Challenges and opportunities of achieving zero carbon in the Nordic countries

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Defining Nordics

The Nordic countries – or Nordics – make up a region in Northern Europe and the North Atlantic. Situated on the historical territories of Scandinavia, they share a common culture and history. Five states and three territories make up the Nordics: Finland, Denmark, Iceland, Norway, Sweden and Greenland, the Faroe Islands, and the Åland Islands. More than 27 million people live in the Nordic countries, and they speak 18 languages. Sweden, Denmark and Finland are members of the European Union, and while Norway and Iceland are not part of EU, their connections with the rest of the Nordic countries are traditionally strong, and cooperation in zero carbon movement is no exception.

The Nordic countries are members of the Organisation for Economic Co-operation and Development and OECD Nuclear Energy Agency (NEA).

The Nordic region is the world's 11th largest economy [1] and performs above the EU average in economic development. Nordics attract significant foreign investment, accounting for 7% of Europe's total Foreign Direct Investment (FDI) inflows, in a region having 4% of the European population [60].

The Nordic countries share a common view on the economic development. In 2019, the new Nordic Vision 2030 was approved by the Nordic prime ministers. It defines the strategic framework for developing the region into the world's most sustainable and integrated region.

Innovation is key to development in the Nordic countries. The share of employment in knowledge-intensive sectors is well above the EU28 average. Sweden continues to be the EU innovation leader, followed by Finland and Denmark, while Norway and Iceland rank 10th and 14th, respectively, and above the EU average [60].

Common challenges for achieving zero carbon targets in the Nordic countries reflect the fact that they all lie in the northern part of Europe, and all share a similar cultural and economic background. This geographical, cultural and economic similarity underpins the Nordic countries' joint approach to achieving zero carbon. The common desire – shared by all Nordic countries – is to make the region the most sustainable and integrated region in the world by 2030 [187].

However, divergences between the Nordic countries are substantial enough to be reflected in their zero carbon policies and priorities. Finland and Sweden are the most heavily forested countries in Europe. They supported the COP26 decision to end deforestation by 2030, but it is important for them to ensure forestry policy remains high on the national agenda. Norway's coastal location is enabling wider wind power use, but abundance in oil supply and long domestic air traffic distances make the country reluctant to take necessary steps towards zero carbon targets in these sectors. Denmark's climate is milder than its Nordic neighbours. More than half of the country is farmed, making the agricultural sector a heavy carbon emitter. Iceland's geographical location makes it a unique example of a highly but unilaterally developed country with emphasis on fishing, metal and mineral industries.

International agreements on climate change and the Nordic countries

Achieving net zero CO_2 emissions (or carbon neutrality) means balancing anthropogenic CO_2 emissions on a global scale by anthropogenic CO_2 removals over a specified period[1]. A climate-neutral world by mid-century is a primary goal stated in the Paris Agreement, which is to be achieved by limiting global warming to below 2 degrees Celsius, compared to pre-industrial levels.

The United Nations Framework Convention on Climate Change (UNFCCC, 1992) remains the main international treaty addressing climate change.

The most important contemporary international agreements on climate change are the Paris Agreement [143], adopted by all UNFCCC Parties in 2015, the UN 2030 Agenda and Sustainable Development Goals [196] and the EU Commission's strategy, including its new EU Green Deal [7]. The Paris Agreement requires participating countries to prepare plans for climate action or Nationally Determined Contributions (NDCs).

The UN Climate Change Conference COP26 was held in Glasgow, Scotland in November 2021, after being postponed due to the COVID-19 pandemic. Hopes were for COP26 to play a significant role in keeping pace with zero carbon goals. Nordic ministers for climate and environment declared their full support for COP26 and confirmed their commitment to the goal of mobilising $100 billion per year from 2020 [126]. In November 2021, they discussed cooperating to achieve the targets set by COP26 [118]. In Glasgow, Nordic Energy Research[2], an intergovernmental organisation within the Nordic Council of Ministers, presented Nordic solutions for clean energy in energy, maritime and wind power sectors [120].

Pledges made by the Nordic countries at COP26[3].

	End deforestation	Net zero target date	Phase out coal	Cut methane emissions
Denmark	yes	2050	yes	yes
Finland	yes	2035	yes	yes
Iceland	yes	2040	no	yes
Norway	yes	No target set	no	yes
Sweden	yes	2045	no	yes

All Nordic countries except Norway have zero carbon goals enshrined in law or policy[4], support international climate negotiations, and show willingness invest in innovative climate friendly solutions [94]. Sweden plans to double climate aid to low income countries by 2025 [128], Norway by 2026 [117], and Denmark will contribute at least 1% of its international funding target for climate efforts in developing countries [103].

The Nordic countries fulfil their international agreements on climate change on three interrelated levels: individually, as EU member states or members of the European Economic Area (EEA), and through cooperation at the Nordic level.

All Nordic countries also participate in the EU Emissions Trading System (EU ETS), the EU's main tool for reducing GHG (greenhouse gas) emissions.

The main partnership agreement on zero carbon in the Nordic context is the Helsinki Declaration on Nordic Carbon Neutrality (2019) [76]. It supports the cooperation of the Nordic countries on the road to renewable energy, promoting joint Nordic business and research, and encouraging investments in climate friendly sectors of economy.

[1] https://www.ipcc.ch/site/assets/uploads/sites/2/2018/07/SR15_SPM_version_stand_alone_LR.pdf
[2] https://www.nordicenergy.org/
[3] https://www.aljazeera.com/news/2021/11/14/infographic-what-has-your-country-pledged-at-cop26
[4] https://www.wri.org/insights/how-countries-net-zero-targets-stack-up-cop26

The EU dimension

In 2019, following the European Green Deal, the European Commission adopted a package of climate proposals designed to make the EU's policies fit for reducing GHG emissions by at least 55% by 2030, en route to the 2050 net-zero goal [59]. These 'Fit for 55' legislative package measures include tightening changes in the EU ETS, an alignment of taxation policies with the European Green Deal objectives. EU member states are advised to use all their emissions trading revenues on climate and energy-related projects. Strengthened emissions reduction targets are set in the Effort Sharing Regulation[5] (emissions targets for each EU member state), the Regulation on Land Use, Forestry and Agriculture [155] (carbon removals by natural sinks equivalent to 310 million tonnes of CO_2 emissions by 2030), the Renewable Energy Directive [11] (40% of energy from renewable sources by 2030), a revision of the Energy Taxation Directive [154] (to align taxation of energy products with EU energy and climate policies) and several other directives.

The new EU initiative defines new 50% reduction targets for those Nordic countries which are members of the EU (Denmark and Finland are aiming at 39% reductions by 2030 and Sweden at 40% compared to 2005). Emission targets in Norway and Iceland, which are not members of the EU, remain at their previous level (40% both). This level was agreed in 2019 when the EU, Iceland and Norway agreed to deepen their cooperation on climate action [183]. In July 2021, prior to the announcement of 'Fit for 55' initiative, Norway and Iceland announced their commitment to cooperate with the EU on climate change and their readiness to discuss the proposals, although no clear promises were made to announce the exact amount of GHG reductions by 2030.

The ETS, established in 2005, is the main EU mechanism for achieving zero-carbon targets [58]. In 2021, the EU announced plans to strengthen the ETS to help achieve climate neutrality in the EU by 2050. EU countries are introducing policies and incentives to maximise the use of low-carbon technologies through carbon-pricing instruments such as the EU ETS. The EC proposed 12 policies, targeting energy, industry, transport, and heating[6].

The Nordic countries will try to advance their own interests during negotiations. For instance, possible biomass exclusion from the list of renewable sources of energy would face objections from Finland and Sweden, where it plays a significant role. The Nordic EU countries will support the ban on coal, but eastern EU countries will worry about the economic and social consequences of such step.

For the Nordic countries, one of the challenges is that ETS legislation is not adapted for situations when CO_2 is transported to storage sites across national borders, for example from Sweden and Finland to storages sites in Norway and Denmark. To solve this problem the Nordic countries are establishing the Measurement Reporting Guideline (MRG) for shipping CO_2 [188].

The Nordic approach to zero carbon

Nordic countries share a common desire to work together to achieve – and even exceed – zero-carbon targets set by the Paris Agreement and EU Green Deal. However, each country defines and interprets 'carbon neutrality' differently and has a different legislative timescale for reaching this goal. For some of the Nordics, carbon neutrality is defined as reductions on their own territory, while others provide for the use of international mechanisms to offset national emissions.

The Nordic countries share a common desire to lead global green transformation, rather than merely participating in the decarbonisation process. National targets for Nordic countries on achieving zero carbon are ambitious: Norway – 2030 carbon neutral, Finland – 2035 net zero GHG emissions, Iceland – 2040 carbon neutral, Sweden 2045 – zero net GHG emissions, Denmark – 2050 zero net GHG emissions [115].

[5] https://ec.europa.eu/info/files/effort-sharing-regulation_en
[6] https://ec.europa.eu/clima/eu-action/eu-emissions-trading-system-eu-ets/revision-phase-4-2021-2030_en

The Nordic countries are also keen to capitalise on their high environmental standards, environmental R&D and well-organised systems of bioeconomy investments.

There are aspects where the Nordic countries' approaches are different, such as the use of international mitigation transfers and sectoral boundaries. Norway allows the potential use of international transfers, which means that mitigations that occur outside a country's borders can be counted towards the net zero target. Sweden allows such transfers but specifies an upper limit to their use. Sweden also excludes international aviation and shipping emissions from its pledge to achieve zero-carbon [110].

Nordic cooperation on emission reductions

The Nordic countries are working hard to boost cooperation on many levels and in many areas. The Nordic Council of Ministers, whose secretariat is headquartered in Copenhagen, Denmark, has been the official body for intergovernmental cooperation between the Nordic countries since 1971. Within the framework of the Nordic Council of Ministers there are several Nordic working groups on climate [197]:

- Nordic Working Group for Circular Economy (NCE)
- Nordic Working Group for Climate and Air (NKL)
- Nordic Working Group for Chemicals, Environment, and Health (NKE)
- Nordic Working Group for Biodiversity (NBM)
- Nordic Working Group for Environment and Economy (NME)
- Nordic Working Group for Oceans and Coastal Areas (NHK)
- Nordic Working Group for Sustainable Cities
- Nordic Energy Research
- Nordic Networking group on Carbon Capture, Use and Storage (NGCCUS)

Declarations by the Nordic Council of Ministers refer to zero carbon targets and announced the commitment of Nordic countries to the ideas of Paris Agreement. These declarations include the Nordic Declaration on Clean Energy (2018) [121]; Nordic Ministers for Climate and Environment – the road to COP26 and beyond (2021) [126]; and the Nordic Cooperation Vision for 2030 (2019)

[141]. In 2021, the Nordic Council of Ministers also adopted Nature-based solutions[7] (NBS) from the IUCN, International Union for Conservation of Nature.

Nordic countries' cooperation on climate protection is supported by the Nordic Environment Research Corporation (NEFCO) and the Nordic Investment Bank (NIB), which act according to the Nordic priorities outlined in the Helsinki Declaration on Nordic Carbon Neutrality (2019). Both institutions are providing support to green projects, not only in Nordic countries, but also to Baltic states and other countries in Eastern Europe, including Russia.

NEFCO was established in 1990 as an International Financial Institution (IFI) and is the only Nordic institution accredited by the Green Climate Fund[8] (GCF), a global platform for investing in low-emission and climate-resilient development in developing countries. Since then, NEFCO has financed many private and public projects. In Nordic countries NEFCO mainly supports SMEs which intend to expand globally, while in Eastern European countries its support is aimed mainly at municipal environmental programmes.

In 2018 NEFCO launched the so-called Nordic initiative for Cooperative approaches (Finland, Sweden, and Norway) to facilitate partnerships that support efforts to achieve carbon neutrality in the Nordic countries and around the world [123].

The Nordic Investment Bank (NIB) is co-financing projects that are linking national electricity markets, providing a better balance of power in the network and thereby reducing GHG emissions. In 2020, NIB and the Norwegian Statnett made an agreement to upgrade the main electricity grid in Norway (Western Corridor). This will enable Norway to benefit from surplus wind power in Denmark, Germany and the UK, reducing fossil fuel power generation in Norway [193].

By 2020, the Nordic countries established the Nordic Environmental and Climate Cooperation Programme [145], which targets at implementation of the Sustainable Development Goals in the 2030 Agenda and developing Nordic cooperation for the green transition.

In 2021, NEFCO announced that its focus would be on promoting Nordic green technologies and solutions that have a significant impact on the climate and environment [109]. NEFCO represents the Nordic approach to identifying areas essential to achieving carbon neutrality in energy, transportation, food and agriculture, forest, manufacturing and materials, water, seas and oceans and waste.

