ANALYSIS

CLIMATE CHANGE, ENERGY AND THE ENVIRONMENT

HYDROGEN IN THE NORDICS

Drivers of European Cooperation?

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Building on their strong renewables potential, the Nordics are ambitiously pursuing hydrogen strategies for the decarbonization of industry and transport.

The Nordics could play a pivotal role in Europe's emerging hydrogen economy: as technology providers, as producers of green industrial products and as exporters of hydrogen.

Engagement between the Nordics and their European neighbours should be enhanced in order to mobilise their potential for mutually beneficial cooperation.

FRIEDRICH EBERT STIFTUNG

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Auswärtiges Amt

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INTRODUCTION

Under the European Green Deal, hydrogen plays a central role in the decarbonisation of so-called »hard-to-electrify« sectors and represents an important target of green industrial policy, as Europe seeks to gain leadership in this emerging segment of carbon-neutral industrial systems. Moreover, following Russia's invasion of Ukraine, it has been declared an important building block in efforts to reduce Europe's dependence on Russian natural gas (Rouzo 2021). While it is almost certain that the EU will need to import a significant share of clean hydrogen to meet its climate-neutrality targets, it also increasingly recognised that it will be important to build up significant capacities in the EU and its immediate vicinity. This can help strengthen the EU energy system's resilience by reducing import dependencies and serve as a home market for European equipment and technology in the race for industrial leadership in the sector. This was one of nine policy messages formulated in a previous policy paper published jointly by the Friedrich Ebert Foundation and the Research Institute for Sustainability (RIFS) on the role of international cooperation in the development of an international hydrogen economy (Quitzow et al. 2023a).

Against this background, the Nordic region, with its abundant renewable energy resources at competitive costs could play an important role as a potential hub for hydrogen production and trade, involving EU members Finland, Sweden and Denmark, as well as Norway and Iceland, both members of the European Economic Area. The Nordic states[1] are positioning themselves as leaders in the energy transition and are pursuing ambitious decarbonisation targets in an effort to combat climate change. Hydrogen's possible role in achieving carbon-neutral societies has encouraged an increase in the activities of various stakeholders in the region in the form of concurrent policy development, R&D and industry development. The Nordic countries aim to use hydrogen to help achieve their interrelated climate and energy goals and as a key tool in the transformation of their industries.

In this vein, this policy paper explores the role the Nordics could play in an emerging European hydrogen economy. It provides, first, a brief overview of the current state of climate and energy policy in the region. It then goes on to review the state-of-play in the hydrogen sector, including national hydrogen strategies and the current project landscape in the Nordics. Finally, it reviews the role of Nordic cooperation both within the region and with other European partners in supporting a rapid development of the hydrogen economy. It concludes by identifying potential entry-points for increasing cooperation in the future.

1 This paper focuses on Denmark, Finland, Iceland, Norway and Sweden.

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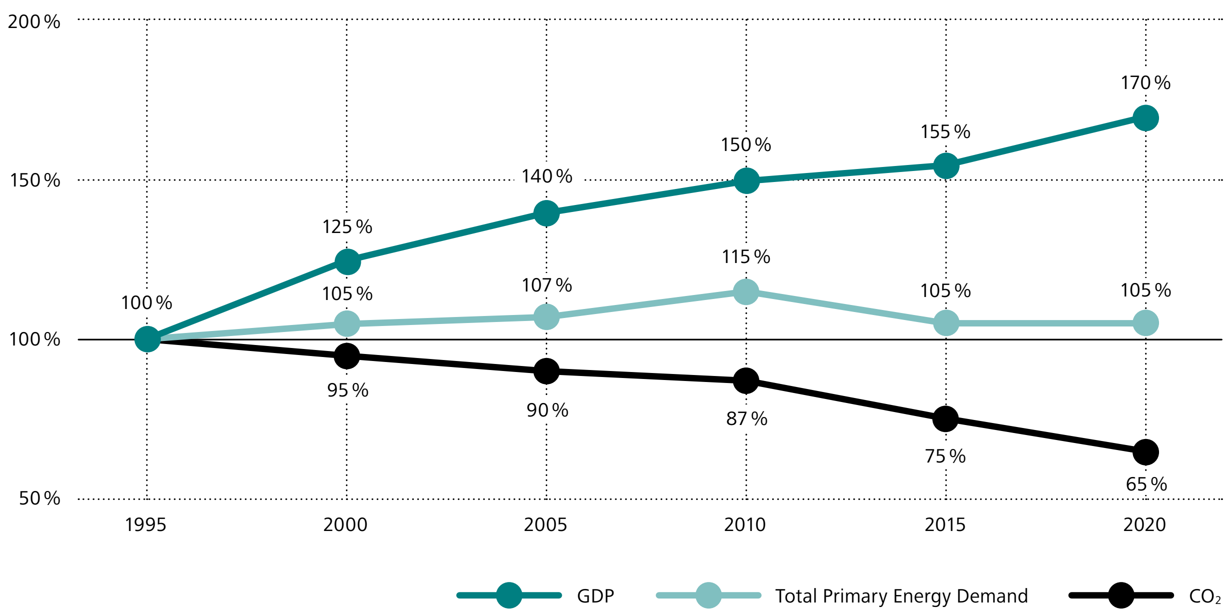
CLIMATE AND ENERGY POLICY IN THE NORDICS

