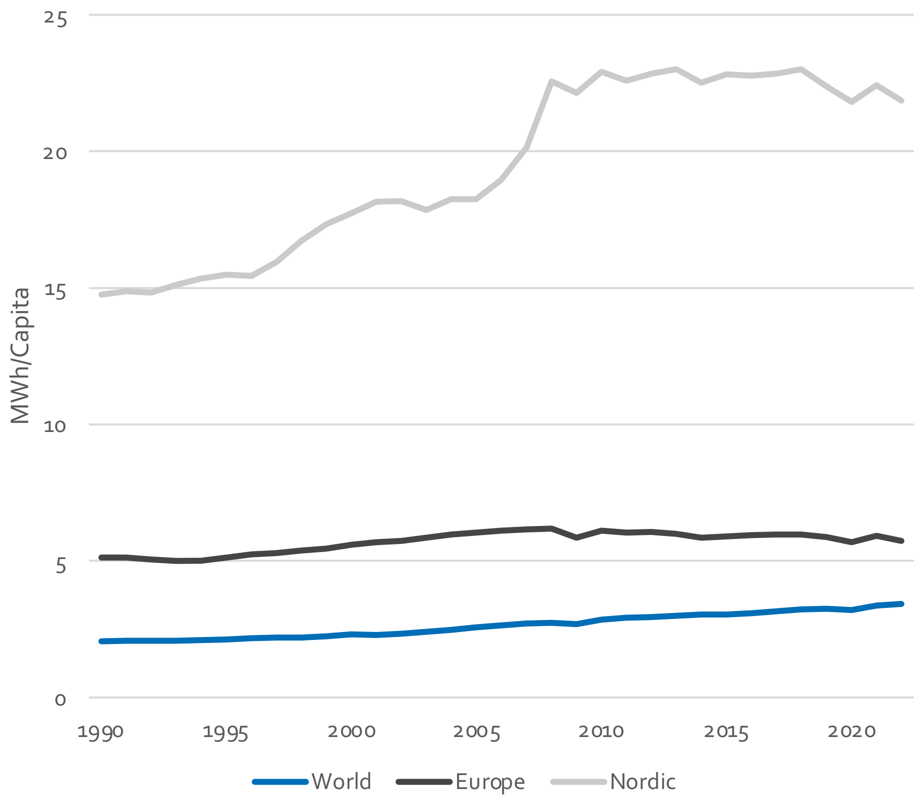


Figure 12.1: Electricity consumption per capita 1990-2022

Source: *IEA*

Renewable energy share in power generation

Since the 1990s, the share of renewables in power generation has risen significantly—globally by 11 percentage points, and in Europe by 27 percentage points. The Nordics, already leaders in renewable energy, have increased their share by 22 percentage points, thanks to abundant natural resources like hydropower, geothermal, and wind power, along with strong governmental policies supporting green energy.

By 2022, renewables accounted for 78% of Nordic power generation, compared to 38% in Europe and 26% globally. This achievement reflects the region's early adoption of renewable technologies and continued investment in sustainable infrastructure, setting a global benchmark.

The Nordics' high renewable share not only underscores their environmental leadership but also results in significantly lower CO2 intensity in power generation compared to Europe and the world. This demonstrates that economic growth can go hand-in-hand with reducing carbon emissions and promoting sustainability.

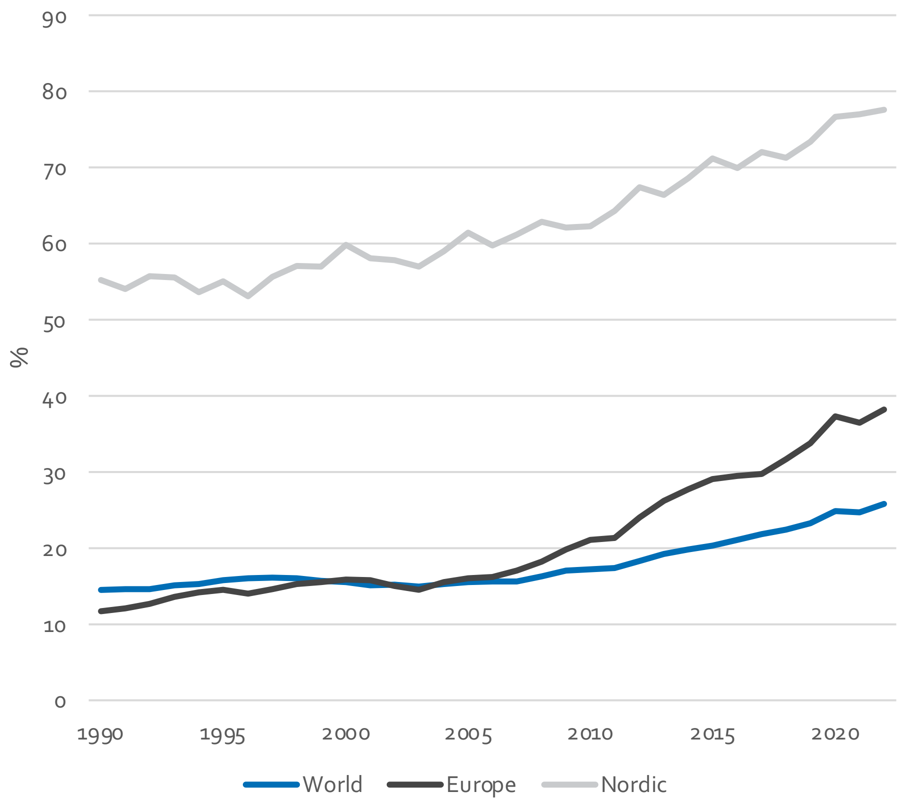


Figure 12.2: Renewable energy share in power generation 1990-2022

Source: IEA

13

Joint Nordic Action

Sharing the road to carbon neutrality

Recommendations for Enhanced Nordic Cooperation

Energy Security and Resilience Strategy

- Develop a Nordic energy resilience framework to manage risks from geopolitical tensions, climate change impacts, and supply chain disruptions.
- Coordinate strategic energy reserves and emergency response plans to strengthen energy security across the region.

Coordinated Nordic Grid Development

- Develop a coordinated Nordic grid plan, leveraging offshore wind synergies.
- Conduct a common Nordic modelling exercise to assess synergies and ensure efficient resource allocation.

Nordic CCS Strategy

- Formulate a Nordic carbon capture and storage (CCS) strategy to capitalise on shared infrastructure for carbon transport and storage.
- Enhance collaboration to realise economies of scale and improve overall cost-effectiveness in CCS.

Nordic Hydrogen Infrastructure Roadmap

- Create a joint roadmap for electricity and for clean hydrogen infrastructure, addressing production, transport, and storage needs across the Nordics.
- Focus on harmonising standards to support an integrated hydrogen economy and cross-border trade.

Recommendations for Enhanced Nordic Cooperation

EU Regulation Alignment

- Establish a coordinated Nordic position on relevant EU regulations to support seamless implementation.
- Work together to align Nordic interests and enhance influence in EU regulatory processes.

Pool resources for innovation

- Secure common funding for pilot projects that demonstrate emerging technologies with the potential to benefit all Nordic countries.
- Focus on identifying and scaling the most promising green technologies for the Nordic region, such as advanced PtX solutions and innovative offshore wind technologies like floating offshore.