The Call on Carbon initiative[9], launched by climate-business networks in Finland, Sweden, and Norway in 2021 is calling for more climate investment and a more effective carbon pricing system.

The Nordic business community and zero carbon goals

Nordic businesses see an opportunity in the green agenda, and the Nordic leaders' political declaration was supported by a joint declaration of Nordic business confederations [127].

The Confederation of Danish Industry[10], the Confederation of Finnish Industries[11], as well as the Confederation of Norwegian Enterprises[12] and Confederation of Swedish Enterprises[13] are all committed to supporting climate policy. Along with the commitment to contribute positively to the EU's long-term climate policy, Nordic business groups are also focused on maintaining a competitive industrial stronghold. They want to enable European companies to provide climate solutions globally. In other words, Nordic companies count on governmental support programmes to ensure their competitiveness.

[7] https://www.iucn.org/theme/nature-based-solutions
[8] https://www.greenclimate.fund
[9] https://calloncarbon.com/
[10] www.danskindustri.dk
[11] https://ek.fi/en/
[12] www.nho.no/en/
[13] https://www.svensktnaringsliv.se/

The Nordic Business community supports the EU's carbon-pricing instruments (EU ETS[14]) in the form of Pigouvian taxes[15], encourage greater investment in low carbon technologies and innovation programmes, including digitalisation. In the transition towards a low carbon economy, Nordic businesses rely on the deployment and development of low emission technologies, products and services in Europe [127].

There is also a common belief that climate neutrality could also promote the creation of smart infrastructure based on advanced technologies such as 5G. The EU Commission supports the "100 climate neutral cities by 2030" mission [2], and the Nordic countries launched a project on Nordic Transition Partnership for Climate Neutral Cities 2030 to enable small- and medium-sized municipalities to become carbon neutral by 2030 [128].

Zero carbon R&D in Nordic countries

The Nordic countries are world leaders in environmentally-related R&D.

The Helsinki Declaration on Nordic Carbon Neutrality is supported by research and scenario modelling of the development of the region's carbon neutral energy sector. The clean energy scenarios in Tracking Nordic Clean Energy Progress 2020 [195] build on the analysis of regional long-term low-carbon technology pathways published in 2013 and 2016 [122]. Unlike previous research, this project clearly targets developing carbon neutral scenarios for the Nordic countries, strengthening cooperation between Nordic energy researchers, and analysing energy technologies with global and Nordic climate change mitigation potential. Three scenarios were developed and explored: Carbon Neutral Nordic (the least expensive approach based on current national strategies for zero carbon), Nordic Powerhouse (the opportunities for the Nordics to play a larger role in European energy transition) and Climate Neutral Behaviour (where Nordic societies are adopting energy and material efficiency measures in all sectors).

The crucial importance of R&D investments for a low-carbon future is widely recognised in the Nordic countries, and the focus of R&D investments is believed to be in low-emission energy

[14] https://ec.europa.eu/clima/policies/ets_en

[15] https://www.investopedia.com/terms/p/pigoviantax.asp

and materials. Accelerating decarbonisation through R&D investments is identified as removing of bottlenecks in technology adoption, boosting technology commercialisation and promoting synergies and cooperative models between sectors [168].

CCS, BIOCCS (bioenergy carbon capture and storage) and other Negative Emission Technologies (NETs) are the focus for RDI investments in the Nordic countries and are identified in national strategies [144]. In this area, the Nordic countries rely on support from the EU Innovation Fund worth €20 billion in 2020-2030 for the commercial demonstration of innovative low-carbon technologies[16].

Economy sectors and zero-carbon goals

The Nordic approach to achieving zero carbon targets is based on technological innovations and policy commitments. The Nordic countries' environmental priorities are to accelerate the green transition in the economy. The Declaration on Nordic Carbon Neutrality in 2019 announced plans to assess scenarios for how Nordic countries could achieve carbon neutrality. This assessment was published in 2020 [188], including implications for various sectors.

The main areas where the Nordic countries intend to significantly reduce GHG emissions are transportation, energy, industry (including forestry and agriculture), and construction and housing.

The Nordic countries share a common understanding of the importance of support from society in the process of low-carbon transition. A fair transition also means a comprehensive policy of adjustment that takes a broad view of the structural changes in society and aims to build a society with social and regional viability [9].

Most of today's GHG emissions worldwide are energy related, and a future zero carbon economy will rely much more heavily on electricity.

The Nordic countries are ahead of schedule of fulfilling the EU Renewable Energy Directive (32% renewables target by 2030)[17], which is partly due to the region's abundant renewable energy resources, including biomass, wind, solar, hydropower and geothermal [151].

Electricity generation constitutes more than a quarter of the EU's emissions and clean-energy sources are the only solution to cut the carbon dependency of the electric power sector. The introduction of carbon pricing is considered as the most important immediate measure also as an incentive to invest in the development of new low-carbon technologies [180].

The year of 2021 is decisive in terms of fighting GHG emissions in the energy sector. In March 2021, the International Energy Agency held the IEA-COP26 Net Zero Summit, where Seven Key Principles for Implementing Net Zero [158] carbon were presented and accepted by IEA members. The seven principles emphasise the importance of net-zero-aligned roadmaps, the essential role of net-zero sectors, innovations and investments as well as the importance of providing net-zero energy systems sustainability and security. A roadmap for the global energy sector was prepared by the IEA [110].

On the road to zero-carbon, the Nordic countries face a combination of technical and governance challenges in their energy sectors [188], including cold climate conditions complicate the use of low-carbon energy technologies such as wind turbines (Finland, Sweden, and Norway); growing electricity production from renewable sources of energy makes cogeneration of heat and power in district heating less profitable and attractive for business, and complicates the transition towards a decentralised electricity system in the Nordic countries; and insufficient public support for R&D in low-carbon heating systems (bio-coal, solar heat, seasonal heat, and cold storage etc.).

Opportunities in Nordic countries' energy sector reflect their knowledge and expertise in dealing with cold climate conditions in maritime, mining, and oil and gas industries (Finland, for

[16] https://ec.europa.eu/clima/eu-action/innovation-fund_en

[17] https://ec.europa.eu/energy/topics/renewable-energy/directive-targets-and-rules_en

example, is a world leader in polar shipbuilding and Norway in Arctic oil production) and the fact that bioenergy with CCS has huge potential across the Nordics.

The Nordic countries use different methods to produce electricity, from hydropower and biofuels to nuclear, geothermal and wind energy. Hydropower provides more than half of all electricity generated and is increasingly being supplemented by biomass, wind and solar. Fossil fuels, however, still constitute a substantial share of total primary energy production in the Nordic countries (40% in 2018 [195]), and reduction of fossil fuel usage in energy production is a crucial task for the Nordic energy sectors. Renewable energy share in the Nordics has risen from 31% in 2008 to 40% in 2018 compared to the EU average of only 15%.

Nordic electricity generation is already almost decarbonised (it was 87% carbon-free in 2020 [185]) due to the combination of electricity trading (Nord Pool), wind and hydropower [123]. Natural differences between countries in terms of electricity production, however, make it difficult to achieve 100% carbon-free goal.

Sweden, Denmark, Norway and Finland are part of Nord pool AS[18], a pan-European exchange and the leading electricity power market in Europe. Nord Pool AS has 360 trading customers in some 20 countries. The level of cooperation between Nordic countries in electricity trade is extremely high, encouraging development of renewables across the entire region. In 2020, the Nordic power market experienced the lowest power prices in 20 years, due to record high hydro reservoirs and rapidly rising wind generation [148].

One scenarios for the Nordics achieving the zero carbon goal in 2030-2050 is known as Climate Neutral Nordics. This focuses on direct and indirect electrification of the existing energy systems in the Nordic region, and relies on large onshore wind resources, offshore wind potential and flexibility from hydro reservoirs in the Nordics.

The energy sector is very important for economies of the Nordic countries. At the same time, it has a great value for achieving zero carbon. According to NEFCO, the main solutions to the problems of achieving zero carbon in the energy sector are:

- reducing the use of fossil fuels by increasing energy efficiency and using more efficient technologies
- replacing fossil fuels with renewable energy sources
- renewable energy conversion, transmission, and storage
- Ensuring access to renewable energy at affordable prices in remote areas [127].

Technological solutions related to low-emission energy production, energy and materials efficiency have great potential in the Nordic countries. A range of technologies figure in Nordic countries' strategies and road maps to a zero-carbon future, including: power-to-X, capture and utilisation or storage of carbon dioxide (CCU/CCS), biofuels, hydrogen and electrification, smart solutions and digitalisation, use of IoT and AI, smart automation and control systems, robotics, and cloud services.

According to Nordic national strategies and roadmaps, it is impossible to achieve zero-carbon targets in the energy sector through advanced technologies alone. The only way to overcome the obstacles is through changes in legislation and taxation.

Emission reduction goals in the transport sector are ambitious across the Nordics but achieving them will require serious measures. Domestic transport accounts for 20-30% of GHG emissions in the Nordic countries, although trends in transport sector emissions vary between countries. Sweden and Finland are reducing emissions in this sector, while the other three Nordic countries are lagging. In Norway almost one third of GHG emissions comes from domestic aviation and shipping, whereas in other Nordic countries this share is less than 10% [188]. Domestic and interstate ferries and

[18] https://www.nordpoolgroup.com/

vessels play important role in Nordic transportation systems. Electrification of this mode of transportation will substantially decrease carbon emissions (up to 95%).

In the Nordic countries, biofuels are one option for reducing GHG emissions in the transport sector. In 2019 it accounted for 13% of the total energy consumed in Nordic transport. Finland and Sweden invest in biofuels the most to achieve their targets in the sector [151].

Subsidising zero-emission cars is considered a good instrument, albeit one with limitations as it may negatively affect development of public transport and cycling. It is suggested that Nordic cities should be given greater legislative powers to incentivise the use of zero-emission vehicles (environmental zones, traffic fees or determining vehicle categories in zero-emission zones). Currently there are examples of other support measures introduced in the Nordic countries for low-emission vehicles, including preferential treatment of zero-emission vehicles for taxi licenses (Denmark) or reduced ferry fees (Norway), but various tax benefits remain the main tool for incentivising zero-emission car sales (cheaper annual vehicle tax, registration tax and VAT exemptions or reductions) [205].

Various Nordic cities have introduced low-emission zones for heavy vehicles, but no zero-emission zones have been established so far. The only low-emission zone for passenger cars in the Nordic countries is in central Stockholm, Sweden (Hornsgatan street) [199].

The Nordic maritime sector has great potential to achieve zero-carbon targets. The Nordic countries have just begun to electrify domestic ferries and passenger vessels, with Norway and Finland leading the way, and new electric ferries can cut emissions by 95%.

Agriculture and forestry sectors have great potential for achieving zero-carbon goals in the Nordic countries.

Achievements in GHG emission reductions in agricultural sectors in Nordic countries are less obvious compared to other sectors of economy. For example, from 1990 to 2020 Denmark, Finland and Sweden reduced total GHG emissions by 30%, 22% and 26%, but in the agricultural sector reductions were only 16%, 13% and 6% respectfully [124].

Opportunities for achieving zero-carbon goals in Nordic agricultural sectors include investing more in legume farming, replacing feed imports with locally produced grass and protein crops, and diversifying agricultural production in general. Nordic companies have advanced technology for plant-based protein production and land-based aquaculture. Organic fertilisers decrease the need for artificial fertilizers and reduces the use of fossil fuels and phosphorous mining [109]. The Nordic countries rely in climate-friendly agriculture technologies such as advanced farming, manure processing technology, biogas plants, and alternative motive power sources for machines.

Most Nordic countries have large forestry sectors, Sweden, Norway, and Finland being three of the most forested countries in Europe with an average of 93 tonnes of carbon per inhabitant stored in living forest biomass. [179]. These countries support the use of CCS technologies in biomass-based combined heat and power production in the pulp and paper industry and district heating. Preventing forest loss is one of the most important ways of mitigating GHG emissions. The Nordic countries have always been strong players in the forestry sector, but Nordic companies rely on intensive use of forest resources rather than environmental

solutions so achieving zero carbon goals will require a balance between forest harvest and conservation.

Possible zero-carbon measures in Nordic forestry sectors could include introducing low-emissions fuels standards that could serve as incentives for biofuels and methods of optimising wood use. Increasing agro-biomass also faces several obstacles such as adverse effects on the environment from the biofuel production and poor returns on biofuel production investments [110]. A major challenge related to increasing the production of biomass is the complexity of developing sustainable biofuels without adverse effects on the environment and biodiversity. And as well as poor profitability, challenges include uncertainty of future demand for biofuel and general lack of funding.

The industry and manufacturing sector is one of the largest contributors to GHG emissions worldwide. The Nordic countries rely on switching to hydrogen in industrial processes [78], especially in the steel industry (for example the Swedish/Finnish company SSAB[19]).