Climate and energy policies in the Nordic countries are based on the premise that well-planned efforts to reduce greenhouse gas emissions can mitigate climate change and promote sustainable economic growth. The Nordic countries have set ambitious national goals for decarbonisation and the transformation of their energy systems. While decarbonisation is at the core of all strategies, specific concepts and targets vary across countries. Denmark is aiming for net-zero emissions by 2050, Finland for carbon-neutrality by 2035, Sweden by 2045, Norway by 2030 and Iceland by 2040 (Wråke et al., 2021).

Energy consumption per capita in the Nordics is higher than the EU average. This can be explained by the region's climatic conditions, low population density and related distribution across the region, and the region's energy-intensive industries. At the same time, CO2 emissions per unit of electricity produced are approximately one-fifth of the global average. While its CO2 emissions have decreased over time, its GDP has continued to expand (see Figure 1). Thus, Nordic climate policy has contributed to the decoupling of economic growth from greenhouse gas (GHG) emissions (Bhowmik 2019).

Figure 1
Growth rate: GDP, CO_2 and Total Primary Energy Demand in the Nordic Countries



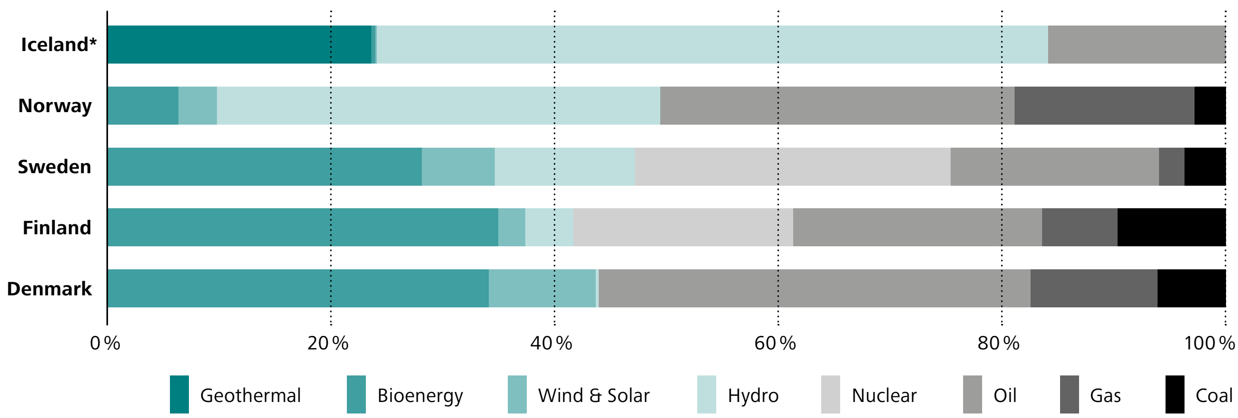
Source: Authors' own based on data from Bhowmik (2019).