In the construction and housing sector, the Nordic countries have increased cooperative efforts to reduce GHG emissions. In 2020, Nordic Ministers for Housing and Construction approved a new action plan for 2021–2024 [119]. Key points in the strategy are creation of construction emission databases in the Nordic countries, and sharing information and best practice. A special joint steering group will be created to coordinate the harmonisation of Nordic building regulations. In most Nordic countries climate declarations that come in force between 2022 and 2027 will strictly regulate carbon footprint in construction[20]. In Iceland, however, the regulatory system for the construction sector is still under consideration.

Construction and housing are key to carbon strategies in all Nordic countries, and Sweden, Norway, Finland, and Denmark have all prepared special sector roadmaps. GHG emissions in construction and housing account for between 4 and 13% of Nordic emissions [168]. Since 1990 Nordic countries have reduced emissions in this sector by 19% in Norway to 58% in Sweden.

The capitals of three Nordic countries – Stockholm, Oslo and Copenhagen – are members of the C40 Cities Climate Leadership Group[21]. This international organisation is focused on fighting climate change and reducing GHG emissions. These cities' climate action plans are developing pathways to delivering emissions-neutral cities by 2050.

Copenhagen has already reduced carbon emissions by 42% since 2005, Oslo by 36%, and Stockholm plans to achieve net zero emissions by 2040. Stockholm may be a good example of how to cope with the economic sector zero carbon problem. Stockholm residual emissions are from shipping, aviation and fossil fuel-based plastics in waste incineration facilities. To compensate for these emissions, the city is creating carbon sinks and investing in bioenergy CCS [26].

Possible carbon reduction measures in the construction sector include developing of insulation technologies and low-carbon building materials, CCU, and smart thermostats and gauges.

In the Nordic countries, much attention is focused on reducing GHG emissions in waste management. The Circular Economy Action Plan [25] is the central to the European Green Deal and waste is described as secondary raw materials that could reduce fossil fuel use. Recycling is one area where the Nordic countries are trying hard to be leaders in innovation, and many solutions in both waste management and material recycling can be found in the region.

The Nordic countries have significant capacity in wastewater management and have introduced water-saving technologies in production, urban environments, housing, and irrigation machinery. Municipal wastewater treatment is also linked to nutrient recycling when usable bio solids are produced from wastewater treatment sludge [109].

[19] https://www.ssab.com/

[20] https://www.oneclicklca.com/baeredygtighedsklassen-low-carbon-targets-for-denmark-construction/

[21] https://www.c40.org/

Covid-19 and zero-carbon goals in Nordic countries

In 2020, carbon emissions from energy use declined by over 6%, the largest decline since 1945 but the average reduction in emissions the world needs each year to meet the Paris Agreement targets for the next 30 years [164]. This conclusion is supported by the International Energy Agency (IEA[22]) special report "Net Zero by 2050. A Roadmap for the Global Energy Sector" [110].

At the beginning of the COVID-19 pandemic the head of the IEA mooted the idea of reviving the world economy through low carbon technologies [147]. The Nordic governments also indicated that low carbon development is likely to be part of the engine of recovery.

In 2020, Nordic countries started to analyse the impact of the COVID-19 crisis on achieving zero carbon goals. In August 2020, Nordic sector roadmaps were not adjusted and possible reductions in GHG emissions were not assessed. All Nordic governments have, however, announced in various contexts that they would incorporate thinking about green transition as an engine of recovery [188], and

NEFCO's strategy for 2021-25 also reflects on the COVID-19-related rise in remote working and new ways of working, which could lead to a more environmentally friendly transportation sector [109].

According to the IEA's Seven Key Principles for Implementing Net Zero, the recovery after the COVID-19 pandemic presents countries with "a historic opportunity to jumpstart progress toward achieving net zero emissions" [110].

In Finland, it is hoped that the EU's COVID-19 recovery measures may offer new financing mechanisms for the industry's low-carbon investment needs, including R&D and pilot projects [168].

[22] https://www.iea.org/

In 2020, GHG emissions in Finland decreased by 9%. However, the impact of the pandemic on emission reductions in Finland cannot be quantified because it is mixed with weather conditions and cyclical fluctuations in industry [74].

In Norway GHG emissions in 2020 were between 5% and 9% lower than in 2019 due to COVID-19 [28].

The Nordic countries used climate taxation as a response to regional economic crises, such as in the early 1990s, and a similar approach could be taken for COVID-19 recovery plans [71].

Arctic impact factor

The Arctic is one of the global regions most affected by carbon emissions and climate change, with current Arctic temperatures rising at a rate two to three times the global average.

The Nordic Arctic region can be defined as Greenland, Iceland, the Faroe Islands, and the Northern regions of Norway, Sweden, and Finland.

The leading intergovernmental forum that addresses issues related to the Arctic and promotes cooperation in the Arctic region is the Arctic Council[23]. All Nordic countries are members of the Arctic Council along with Russia, Canada and the United States.

All Nordic countries have Arctic strategies defining economic development and sustainable resource management goals. Until recently, however, these goals have not been linked to targets for achieving carbon neutrality. Natural resource exploration and utilisation are central to the economy of the Nordic Arctic, and until recently have been at odds with the idea of mitigating GHG emissions [98].

[23] https://arctic-council.org/en/

In 2019, members of the Arctic Council disagreed about including the term "climate change" within the text of their declaration, but in May 2021 they finally acknowledged the enormous threat climate change poses to the region's nature and people. The Arctic Council adopted a 10-year strategic plan for renewable energy development in Arctic communities and a 25-30% reduction of black carbon emissions by 2025 [17]. The Arctic Council's expert group on black carbon and methane has recommended the need to accelerate efforts to mitigate black carbon from international shipping and implement measures to mitigate black carbon from domestic shipping activities [16].

In the Arctic region any activity, especially construction, may lead to more carbon emissions compared with other areas due to exceptionally high energy consumption, the fact that renewable energy technologies are not easily utilised in the Arctic, extreme cold winters require more heating, and transportation distances are long [203]. Arctic Norway also relies on aviation, which is a huge source of GHG emissions [98].

Country by country

Denmark

Denmark has reduced GHG emissions by 32% since 1990, mainly through increased use of renewable energy in industry [188] and decreasing emissions in energy sector.

In 2019 Denmark adopted the Climate Act setting a target to reduce Denmark's emissions by 70% (7 million tonnes of CO_2e) by 2030 compared to 1990 and to achieve climate neutrality by 2050 [178]. A series of 13 climate partnerships are enabling different sectors of the economy to coordinate efforts to reduce carbon emissions [150]. In 2020 these so-called Klimapartnerskaber published sector roadmaps to achieve Denmark's 2030 target of cutting carbon emissions by 70% compared with 1990 levels.

Denmark published its long-term strategy for global climate action in 2020 [31] under the supervision of the Danish Council on Climate Change (Klimarådet) [6] - an independent body of experts advising on how Denmark can achieve zero-carbon targets under the Paris Agreement. The key recommendation is to increase the carbon price to $200-250 per tonne by 2030. Climate-friendly projects are supported through the Green Future Fund[24], the Danish state's investment fund founded in 2020 and tasked with promoting new technologies and conversion to renewable energy [44]. Previously established by state the Danish Green Investment Fund[25] also co-finances investments promoting the green transition as part of the Greener Denmark agreement (Danmarks Grønne Fremtidsfond[26]) [70].

Denmark's first Climate Program (2020) [31] describes how the government will support and facilitate reaching zero-carbon targets. Denmark's Finance Act (2021) includes green initiatives of €600 million as part of the country's recovery from the COVID-19 crisis which will reduce CO_2e by 0.2 million tonnes.

Denmark's Recovery and Resilience Plan (2021) emphasises green transition and will support massive investments in zero-carbon projects with 90% of funding (60% of the total Danish recovery spending) allocated to green transitions initiatives. The recovery plan contributes one third of required 70% reduction (2.8 Mt) of the county's reduction target [45].

Low-carbon research and technologies are of primary interest to Denmark's government. In 2020 the Danish Ministry of Higher Education and Science mapped climate-friendly research needs and potentials. Four missions were prioritized (with a budget of DKK 750 million): CCS or utilisation, green fuels for transportation and industry (Power-to-X, etc.), climate and environment-friendly agriculture and food production, and recycling and reduction of plastic waste [70].

[24] https://www.ekf.dk/en
[25] https://gronfond.dk
[26] https://dgff.dk/

Denmark will increase green research funds to meet climate targets in coming years, starting from the 2020 level (DKK 2.3 billion). This is part of Denmark Finance Bill for 2021 and reflects measures to restart the country's economy [70].

Innovation Fund Denmark[27] supports strategic research and innovation in Denmark, and the Danish government has mandated the fund to support the country's climate priorities and implement green research [70].

Two-thirds of Denmark's emission reduction since 2005 came from the energy sector [27]. In 2020, GHG emissions in the energy sector declined by 12.4 % due to the significant decrease in energy consumption (8.5%) caused by COVID-19 [37].

To achieve zero-carbon targets Denmark is focusing the energy sector on expanding production of offshore wind energy and electrification of heating, transport, and industrial processes, and trying to replace remaining coal in the power plants and natural gas in district heating [188].

In 2019 wind power provided 47% of Denmark's total electricity consumption and this share is rising fast (16% between 2018 and 2019) [159]. This has been achieved with the help of Norway, where large hydro resources (dams or pumped storage) help smooth the variability of wind output [180]. Wind power is promoted as a tool for combating climate change through the North Seas Energy Cooperation (NSEC) [186].

By 2030 Denmark aims to build two energy islands (2 and 4 GW) on the North Sea island of Bornholm, and another offshore wind power station (1 GW) will be established on the island of Hesselø. These three stations will triple Denmark's current capacity [36] and Denmark has set aside an additional DKK 237 million for experimental wind turbines in 2021-24 [70].

The energy sector roadmap prepared by Denmark's climate partnerships proposes reaching carbon reduction goals by increasing the use of surplus heat, switching to biogas and reducing the total use of fossil fuels for buildings, transport and industry by 50% [149].

By 2030 one of the world's largest green hydrogen plants (1.3 GW) will be built in Copenhagen (Green Fuels for Denmark project) [142] to provide hydrogen-based fuels for heavy transport, ships and aviation using offshore wind power (250 MW offshore wind farm project in the Øresund Strait). In 2021, the Danish government allocated DKK 850m (€114 million) to development of Power-to-X projects domestically and in the EU [40]. Denmark also established a partnership with the Netherlands (worth DKK 1 billion) to build a PtX electrolysis plant with a total capacity of 100 MW [39].

In 2020 Denmark announced that extraction of oil and gas in the Danish part of the North Sea will cease by the end of 2050 [67].

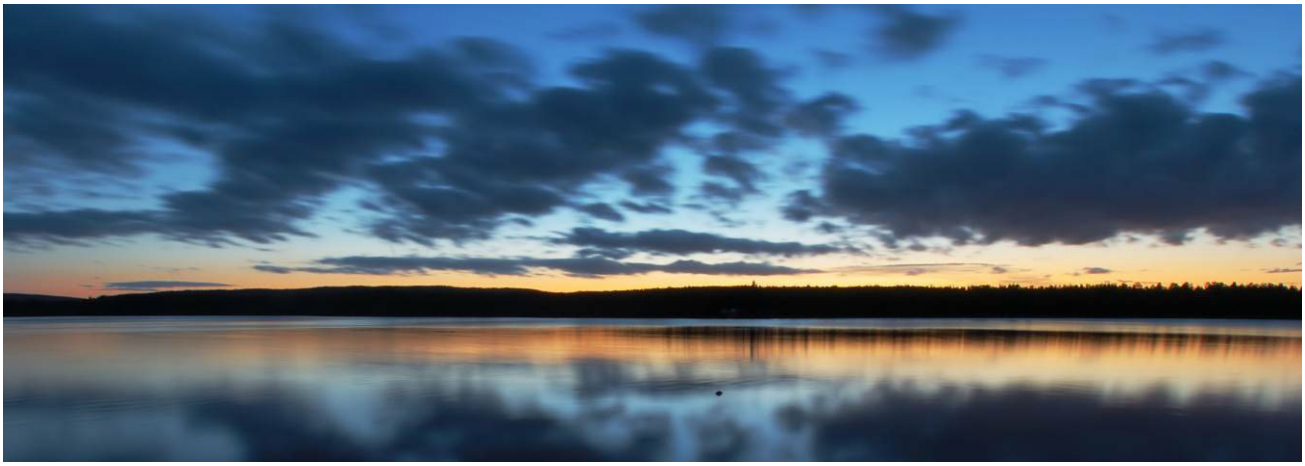
The transportation sector produces around one third of Denmark's GHG emissions, but by 2030 it will account for only 14 million tonnes of GHG emissions (of which road transport accounts for 92%). International maritime and air transport are not included in the Danish inventory of GHG emissions [70].

Low-emission transportation in Denmark is supported by annual vehicle tax reductions and preferential treatment of zero-emission vehicles for taxi licenses. From 2025, only zero-emission vehicles will be granted new taxi licenses [205].

To achieve zero-carbon targets in the Danish transportation sector there is a need for development of new green fuels based on Power-to-X technologies. In the long-term, this could reduce emissions by between 1.5 and 7.5 million tonnes, including between 1 and 4 million tonnes in international maritime and air transport [70].

In Denmark domestic transport emissions, mostly from land transportation, account for between 21% and 31% of total GHG emissions [188], and Denmark is planning to expand a strengthened ETS system to include road transport.

[27] https://innovationsfonden.dk



Changes in taxation will lead to 775,000 zero- or low-emission passenger cars in Denmark by 2030 [31] and the Danish recovery plan's (2021) financial support is aiming at 1 million green cars in 2030, with GHG reductions of 2.1 million tonnes [45]. A distance-based toll for heavy-goods vehicles based on a differentiation according to CO_2e-emissions will come in force in 2025.

In 2021 a consortium of several Danish and European countries received investments from Innovation Fund Denmark to develop production of sustainable fuels from biowaste and residual biomass for shipping and aircraft and [111], and

Danish aviation aims to be CO_2 neutral by 2050.

In 2019 the Danish shipping company Mærsk announced that it would begin building carbon-neutral vessels in 2030 and have fully carbon-neutral logistics by 2050 [192].

Denmark's industrial sector accounts for approximately one fifth of country's emissions, and the Danish Climate Agreement for Energy and Industry will lead to a reduction of 2.7 million tonnes CO_2 by 2030 [36].

According to Denmark's recovery plan, a green transition of Denmark's industry will be subsidised by DKK 2.5 billion between 2020 and 2030 for electrification and energy efficiency improvements [45]. For the next 20 years, Denmark will support biogas and other green gas use with DKK 12.8 billion [70], and an additional DKK 2.9 billion will go to industry sectors where biogas is the only alternative to green electricity [36]. Plans for the phasing out oil and gas boilers will be financed by DKK 2.3 billion investments.

The Danish mineral and metal industry account for approx. 3% of national emissions, with cement as the largest emitter [188]. There is a need for new processing technologies and an increase in biomass/biogas use. Cement production emissions will be reduced by changes in cement composition (lower chalk content) and electrification of machinery. Aalborg Portland's cement factory is testing new technology new and plans to reduce GHG emissions by 30% by 2030 (less than 500 kg per tonne of grey cement) [167].

Denmark is currently studying the feasibility of permanent CO_2 storage in the North Sea (CCS Project Greensand[28], supported by the Danish Energy Agency).

In the construction and housing sector, Denmark achieved a 45% decrease in GHG emission, second only to Finland among the Nordics (50%) [188].

DKK 30 billion have been allocated for renovation of social housing, with a further DKK 1 billion reserved for the country's municipalities and regions to make investments in energy efficiency [36], including measures such as battery storage for intermittent renewable power [113].

In 2021 a series of voluntary environmental requirements were introduced in the Danish national construction sector, recognising the importance of operational emissions reduction [19].

[28] https://projectgreensand.com/

Climate partnership roadmap proposals for construction and buildings include intelligent energy management and energy renovations, preparing CO_2 accounts for all buildings, bridges and roads, and electrifying gas- and diesel-powered equipment for fossil-free building sites [149].

Sixty percent of Denmark is farmland [124], and the agricultural sector produces approximately one third of Denmark's GHG emissions [45], amounting to 17.4 million tonnes of CO_2 in 2017 [12]. In 2019 Denmark announced set a goal for making its agriculture sector carbon neutral by 2050 [38].

In 2021 the new strategy for Danish agriculture [12] set a target to reduce emissions by 80% in the farming sector through a range of measures, including more efficient use of nitrogen fertiliser and reducing emissions from manure) and offsetting the remaining 20% by restoring forests and peatlands [13]. Denmark's recovery plan also supports rewetting and taking carbon-rich soils out of production [45]. It will allocate DKK 2 billion for this restoration of carbon-rich farmland, which will save 270,000 tonnes of CO_2e per year by 2030 [70].

Denmark's rural development program (2021) doubles the funding of the existing private afforestation to DKK 70 million and will result in GHG absorption 10,000 tonnes of CO_2e per year by 2030 [70].

In the agricultural sector, Denmark is also investing in removal of emissions from low-lying pitlands land [188] and supporting people, who are willing to buy small forest areas for protection use [188].

GHG emissions from agriculture and forestry are expected to remain largely unchanged in 2030 compared with today: around 16 million tonnes of CO_2e, accounting for 37% of Denmark's total emissions. The main sources are cultivation of land, fertilisers, and slurry [70]. Denmark is developing new technologies for the sector, some of which, such as bio-refining, are very promising [189].

Denmark has paid much attention to waste management but developing waste incineration system does not fit well with reducing GHG emissions. Most GHG emissions from waste management come from waste incineration [70], and Denmark incinerates the largest amount of waste in Europe, allowing it to produce 20% of district heating and 5% of its electricity [43]. The Danish Waste Association has published a strategy [181] for waste-to-energy sector to become carbon neutral by 2030.

A new partnership – Carbon Capture Cluster Copenhagen (C4) – has been established in Copenhagen and includes Denmark's three largest waste-to-energy plants, energy networks and utilities and port operators. Its goal is to capture 3 million tonnes of CO_2 per year [22].

The Danish Climate Agreement for Energy and Industry 2020 allocates DKK 800 million per year from 2024 for CCS, which will reduce emissions of CO_2e by 0.9 tonnes in 2030 [36].

Over the next 10 to 20 years, Denmark is expected to store or utilise 4 to 9 million tonnes of domestic carbon emissions. The potential country's underground storage capacity is estimated at 22 billion tonnes of CO_2, but there is a need for development of a cost-effective and environmentally acceptable infrastructure for the transportation and storage of CO_2 [70].

Finland

In 2020 Finland reduced GHG emissions by 32% compared with 1990 levels (-23 MT CO_2). However, forestry and land use are not included in the calculations, and COVID-19 accounted for a 9% decrease from 2019 [74].

Finland's national Climate Change Act [86] came into force in 2015. Under the Act, Finland must reduce its GHG emissions by 80% by 2050 from 1990 levels. The Finnish government, however, has already set the more ambitious goal of Finland being carbon-neutral by 2035. The Finnish climate strategy [87] and medium-term plan [91] are still under discussion, the carbon neutrality target will be assessed in 2025.

In 2020 comprehensive and coordinated roadmaps for 13 sectors of Finland's economy were prepared [168]. Published in 2021, the roadmaps consider three scenarios: a baseline scenario (existing zero-carbon measures in force) and two more ambitious scenarios (with additional zero-carbon measures). The roadmaps are heavily reliant on technological solutions related to low-emission energy production, energy and materials efficiency, alternative power sources, exploitation of waste heat, and the capture and utilisation or storage of carbon dioxide. Finland's approach to zero-carbon also includes smart solutions and digitalisation and increased investment in R&D. Roadmaps prepared under the Finnish Government Programme are currently being used for Finland's next climate and energy strategy which is expected to be published in 2022.

The task of achieving zero-carbon goals in Finland requires a transformation of energy sector, developing energy networks and dismantling administrative obstructions. Some of emissions are not included in the EU Emissions Trading System, and Finland is planning to reduce them too [74].

Finland's approach focusses on studying and understanding interconnections between different sectors of the economy which are trying to operate on low-carbon level. Decarbonisation of the Finnish energy and technology industries will affect commerce, and use of low-carbon raw materials will have an impact on the construction industry. [168].

Finland has ambitions to become one of the leading international provider of solutions for climate change mitigation, and the country views the transition to a low-carbon world as a great opportunity for Finland.

A new Sustainable Growth Programme for Finland, funded from the Next Generation EU recovery package was launched in 2021[29]. The programme aims to reduce GHG emissions and focuses on a green transition.

Finland supports low-carbon research through governmental funds, and in 2021 the government agency Business Finland[30] launched a Low Carbon Built Environment programme (2021-2023, €40 million) to promote low-carbon building solutions. Most of the financing will go to support research, development, and innovation.

In 2021, the Bank of Finland announced that its carbon neutral by 2050 targets would be achieved by channelling cash flows to low-carbon investments which also reduce the portfolio's carbon footprint. It is also preparing a climate roadmap with intermediate targets [18].

Several Finnish start-ups declare decarbonisation targets in their activities and raise funds on this basis.

- Set up in 2016, the company is developing a range of low-carbon building materials made from a variety of industrial waste streams. In 2021, it raised €2 million funding for carbon-neutral construction materials production from Voima Ventures[31] (a strategic partner of Technical Research Centre of Finland[32]) and Taaleri Sijoitus Oy[33] (a Nordic investment and asset manager with an emphasis on renewable energy). [112].
- Carbo Culture[34] (2017). This large-scale biotech start-up is promoting the use of biochar (charcoal produced by pyrolysis of biomass in the absence of oxygen) in a process of carbon removal [35]. In 2021, it raised $6.2 million from the Silicon Valley VC True Ventures[35] and Cherry Ventures[36]. The target is to reduce the cost of carbon removal from $600 per CO_2 tonne to $200 by 2024 [92].

[29] https://ec.europa.eu/info/strategy/recovery-plan-europe_en
[30] https://www.businessfinland.fi/
[31] https://voimaventures.com/
[32] https://www.vttresearch.com/en
[33] https://www.taaleri.com/en
[34] https://www.carboculture.com/
[35] https://trueventures.com/
[36] https://www.cherry.vc/

- Soletair Power[37] (2016). Their technology combines DAC (Direct Air Capture), potentially 100% negative carbon emission technology) with building integration and absorbs CO_2 from ventilation units inside buildings. The process also creates renewable energy by converting its captured CO_2 into hydrocarbons, a type of fuel. In 2019-2021 the company raised €1.5 million in investment [201].
- Teraloop[38] (2014). The company specialises in kinetic energy storage systems for industrial users and power-grid operators, helping decarbonise the energy system. In 2019 it received a grant worth €2.4 million from the EU's Horizon 2020 SME programme [64]. In 2021, it was shortlisted[39] for the New Energy Challenge 2021[40].
- Geyser Batteries[41] (2018) offers high-power, heavy-duty energy storage solutions based on a water-based electrolyte (ElectroChemical Recuperator technology). In 2021 the company raised €1.1 million in investment[42] from Tesi[43] (Finnish Industry Investment Ltd.) The company was shortlisted or the New Energy Challenge 2021[44].
- Puro.earth[45] (2018) provides carbon removal as a service for corporate buyers through a network of 15 suppliers, four of which are in Finland and they use CCS technologies in agriculture. Carbon removals are verified and certificates issued for each metric tonne of CO_2 removed [29]. Nasdaq became majority investor in Puro.earth in 2021 [104].
- Ilmatar Energy[46] (2011). A power producer focused exclusively on renewable energy (wind farms). In 2021, it secured funding worth €200 million from Omnes Capital[47] to build 1GW of new wind power in Finland by 2027 [62].
- Enfuce[48] (2016). A card issuing and payment processing services start-up, Enfuce is Finland's largest fintech start-up. One of the company's services is My Carbon Action[49], which allows end-users to track the carbon footprint of their purchases. In 2021 the company raised €7 million [43].
- Hycamite TCD Technologies[50] (2020) produces hydrogen and carbon from methane and biogas with sustainable catalysts. Supported by the European Regional Development Fund[51] and the European Social Fund[52]. In 2021 Hycamite was named one of the 25 most innovative cleantech start-ups in northern Europe [79].
- Solar Foods[53] (2017). Its technology uses captured carbon dioxide, bacteria, and electricity to a create protein food (Solein) that creates only 1% of the GHG emissions of meat protein or 20% of those from plant protein production. In 2021, the company received €10 million [160] from the Finnish Climate Fund[54].

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[37] https://www.soletairpower.fi/
[38] https://www.teraloop.org/
[39] https://getinthering.co/newenergychallenge-shortlist-2021/
[40] https://newenergychallenge.com/
[41] https://www.geyserbatteries.com/
[42] https://www.geyserbatteries.com/bridge-round
[43] https://www.tesi.fi/en/
[44] https://newenergychallenge.com/
[45] https://puro.earth/
[46] https://ilmatar.fi/en/
[47] https://www.omnescapital.com/en/
[48] https://enfuce.com/
[49] https://enfuce.com/mycarbonaction/
[50] https://hycamite.com/
[51] https://ec.europa.eu/regional_policy/en/funding/erdf/
[52] https://ec.europa.eu/esf/home.jsp
[53] https://solarfoods.fi/
[54] https://www.ilmastorahasto.fi/en/

- Green Carbon Finland[55] (2019). The company specialises in developing new ways to automate carbon footprint calculations for companies, products and consumers, and carbon sink projects with Finnish forest owners.

GHG emissions relating to energy production and consumption accounted for 72% (34.7 million tonnes CO_2) of Finland's total emissions in 2020 [23]. The Finnish energy sector has plans to reduce GHG emissions by 50% by 2030-35 and move the energy system towards low-carbon operation.

Along with the UK and US, Finland is one of the few countries where existing mechanisms providing long-term revenue certainty for low-carbon producers have been aimed at maximising carbon reductions rather than maximising deployment of variable renewable energies. [180].

Electricity is one of the most effective means of reducing emissions. Finnish zero-carbon roadmap scenarios estimate that by 2050, demand for industrial electricity will increase by 100% and the country's electricity consumption by more than 50%, meaning that 80 TWh of new electricity production capacity will be needed per year. Electricity demand from the forest industry is expected to decrease, while increasing in chemical and technology industries. Major investments will be required to build low-emission electricity production capacity and to expand the transmission network [168].

The main concerns for Finland's energy sector are the ban on coal by 2029 and changes in the electricity systems. Electricity and heat production will be the primary means of achieving the goal of cutting emissions from electricity production from 131 to 10 kg CO_2/MWh (2017 to 2035) and from 148 to 35 kg CO_2/MWh in district heating [168].

Finnish district heating systems will take advantage of waste heat, geothermal heat pumps and industrial heat pumps which could cover one third of district heating demand. Wood-based fuels in heat production will still play a significant role, but non-burning technology will have a bigger share. Today, district heating system in Finland still rely on combustion of fossil fuels and peat. Oil is not widely used as fuel in Finland[56], and the development of low-carbon production will further reduce it.

From 2030 natural gas in the Finnish energy sector will be gradually replaced with biogas and hydrogen. Peat use will be reduced by up to 30% by 2035 when these will be the remaining two sources of emissions in the Finnish energy industry.

Finland's bioenergy industry is connected to the energy, forestry, technology and transport industries. In May 2021 the Bioenergy Association of Finland issued a report on *The Contribution of the Bioenergy Industry to a Carbon-Negative Future in Finland* [20], which discusses the impact of the sector to a zero-carbon Finland. Finland's bioenergy for the most part (90%) is renewable wood energy, which comes from forest industry side streams. The future role of bioenergy in Finland is to replace imported fossil fuels, produce more electricity and heat; currently, however, it is largely a domestic energy source. In the coming decade, the use of biogas and liquid biofuels in Finland is expected to increase by 10–20% by 2030 compared to 2019 levels. Other proposed measures include reducing the use of peat for energy, using biomass with carbon capture and creation of sustainable and even carbon-negative biomass-based products [168].

The Finnish transportation sector is responsible for 29% of the country's total emissions, and this share has been rising for the past 30 years [72]. Plans are to reduce emissions by 50% by 2030 compared to 2005 and for transport to be fossil-free by 2045. This will be achieved through a combination of measures including modernisation of Finland's cars (low-emission cars and changes in taxation); introduction of sustainable public transport in cities (low-emission vehicles and promotion of cycling); introduction of renewable fuels (incentives for biogas, synthetic, carbon-

[55] https://greencarbon.fi/eng/

[56] https://www.tilastokeskus.fi/tup/julkaisut/tiedostot/julkaisuluettelo/yene_efp_202100_2021_23713_net.pdf

neutral fuels); and promotion of sustainable transport services (digitalisation of logistics and transport, remote connection technologies, etc.). Over the next 10 years, however, there seems no alternative to diesel for heavy transport in Finland [168].

Finnish roadmap calculations show that increased use of renewable fuels and biogas could contribute to 25% of GHG emission reductions; modernisation of cars by taxation could contribute 20%; and digitalisation of cargo traffic a further 10%.

Finnish transportation investment needs for low-carbon operation include: €400 million for railway network electrification and freight transport improvements; €5–10 billion for railway market-share boosting projects; and €2–3 billion for urgent improvements to the core road network [168].

The main inland water project for Finland in the 2020s will be a €80 million project in the Saimaa Canal, where the first of a new hybrid propulsion concept (bio-oil and battery technology) cargo ship will come into use in 2024, designed by Meriaura Group[57] [63]. Finland is also planning to use biogas and biofuels in maritime shipping, and is a global leader in icebreaker design, polar shipbuilding, ice technology and fleet operation.

Biofuels already account for 9.3% of Finland's transport energy use. A domestic electric ferry – which emits 95% less and costs 80% less than a standard ferry – was introduced in Finland in 2017[58].

Finland is supporting the development of low-emission transportation primarily through tax revenues (reduced annual tax, purchase bonuses. registration tax reduction), and there is also a support programme for public transportation charging stations [205].

Emissions in industry accounted for 10% of total Finland's emissions in 2019 [72].

Finnish zero-carbon roadmap scenarios reveal a need for major investments to replace production capacities which use low-carbon technology. Every Finnish industry sector need investment as well as other measures to achieve zero-carbon targets. Due to long investment cycles in industry, some investment, especially in the chemical and technology industry, will require government support. Investments in industry will reduce GHG emissions over years or decades, and step-wise rather than linearly [168]. Finnish chemical industry investment needs for low-carbon operation to 2050 are €50 to €58 billion [168].

The mineral and metal industry are traditionally important to the Nordic countries, and involve mining, processing of steel and non-ferrous metals, as well as mineral, cement, and concrete production. Most of GHG emissions come from the steel and cement industries [188]. In Finland direct emissions from the mineral and metal sector account for approximately 5% of Finland's total emissions (90% from steel and 10% from mining). To reduce these emissions by 7% in 2045, the Finnish steel sector is developing HYBRIT technology[59] to replace coking coal with hydrogen. Other zero-carbon measures in these sectors of the Finnish economy include replacing coke in metal processing with biomass, CCS/CCU, utilisation of side streams and manufacturing of synthetic fuels [188].

Electrification of mining transport and machines is a major priority in Finland. Leading Swedish technologies for electrified transportation are being used at the Kevitsa mining site near Sodankylä in northern Finland, a joint venture with Swedish Boliden and another example of Nordic cooperation in reducing GHG emissions [188].

The Finnish construction and housing sector is responsible for about one third of the country's GHG emissions, while delivering 15% of Finland's GDP and employing more than 500,000 people. The main sources of emissions are use-phase energy consumption, construction materials and emissions from construction sites functions and transport. Finland has achieved a 50% decrease in construction and housing emissions since 1990, and plans to reduce GHG emissions by 66% by 2035

[57] https://meriaura.fi/

[58] https://www.rivieramm.com/opinion/opinion/finferries-starts-a-quiet-revolution-26042

[59] https://www.ssab.co.uk/fossil-free-steel/hybrit-a-new-revolutionary-steelmaking-technology

compared to the current level using various energy efficiency measures, especially in heating. A near zero-carbon level could be achieved by 2050, with emissions reduced by 95%. Proposed measures include utilisation of local construction materials, reduced transport emissions, use of recycled and recovered materials along with electrification of construction sites. To improve energy efficiency of current building stock in Finland, the construction industry will need investment of €10–20 billion by 2050. There is also a need for reform in the construction industry's low-carbon regulations [168]. Pursuing the goal of making Finnish cement production carbon neutral before 2050, the sector is planning to introduce CCS technology at a cement plant after 2035 [188].

Emissions from the agriculture sector have decreased from 7.5 Mt in1990 to 6.6 Mt CO_2e, accounting in 2013 for 12% of total emissions [72]. Finland's direct emissions from agriculture and forestry constitute about 12% of total GHG emissions. Finnish measures in this sector include changing land use, increasing carbon capture in soils and forests and renewable energy production, and Finnish reforestation, land restoration and protection projects have already proved useful for decarbonisation.

Among the Nordic countries, Sweden and Finland have the largest supply of biomass suitable as energy sources, including agro-biomass (energy crops, straw, grasses and manure), and biofuels account for 40% of Finland's GHG emissions [188].

Finnish agriculture was responsible for 16 million tonnes of CO_2e emissions in 2018 and has remained roughly stable for the past 10 years. Of these emissions, 75% comes from soil and field use, 19% from livestock and manure processing, and 6% from energy consumption [168].

Finnish agriculture may contribute to GHG emissions reduction by increasing carbon sequestration in mineral soils, switching to low-carbon energy, and mitigating peatland emissions. Irrespective, the sustainability and profitability of agriculture is a major concern for Finland [168].

Finland is planning to reduce GHG emissions in agriculture by 29% by 2035 and by 38% by 2050 (amounting to 6 million tonnes of CO_2e by 2050). A challenge is the need to compensate farmers for loss of subsidies associated with use of low-profit peatlands. An even more ambitious scenario exists, where GHG emissions could be reduced by 42% by 2035 and by 77% by 2050, but it would require wide-scale restoration of peat soils, adjustable subsurface drainage, and reforestation of shallow peat fields.

For low-carbon operation until 2050, Finnish agriculture and forestry investment needs amount to €300–500 million for peatlands; €140–230 million for poor-quality land reforestation; €2.1–3.3 billion for sustainable intensification of agriculture; €1.07 million to €1.90 million for biogas plants. The Finnish sawmill industry, traditionally important for the country, will require approximately €100 million over the next ten years [168].

Emissions from the waste management sector have decreased by 62% from 4.7 Mt in 1990 to 1.8 Mt CO_2e in 2019, and in 2019 waste management accounted for 3% of total country's emissions [72]. The decrease can be attributed to changes in waste legislation, implementation of the Finnish Waste Act[60] (last modified in 2011), the European Landfill Directive (1999/31/EC) and changes in agricultural policy.

Finland is changing waste taxation and preparing new waste strategies to reduce carbon emissions. The National Waste Plan[61] is being updated in 2021, which will accelerate reductions in emissions of the Waste sector.

[60] https://finlex.fi/en/laki/kaannokset/2011/en20110646

[61] https://ym.fi/en/national-waste-plan

Iceland

From 1990 to 2019 total GHG emissions in Iceland declined by 3%. International navigation and aviation are not included in these calculations but also declined by 15% and 26%, respectively [107]. In 2018 Iceland's GHG emissions accounted to 4.9 Mt, or without land use, land-use change and forestry (LULUCF) [198] was 3.32 million tonnes in 2019[62]. Iceland has the highest level of GHG emissions per capita in Europe, amounting to 40.9 tonnes per person, compared with the EU average of 7.8 tonnes and Sweden (the lowest) 1.8 tonnes [85].

From 1990 to 2018 the total estimated black carbon emissions in Iceland decreased by 39%. In 2018 it amounted to 205t with fishing, industry, and construction (64%) and road transportation (19%) being the major sources [108].

In 2011 the EU Emissions Trading System (EU ETS) was introduced in Iceland under the provision of the EEA-agreement. The EU ETS covers about 40% of 2018 emissions in Iceland. Iceland will adopt a revised legislation for the EU Emissions Trading Scheme for the period 2021-2030, which primarily covers heavy industry and aviation [82].

In 2016 Iceland announced its intention of being part of a collective delivery by European countries to reach a target of 40% reduction of GHG emissions by 2030 compared to 1990 [198].

In 2018, the country established the Icelandic Climate Council (Loftslagsráð)[63], and independent institution with representatives from across Icelandic society and a government-appointed chair.

In 2019 Green By Iceland (Grænvangur)[64], a platform to strengthen cooperation between industry and government to reduce GHG emissions, was set up. The same year Iceland made an agreement on climate cooperation with Norway and the EU [46] and agreed to reduce overall GHG emissions by at least 40% by 2030. In 2020 Iceland announced it would reduce GHG reductions by 55% by 2030 [139].

In 2020 the revised version of Iceland's Climate Action Plan 2018 was presented. It includes 48 actions, designed to reach carbon neutrality [81]. Key points of the plan are rapid clean energy transition in transport and the land use, land-use change and forestry (LULUCF) sector. According to the plan, by 2030 GHG emissions must be decreased by more than one million tonnes of CO_2.

By 2040 or before, Iceland plans to achieve carbon neutrality by emission reductions in all sectors of the economy and by carbon removal from the atmosphere using carbon capture and mineralisation in rock formations (Carbfix[65]). Currently Iceland is in the process of preparing a long-term, low-GHG emission development strategy in accordance with the Paris Agreement [198], and while it established Green by Iceland to achieve low carbon goals across the economy, Iceland did not publish sector-specific roadmaps.

Climate matters, including low-carbon research and technology, are coordinated by the Icelandic Ministry for the Environment and Natural Resources[66]. The Icelandic Centre for Research (Rannís[67]) administers the national competitive funds for research and innovation, including the Climate Fund, which was established in 2019 with plans to reach €3.7 million funding in five years [89], and the country's Science and Technology Policy 2020-2022 stresses the importance of innovation in tackling challenges such as climate change [157].

[62] https://ourworldindata.org/co2/country/iceland#what-are-the-country-s-annual-co2-emissions
[63] https://www.loftslagsrad.is/english/
[64] https://www.greenbyiceland.com/
[65] https://www.carbfix.com/our-story
[66] https://www.government.is/ministries/ministry-for-the-environment-and-natural-resources/
[67] https://en.rannis.is/

The National Power Company of Iceland (Landsvirkun)[68] is one the largest producers of renewable energy in Europe. The company supports research and operates the Icelandic Energy Research Fund[69], which contributes to environmental and sustainable energy research [100].

Carbfix[70], the most famous Icelandic carbon technology, is based on storing captured carbon in deep basalt rock formations, where it turns into new rock within two years. In 2021 the world's largest carbon capture facility, Orca, opened in Iceland [24] near Reykjavík and the Hellisheiði geothermal power plant.

From 1990 to 2019, emissions from Iceland's energy sector declined by 63% [107]. Iceland's proportion of domestic renewable energy in the total energy budget is close to 85%. [108], with electricity and heating being produced from renewable resources, hydro, geothermal and wind power. This results in lower GHG emissions than other countries that utilise a higher proportion of fossil fuels. By 2030 Iceland's two largest energy companies (Hellisheiði and Nesjavellir) will be carbon neutral [188]. Geothermal energy has produced 3-4% of Iceland's total GHG emissions since 2015 [198], providing heating for over 90% of homes [5], and about 30% of electricity production [107].

At the Krafla geothermal power station[71] carbon emissions are reduced by re-injecting carbon dioxide into the geothermal wells or reusing the carbon dioxide emitted from geothermal gas, which in 2020 amounted to50,000 tonnes of CO_2 [84].

From 1990 to 2019 emissions from the transportation sector increased by 67%, and in road transport alone by 82% [107], due to an increase in car use and tourism.

Transport and fisheries accounted for 37% of Iceland's total GHG emissions in 2018 [198]. Emissions from both domestic flights, navigation and fishing have declined 17%, 11%, and 29% respectively since 1990 [107].

Iceland along with the other Nordic countries focuses on electrification of land and maritime transport [188]. Low-emission transportation is supported in Iceland by tax reductions (annual vehicle tax, differentiated annual vehicle tax) and support schemes for charging stations [205].

In 2011 Iceland introduced a carbon tax on fossil fuels, and removed import duties on electric and hybrid cars. From 2017 to 2019 the share of newly registered electric cars increased from 13% to 23% [83]188, and new registrations of electric vehicles and plug-in hybrids have also been increasing rapidly since 2014 [107].

Iceland has halved GHG emissions from the fisheries, setting an example for the other Nordic countries [98]. Emissions from fisheries rose from 1990 to 1996, and then decreased below 1990 levels in 2011, but while emissions remain below 1990 levels, there are large annual variations [107]. Iceland renewed its membership in the voluntary Carbon Trading Scheme in International Aviation (CORSIA) in 2020 [34].

Industrial processes are responsible for 42% of Iceland's GHG emissions, excluding GHG from land use and forestry [198].

The metal and mineral industry accounts for 38% of national GHG emissions. Reductions in this sector's emissions are stimulated by implementation of new carbon taxes, ETS systems and a phase out fluorinated gases [188].

Until recently, the fishmeal and fisheries industry accounted for 5% of Iceland's emissions, but emissions have now decreased in response to electricity and carbon taxes as well as a drop in production. Fishmeal factories are converting to electric boilers, but the transmission system still limits access to electricity [82].

The chemical industry was once a major source of GHG emissions in Iceland, but after 2004 all chemical plants were closed [107].

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[68] https://www.landsvirkjun.com/

[69] https://www.landsvirkjun.com/energy-research-fund

[70] https://www.carbfix.com/our-story

[71] https://www.landsvirkjun.com/powerstations/krafla

The aluminium industry in Iceland uses renewable energy and its GHG emissions are only one-sixth of the average GHG emissions compared with aluminium production worldwide [102].At present, three aluminium smelters, two manufacturing plants and the energy company Reykjavik Energy are investigating becoming carbon neutral by 2040. Together, they produce 1.76 million tonnes of CO_2 each year.

Until 2007 emissions in the construction and housing sector increased due to the increased activity in the sector. The main emitter was Iceland's largest hydropower plant Kárahnjúkar [108]. After the economic crisis of 2008 emissions halved.

Between 1990 and 2019, emissions in manufacturing industry and construction declined by 76% [107], with emissions from construction being tackled by using low-carbon materials such as locally-produced Icelandic stone wool, as well as timber cladding and cross-laminated timber [169].

In 2018 agriculture was responsible for 13% of Iceland's GHG emissions, mostly from soils and livestock enteric fermentation (a natural part of the digestive process in ruminant animals). From 1990 to 2019 agriculture emissions declined by 6% [198].

Iceland is self-sufficient in all major livestock products. Traditional livestock production is grassland-based, and the sector is making efforts to reduce its use of synthetic fertilisers, improve manure management, boost carbon efficiency of cattle and sheep farming, and increase the biofuel production from plants and waste. Iceland plans to reduce imports and use of synthetic fertilisers and increase its use of domestic organic waste as a fertiliser [82].

Iceland's government plans to launch a project to support sheep farmers and encourage increased carbon sequestration from farming and land use activities [82].

Iceland is not yet fulfilling requirements of the EU's LULUCF (Land Use, Land-Use Change and Forestry) Regulation (2018), but this sector is a priority in Iceland´s Climate Action Plan. Measures include enhanced forestry and afforestation through increased government funding [153]. Almost no changes in Iceland's LULUCF emissions occurred between 1990 and 2019 [107]. Still most of emissions in country's LULUCF sector come from wetlands drained in the 20th century [198].

Waste management emissions (solid waste disposal, incineration and open burning of waste, wastewater treatment and discharge) in 2020 were responsible for 5-6% of total Iceland's emissions [107, 198]. In 2019, Iceland's GHG emissions from waste were almost unchanged compared with 1990.

GHG emissions from the waste sector peaked in 2007 before declining to 1990 levels in 2019 [107]. Solid waste disposal and wastewater treatment activities account for around 80% of GHG emissions in waste management [153].

According to Iceland's Climate Action Plan, the minimum tax on landfilled waste will be at least 0.08€/tonne with the eventual aim being a ban on landfilling of organic waste [108].

In 2020 GAJA, a new biogas and composting plant[72], began operating at Álfsnes near Reykjavík, processing pre-sorted organic household waste. This will result in a decline of GHG emission to 2027, when emissions will start to rise again in line with a projected population increase [153].

Norway

In 2020 Norway's total GHG emissions stood at 49.7 million tonnes CO_2e (emissions from ocean transport and international air transport are not included in national statistics), which is slightly below 1990's level of 51.2 million tonnes CO_2e [52]. If all GHG emissions are considered, there has been an increase of 19.5% from 1990 to 2019 (6.9 million tonnes CO_2e) [73].

[72] https://www.sorpa.is/en/locations/Gas-%20og%20jar%C3%B0ger%C3%B0arst%C3%B6%C3%B0

In 2005 Norway joined the ETS and by 2018 approximately 80% of GHG emissions were subject to cross-sector economic instrument, taxes and the EU ETS [30], and almost 70% of the emissions (non-EU-ETS) are regulated by through taxation [188].

Norway passed a Climate Change Act [14] in 2017. The act set a national target for 2050 of 80-95% GHG emissions reduction below 1990 levels, although some sectors, such as agriculture, are exempt from carbon taxes.

In 2019 Norway agreed a National Plan of cooperation with the EU on fighting climate change [136], and submitted an enhanced Paris Agreement target (NDC) in 2020 and to achieve climate neutrality in 2030 and reduce emissions by 55% compared to 1990 [134]. If the EU climate targets are less ambitious, Norway plans to achieve the difference between its own goals and that of the EU. New sector roadmap proposals have been prepared, although the Federation of Norwegian Industries (Norsk Industri[73]) forecasts only a 23% reduction by 2030 [55].

In 2021 Norway published a white paper describing its action plan for transforming Norwegian society as a whole by 2030. This comprehensive climate action plan was set targets for GHG reductions in every sector of economy [133]. The plan deals with ETS and non-ETS emissions; the latter are to be reduced by 45% through domestic emission cuts. Norway's new approach includes taxation (a carbon tax rate increase from NOK 590 to NOK 2000 per tonne CO_2e in 2030 to meet the EU emissions cut of 40% by 2030).

The recovery plan for Norway's economy amounts to NOK 27 billion, including tax relief for oil and gas companies and support for the aviation industry. Only 12% of recovery financing is designed for green measures, including research and development of green technologies [30].

The 2021 National Budget, set tax rates are NOK 1.27 per standard cubic meter of gas or per litre of oil or condensate (NOK 543 per tonne CO_2) and NOK 8.76 per standard cubic meter for natural gas emissions [132]. The same year, Norway published a National Inventory Report [73] on anthropogenic emissions and removals by sources and sinks.

Development of climate and low-carbon research technologies in Norway is coordinated and supported by the Ministry of Climate and Environment[74] through the state-owned company Enova SF[75] (NOK 3.3 billion for 3,852 projects in 2020 [57]) in cooperation with the Research Council of Norway[76] and the Industrial Development Corporation of Norway (SIVA[77]). The new Green Platform initiative, set up in 2021 [200] is promoting climate-friendly innovation and development during the COVID-19 pandemic [133].

The Research Council of Norway is supporting research in low and negative emissions in the waste-to-energy sector, including the NEWEST-CCUS[78] and CapeWaste projects [93].

Technology Centre Mongstad[79], which tests new capture solutions and advises enterprises on carbon projects, is the global leader in CCS technologies. They

Norway's energy system differs from that of other Nordic countries, and from most other systems around the world. Abundant natural energy resources are combined with large energy export.

Energy industries contributed 42.8% to Norway's GHG emissions in 2019 and since 1990, Norway's GHG emissions from the energy sector increased by 22.2%, primarily due to increased activity in oil and gas extraction and road transport [74].

Two thirds of Norway's energy consumption comes from oil and gas, and one third from electricity, and its renewable energy capacity increased by 24%, from 30 to 37,2 terawatts, between

[73] https://www.norskindustri.no/om-norsk-industri/in-english/

[74] https://www.regjeringen.no/en/dep/kld/id668/

[75] https://www.enova.no/about-enova/

[76] https://www.forskningsradet.no

[77] https://www.regjeringen.no/en/dep/kmd/organisation/etater-og-virksomheter-under-kommunal--og-moderniseringsdepartementet/Subordinate-institutions/The-Industrial-Development-Corporation-o/id85811/

[78] https://www.newestccus.eu/

[79] https://tcmda.com/

2008 and 2020 () [165]. Almost all of Norway's electricity comes from renewables, with more than 90% generated by its 1,681 hydro power stations and 1,000 hydro reservoirs, which allow storage of up to 70% of annual electricity consumption [131]. Surplus renewable electricity enabled Norway to become Europe's largest power exporter in 2020, when it exported 14 TWh [131].

Wind power is generating around 17% of Norway's energy, and to promote development of wind power, Norway invested more than €11 million in a new wind power research centre, NorthWind[80].

Norway has been slower to develop solar power, but several Norwegian companies – including Norsk Solar[81], Kube energy[82] – are now promoting this low-carbon technology both in Norway and worldwide.

Norway is part of the North Sea Energy Hub consortium, which has been developing new energy-islands and integrating offshore wind energy into existing power grids since 2017 [194].

A Norwegian government enterprise Enova SF[83] and the Climate and Energy Fund of Norway[84] are both supporting reductions of GHG emissions in the energy sector through longer term R&D.

GHG emissions from Norway's transportation sector have increased by 18.6% since 1990, accounting for 28.4% of total GHG emissions in 2019, land transport emitting the most (69.1%) [73].

Norway's maritime sector has higher GHG emissions than other Nordic countries, and Norway has committed to reducing emissions from this sector by 50% by 2030. Several low low-emission projects are already underway, including the first electric ferry project in Ampere in Norway[85] and advanced electric charging infrastructure in the port of Kristiansand. Domestic aviation and navigation account for almost one third of Norway's GHG emissions, which means that zero-carbon targets in this sector will be very difficult to reach, especially given that Arctic areas of Norway are heavily reliant on aviation.

The Norwegian government's new National Transport Plan (2022–2033) aims to halve the emissions from the transport sector by 2030 compared to 2005 levels, and is investing up to NOK 80 billion in public transport and active travel in urban areas, and providing 50% of the costs of five large public transport projects [4]. The Urban Growth Agreement (byveksavtal) has also set a zero growth target at federal and city level to halt the growth of car traffic [170]).

Under Norway's comprehensive climate action plan (2021), the biofuel quota obligation for road traffic will be steadily increased up to 2030, and a similar quota for off-road diesel and shipping fuel is being introduced in 2022 [133].

Norway is incentivising low-emission transportation through tax reductions, including cheaper annual vehicle tax, registration tax and VAT exemption, reduced company car tax for zero- or low-emission vehicles, reduced ferry fees, and support for charging stations and electric bus grants [205]. From 2021 Norway is adjusting low-emission transportation tax incentives, and Norway set a national goal for all new passenger cars and vans sold by 2025 to be zero-emission (electric or hydrogen) [137]. In 2020, 54% of cars sold in Norway were electric, the highest market share in the world [50], although only 10% of all cars in the country are electric. Beginning 2022 only zero-emission vehicles are granted taxi licenses in Oslo, which, together with investment in urban development, will help reduce Oslo's GHG emissions, 60% of which comes from transportation [26]. A zero-emission zone will be piloted in Bergen in 2023 for passenger cars, light commercial trucks, and heavy vehicles [199].

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[80] https://www.northwindresearch.no/
[81] https://norsksolar.com/
[82] https://www.energy-xprt.com/companies/kube-energy-94198
[83] https://www.enova.no/
[84] https://www.iea.org/policies/7745-climate-and-energy-fundenova-residential-buildings
[85] https://www.ship-technology.com/projects/norled-zerocat-electric-powered-ferry/

Other examples of climate-friendly land transportation projects in Norway include ASKO battery electric Scania distribution trucks[86] and ELinGO (Electrical Infrastructure for Freight Traffic)[87].

Norway's GHG emissions from industry have increased by 7.4% since 1990, and accounted for 18.5% of total GHG emissions in 2019 [73]. Fossil fuels use outside EU ETS requirements will be phased out by 2030 and by 2025 in heating and construction [133].

GHG emissions from the metals and mineral industry in Norway have declined by 50% since 1990 through technology development and increased use of biomass and hydrogen. However, it remains the main source of GHG emissions in industry, accounting for 53% of emissions in 2019 [74].

Norway intends to electrify 40% of offshore petroleum exploration by 2025 through floating offshore wind turbines [188] such as the Hywind Tampen [80] floating wind farm.

CCS technology is a high priority for Norway´s energy sector. With state aid, a production site in Telemark will be equipped with a CCS facility and in 2021, Norway launched a €1.7 billion CCS project, funded in part by the government, in Langskip CCS project in Oslo (Klemetsrud) [95] which will store captured carbon under the North Sea as part of the Northern Lights CO_2 transport and storage initiative[88]. The project could help Norway achieve its target of 5.5 million tonnes of CO_2e reductions in 2050. The Norwegian government is also looking to hydrogen and ammonia clean fuel businesses as part of its strategy for a low-carbon economy.

The Norwegian construction and housing sector accounts for around 15% of the country's GHG emissions [101] with most emissions in this sector coming from construction sites, production of materials and products, and transport. GHG emissions from construction and housing in Norway declined by 19% between 1990 and 2017, which is the smallest reduction among Nordic countries, although most other Nordics started from much higher levels [188].

Oslo and Norway's other largest cities set a target for all construction sites to be emission free by 2030, a target that some forecasts suggest will be met by 2025 [130]. These plans are supported by two of Norway's largest developers, Veidekke[89] and NCC[90] [204]. Norway's municipalities are also investigating smart building with green solutions supported by US technologies such as Grid-Interactive Efficient Buildings [75].

Energy requirements for buildings are becoming ever stricter, and Norway plans to ban use of fossil oil for heating of people-friendly buildings and for heating and drying during construction and rehabilitation [101].

In 2019 Norway's GHG emissions from agriculture amounted 8.8% (8.4% in 2020 188 of the country's total emissions, amounting to 4.4 million tonnes of CO_2, mostly from enteric fermentation and agricultural soils [188]. GHG emissions from agriculture in Norway decreased by 7.0 % between 1990 and 2019 [73].

Land suitable for agriculture is scarce in Norway, where farms are relatively small and have long transport routes. The agriculture sector is excluded from carbon taxation in Norway, but Fossil fuel use in agriculture is subject to carbon taxes like other sectors. From 2025 use of mineral oil for heating agriculture-related buildings will be banned [136].

Norway has a substantial carbon sink in its forests, amounting to around half of Norway's annual emissions. Forest cover has been increasing, and the volume of growing wood stock has increased by more than 23% between 2008 and 2017 by over 23%. According to its national forestry accounting plan, Norway's average annual removal from this sector will amount to slightly over 24 million tonnes of CO_2eq between 2021 and 2025 [28]106.

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[86] https://traton.com/en/innovation-hub/asko-scania-battery-eletric-trucks.html
[87] https://www.sintef.no/projectweb/elingo/english/
[88] https://www.equinor.com/en/what-we-do/northern-lights.html
[89] http://veidekke.no/
[90] https://www.ncc.com/

Carbon uptake in Norway's agriculture sector will be enhanced by a total of 5 million tonnes CO_2e by 2030 compared to 2021 [133]. How this target will be achieved is as yet undecided, and will be discussed in negotiations between government and agricultural organisations of Norway, including the Norwegian Farmers Union[91], and while the government cannot raise the level of subsides compensating climate measures in agriculture, neither does it want agricultural organisations to oppose climate goals.

In 2019 Norway's waste management sector accounted for 2.1% of national GHG emissions (1.1 million tonnes of CO_2) with solid waste disposal on land being the main source (81.8%). From 1990 to 2019 Norway's GHG emissions from the waste sector declined by 52.3% [73].

Norway's comprehensive climate action plan encourages the implementation of future waste management projects, such as at Fortum Oslo Varme's waste incineration plant [66]. The city expects 200,000 additional tonnes of CO_2e to be avoided by increasing reuse, recycling and sharing, and by investing in CCS technologies in Oslo's waste-to-energy plants. A pilot project has already demonstrated that 90% of CO_2e emissions can be captured [26].

Several companies in Norway, including the waste management firm BIR[92] and Returkraft[93], a waste-to-energy (WtE) company, are using waste for energy production on a large scale, and are planning to build new carbon capture facilities [93]. Six major players in Norway's WtE sector have formed an industrial collaboration to progress climate action for waste incineration facilities. The initiative, known as KAN - Climate Control for Waste Incineration in Norway, will examine CCS technologies for the WtE industry, including financing, transport, logistics and warehousing, as well as climate benefits [93].

Sweden

Swedish GHG emissions amounted to 52 million tonnes of CO_2 in 2018, two thirds of this coming from the industry and domestic transport [156]. This represents a 26% reduction compared to 1990, most of which was achieved in domestic transport, manufacturing and construction.

In 2017, Sweden adopted a climate policy framework including a Climate Act, which came into force in 2018, and the Swedish Climate Policy Council, an independent expert body tasked with evaluating how well the government's overall policy is aligned with the climate goal of no net GHG emissions by 2045 [190].

Under the Act, the government must report annual emissions trends to parliament, and draw up a climate policy action plan every four years[94].

For Sweden, achieving net zero by 2045 means an 85% reduction in emissions compared to 1990 (63% by 2030, 75% by 2040) and using measures such as CO_2 assimilation by forests, verified emission reductions outside Sweden's borders and biomass CCS (bio-CCS).

In 2020 new roadmaps for Swedish industries' fossil-free competitiveness was published [156] as part of the Fossil Free Sweden initiative (Fossilfritt Sverige) [68]. Established in 2016, this initiative introduced a framework for climate policy cooperation between the Swedish government, research organisations, civil society and businesses, and covers more than 70% of emissions in Sweden [174].

Another important instrument is Sweden's Integrated National Energy and Climate Plan [173], based primarily on the climate policy framework, energy policy and the targets in the Energy Policy Framework Agreement and the National air pollution control programme [105].

Climate and low-carbon research in Sweden is led by Rossby Centre[95] at the Swedish Meteorological and Hydrological Institute[96]. The Swedish Research Council for Environment,

[91] https://www.gfar.net/organizations/norges-bondelag-norwegian-farmers-union
[92] https://bir.no/om-bir/english/
[93] https://www.returkraft.no/
[94] https://www.klimatpolitiskaradet.se/en/uppdrag/

Agricultural Sciences and Spatial Planning (FORMAS[97]) supports research projects focused on reducing GHG emissions. Lund University[98] conducts studies on peatland emissions [48] and GHG emission measurement methods [163].In 2020, the government established a climate neutral industry partnership to provide support for zero-carbon innovation by industry and science institutions, and strengthen and accelerate industry's transition to a fossil-free society [88].

In 2018, GHG emissions from the energy sector amounted to approximately 36.4 million tonnes of CO_2e[99]. In 2019, total energy supply in Sweden was 548 TWh, with biofuels contributing 145 TWh, oil 114 TWh and nuclear 181 TWh [49].

Sweden has no national targets for the share of renewable energy in 2030, but the 2016 reference scenario suggests that renewables would account for 65% of gross energy consumption in 2030 All gaseous vehicle fuels will be fossil free 2023, all energy gases in the electricity generation and heating sectors will be completely fossil free 2030 and all energy gases used in Sweden will be completely fossil free by 2045 at the latest [173].

Under the Energy Agreement, the Swedish parliament set a target of 100% of electricity being generated from renewable sources by 2040. However, this is neither a deadline for banning nuclear energy nor is it a policy decision to stop generating nuclear energy. As well as aiming to cut net GHG emissions to zero by 2045, Sweden aims to reduce emissions from activities on Swedish territory to 15% of 1990 levels. The Integrated National Energy and Climate Plan also aims to achieve a 50% improvement in energy efficiency by 2030 [173].

Sweden is part of the Nordic electricity system and fully supports an integrated cross-border energy market. Carbon-pricing instruments in electricity production have been effective in driving decarbonisation in Sweden [188].

Several cross-sectoral policies and measures have been implemented in Sweden to achieve its zero-carbon targets, including an energy and carbon taxation system (a combination of a carbon, fuel and electricity taxes, and tax reduction for sustainable biofuels); a Swedish system of local climate investment (the Klimatkliv [90], or the Climate Leap, excluding the EU ETS); a system of environmental legislation (the Environmental Code [191] and the Planning and Building Act [176], energy management and land-use planning); and the Fossil-Free Sweden initiative [68] .

The Swedish island of Gotland has set a target for having a climate neutral energy supply by 2025, relying instead on biofuels and abundance of wind power resources, and a pilot project for transition to a sustainable energy system is underway on Gotland [49].

By 2030 Sweden aims to reduce emissions in domestic transport sector by 70%, compared to 2010 (domestic flights also excluded) [172]. The use of petrol and diesel in Sweden has decreased by 75 per cent over the past fifteen years, mainly in transportation sector [49]. Now Sweden already covers 11.9% of their transport energy use with biofuels.

According to law, every filling station in Sweden with sales over 1 500 m3 of petrol or diesel must offer at least one type of renewable fuel [177].

A series of electric road demonstration projects is being carried out in in Lund, Gotland, on the E16 road outside Sandviken and at Arlanda airport (including public transport and heavy goods vehicles and cars) [173].

Switching to alternative fuels is a primary goal for Sweden's transportation sector, and is based on the Worldwide Harmonised Light Vehicle Test Procedure including vehicle tax and bonuses for new vehicles [184].

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[95] https://www.smhi.se/en/research/research-departments/climate-research-at-the-rossby-centre/about-rossby-centre-1.8341

[96] https://eurogoos.eu/member/swedish-meteorological-and-hydrological-institute-smhi/

[97] https://formas.se/

[98] https://www.lunduniversity.lu.se/

[99] https://www.statista.com/statistics/411737/annual-greenhouse-gas-emissions-of-the-energy-sector-in-sweden/

GHG emissions from domestic and international air transport account for 5% of Sweden's total CO_2 emissions. Sweden introduced a climate tax on air travel in 2018 [175]; domestic flights will be fossil free by 2030 and all flights originating from Sweden will be fossil free by 2045 [156].

To achieve these goals the Swedish aviation sector is planning switch to alternative fuels. Domestic flights would require about 200,000 m3 of biofuel and international flights about 1 million m^3. Technological solutions for producing fossil-free aviation fuel already exist, but there is yet no functioning market and the price gap between fossil and fossil-free fuels remains wide. As a result, creating an efficient market model for fossil-free aviation fuel is a primary goal for Sweden in this sector.

Low-emission transportation is supported in Sweden by a range of tax reductions, including annual vehicle tax, carbon dioxide-differentiated annual vehicle tax, purchase bonuses, reduced company car tax for zero- or low-emission vehicles, support for charging stations and electric bus grants) [205]. In large Swedish cities, a novel e-taxi demand-boosting initiative was set up in 2019. Known as 'Nollzon' or zero-emission zones, these are voluntary schemes for companies and organisations wishing to boost use of e-taxis by customers and employees [33].

The Swedish metal and mineral industry accounts for 9% of national GHG emissions, with the steel sector accounting for the largest share. Within the cement and concrete sector, initiatives focus on electrification, increased use of biofuels in the production process, circular material flows, increased use of life cycle analysis and CCS. The mining and mineral sector has made significant progress in switching from diesel to electricity-powered technologies. To reduce emissions further, the sector is focusing on new processing technologies, biomass, increased electrification and CCS. In the steel sector, most direct emissions come from the use of coal when iron ore is reduced to iron (85%), and fuel to heat and processing the steel (12%). For carbon reductions, the sector is focusing on new hydrogen process techniques, biocoke for reduction of iron ore and increased use of biogas.

The Swedish mining industry aims to have the first fossil-free mine by 2035 [156], and the concrete industry's target is to have climate-neutral concrete on the market by 2030 with all concrete being climate neutral by 2045 [156].

The state initiative Industriklivet [99] (Industrial Evolution) is a long-term campaign to reduce GHG emissions by Swedish industries by supporting the development of process technologies that reduce emissions. The initiative will spend SEK 300 million per year to 2040 to support Swedish industry's transition to zero-carbon by 2045. One such technology being supported under this initiative is HYBRIT (HYdrogen BReakthrough Ironmaking Technology), a project aimed at fossil-free steel production [173].

Energisteg is a programme for Swedish industry to achieve a 50% improvement in energy efficiency by 2030, particularly in the mining and manufacturing industries.

The construction and housing sector accounts for 20% of Sweden's GHG emissions, primarily from the manufacture of construction materials and buildings energy usage.

The Swedish construction industry is planning to reduce its GHG emissions by 50% by 2030 compared with 2015 levels, 75% by 2040 and net zero by 2045 [156].

To achieve these goals the Swedish construction industry is looking to the government for legislative support (long-term and predictable legal decarbonisation requirements), changes in regulations for waste classification, and new incentives to promote efficient use of energy and resources in the refurbishment of existing property. Several pilot projects in the Swedish construction sector are underway, including the ZeroCO_2 houses project [202].

Sweden is also considering a range of alternatives to reduce GHG emissions in construction, including increased use of bio-based building materials, and local emissions-reduction strategies such as Skellefteå [182].

Municipalities and regions are key to Sweden's climate work. Stockholm set a target to become zero-carbon city by 2040 [166]. Use of coal in Stockholm has been banned since 2020 with all fossil fuels being replaced with renewables. Reductions in heating and transport (43%) will contribute most

to Stockholm's target. The city council plans to achieve zero-carbon targets by introducing differentiated taxes for non-fossil fuel vehicles, providing economic benefits to residents, as well as improving cycling infrastructure and investing in charging infrastructure in ports for vessels. Most food waste (70%) will be collected and converted into biogas, and Stockholm is using solar power (potentially 10%) and new combined heat and power plants (the first entered operation in 2016) for heating energy production [26].

In Sweden, agriculture and forestry account for about 15% of natural GHG emissions, mostly from cattle and land use, and Sweden has the largest supply of forest and agriculture biomass (crops, straw and manure) in the Nordic counties, where 90% of biomass is suitable for energy sources.

In the Sweden's 2014–2020 Rural Development Program (part of the EU's Common Agricultural Policy) measures to reduce GHG emissions were introduced for the agriculture sector, including renewable energy production (biogas and the planting of perennial energy crops), conversion from fossil fuels to renewable energy sources, improved manure management [171], and more efficient use of nitrogen [173]. To meet zero-carbon goals in the forest and agriculture sectors, Sweden is focusing on attracting investments for climate-friendly technologies, such as wind-power, and

Sweden's national forest strategy is promoting sustainable biomass from Swedish forests to achieve zero-carbon targets.

In 2017 Sweden's GHG emissions from waste management amounted to approximately 1.25 million tonnes of CO_2e[100]. In 2019, 6.7 million tonnes of waste were sent to energy recovery (17.8 TWh), producing 15% of Sweden's total CO_2 emissions reported under the EU ETS [77].

Avfall Sverige, the Swedish Waste Management and Energy Recovery Working Group[101] and its member companies are working together to cut emissions from recycling, and the industry wants to cut its fossil emissions by half by 2030, and reduce them to near zero by 2045 [77].

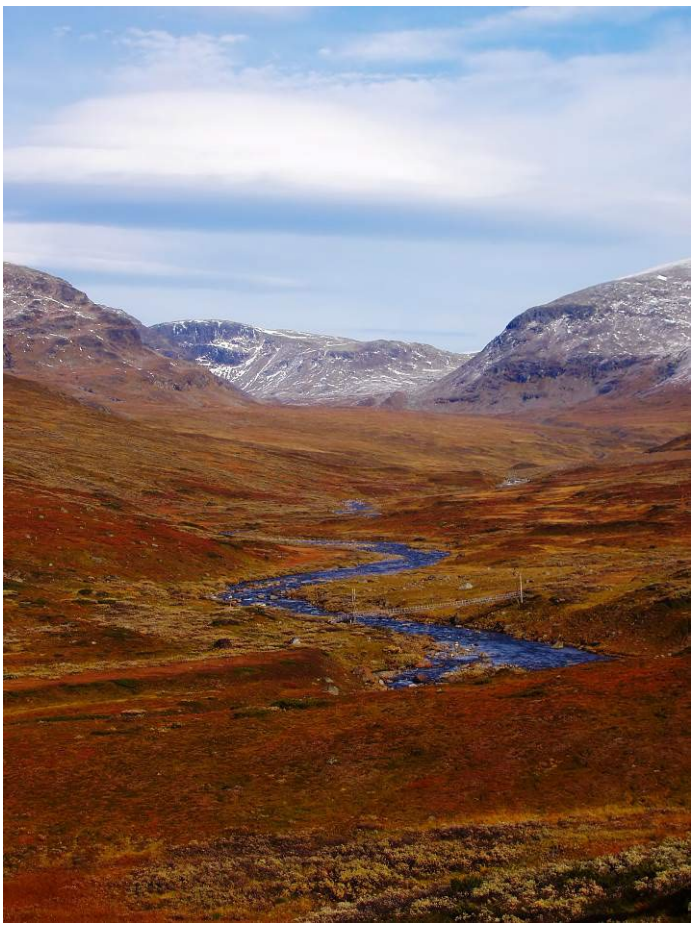
[100] https://www.statista.com/statistics/412358/annual-greenhouse-gas-emissions-from-waste-management-in-sweden/

[101] https://www.avfallsverige.se/

Summary

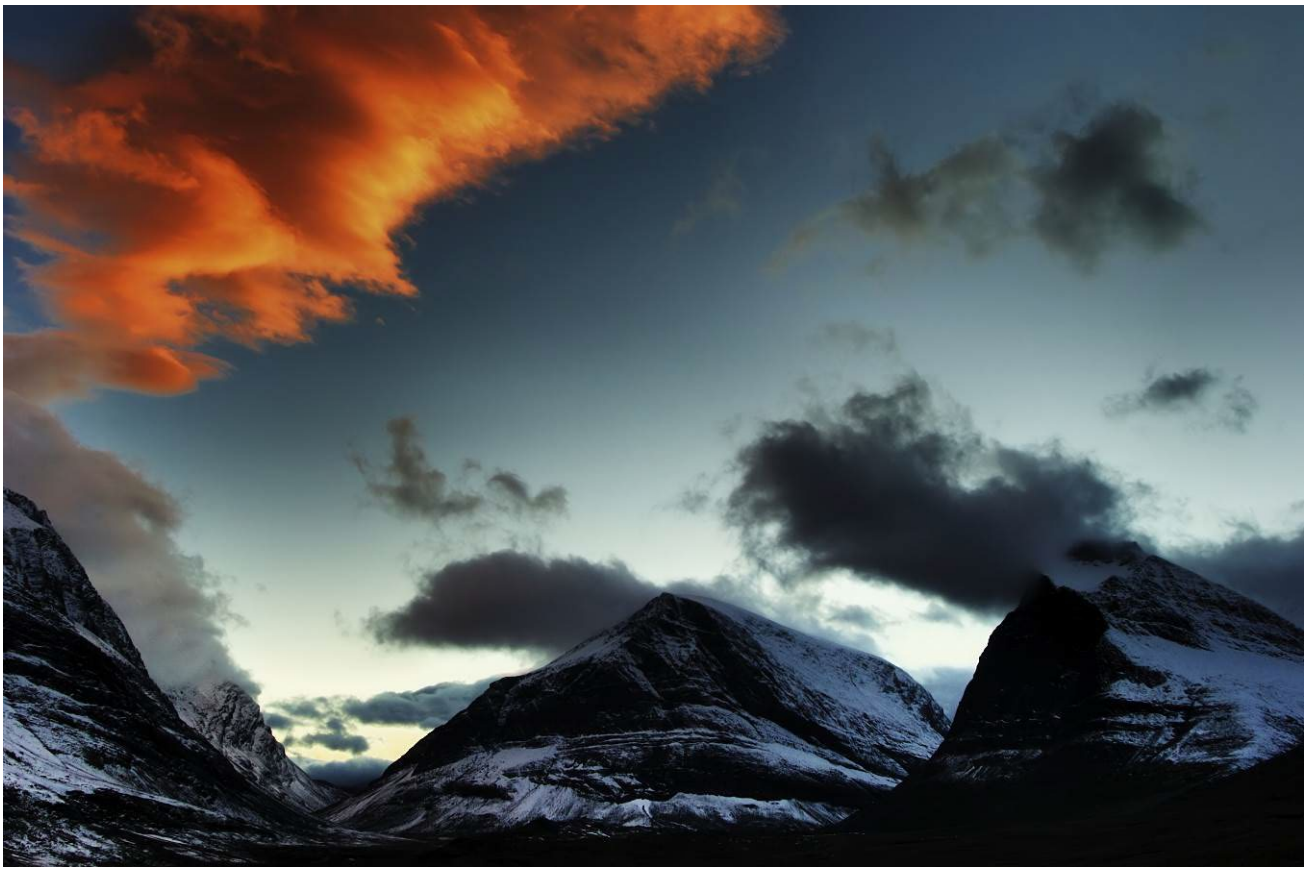
The Nordic countries are united geographically and culturally, and have similar very high levels of economic development. Their strong political connections are reflected in membership of international organisations, and the Nordic Council of Ministers acts as the stage for expressions of common will. Against this backdrop of exceptionally high levels of cooperation and mutual understanding, individual Nordic countries have their own interests to protect and their own visions of achieving their targets. Despite these differences leading to different approaches to achieving their goals, all Nordic countries are committed to a zero-carbon future.

The Nordic countries are all signatories to key international agreements on climate change, such as the Paris Agreement and the EU Green Deal, and are active participants in international climate change events such as COP26. The different pledges made by the Nordic countries at COP26, however, reflect how difficult is to achieve unity on the road to zero carbon even between countries that share so much, and have common goals.



The challenges that Nordic countries face in achieving zero-carbon targets relate to climate directives and legislation used in the region's specific context. Some Nordic countries, such as Sweden and Finland, object to the exclusion of biomass from the list of renewable sources of energy, whereas Norway excludes international flights from its carbon emissions list and has not yet set a timetable for 'zero-carbon day'. Each of the Nordic countries has its own definition of carbon neutrality, Finland's carbon neutrality depending on nuclear energy growth in the near future [138], while Denmark – the EU's largest oil producer – is phasing out oil and gas production in the North Sea only by 2050. [94].

Opportunities for the Nordic countries to achieve zero-carbon targets come from a common understanding of inevitable changes that the world faces. All Nordic countries are working hard to become climate pioneers, but often in different ways. All are major supports of climate-conscious innovation and believe in mutually beneficial climate cooperation. However, each Nordic country has its own vision of how their economies can benefit from climate transitions. Iceland, for example, is promoting carbon capture and mineralisation in rock formations and using geothermal energy; Norway is developing a Europe-wide renewable electricity grid based on hydropower plants. Finland is relying on support of innovative ventures in all areas of a carbon-free, climate-friendly economy, hoping to become a world-leading climate innovator; and Denmark is promoting construction of large-scale wind and hydrogen-powered plants, which could make the country a leader in clear energy, but all Nordic countries expect that new climate-friendly technologies and new zero-carbon sectors will boost employment and economy – as well as contributing to a zero-carbon region in what they hope will be a lower-carbon world.



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