3

RENEWABLE ENERGY DEVELOPMENT AND THE POTENTIAL FOR RENEWABLE HYDROGEN PRODUCTION IN THE NORDIC COUNTRIES

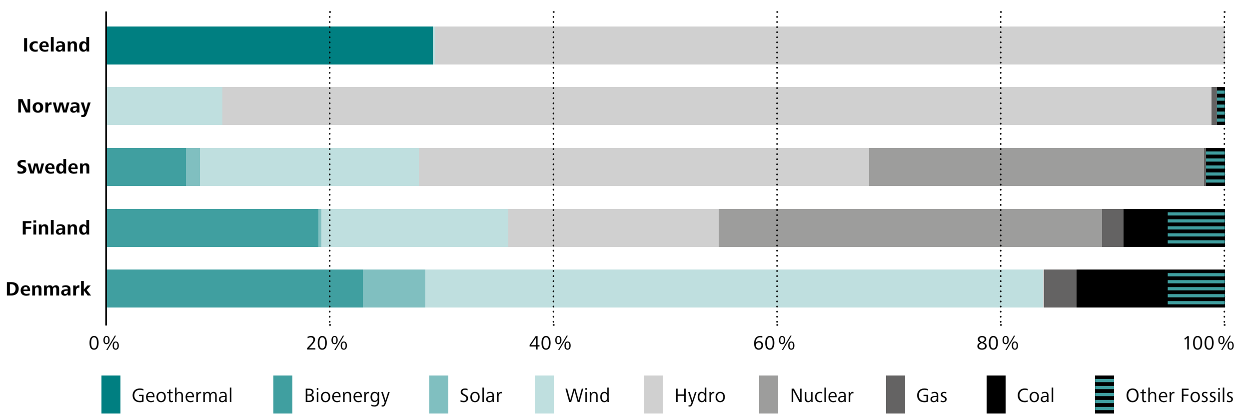
The Nordic countries are not only climate and energy policy pioneers, but also leaders in the deployment of renewable energy technologies (Aslani, Naaranoja and Wong 2013). These technologies include offshore wind in Denmark and the North Sea, bioenergy in Sweden and Finland, and geothermal energy in Iceland (see Figures 2 and 3). Due to its abundant water resources, hydropower is Norway's dominant energy source (Jansen et al. 2022; Jes Fenger and Nordisk Ministerråd 2007) and also plays a key role in Swedish electricity production (IRENA 2020). As a result, in 2020, the Nordics' renewable energy targets all significantly exceeded the EU's target of 20 per cent renewable energy in gross energy consumption. Denmark pledged 30 per cent, Finland 38 per cent, Iceland 72 per cent, Norway 67,5 per cent and Sweden 49 per cent. These targets were either achieved or exceeded two years ahead of schedule (European Commission 2018; Nordic Energy Research 2021). Shares of renewable energy in all Nordic countries are well above the EU average (see Figure 4).

Figure 2
Energy mix (total energy supply) in 2021, in percent



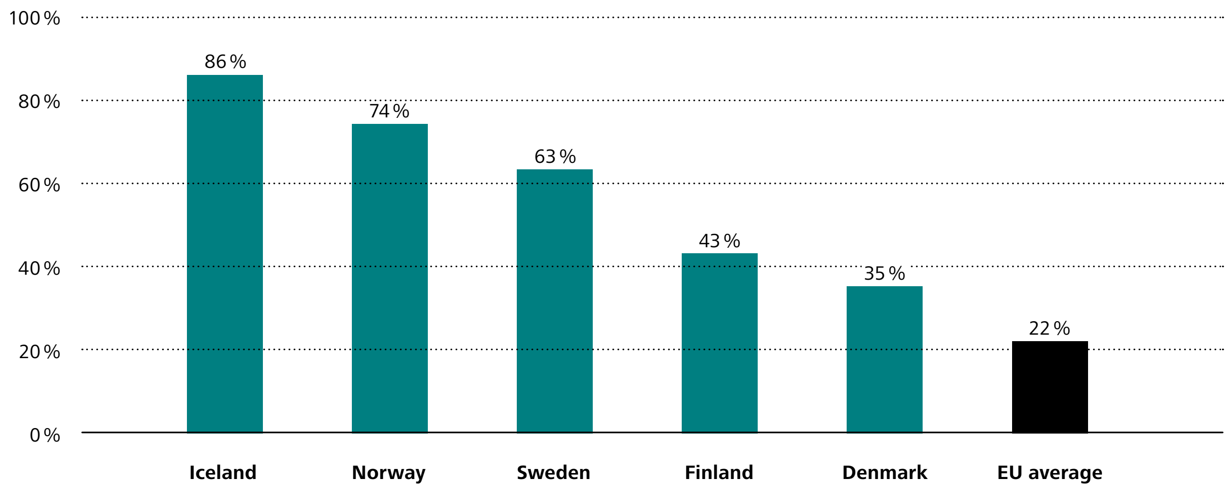
Source: Authors' own based on IEA Country Profiles, Iceland based on Country Profile on My World in Data.

Figure 3
Electricity mix in the Nordics in 2022, in percent



Source: Authors' own based on data from Electrictiy Data Explorer on ember-climate.org.

Figure 4
Share of renewable in total energy in the Nordics in 2021



Source: Eurostat.

The Nordic region has substantial wind energy potential, which it is actively seeking to develop. WindEurope's moderate scenario (2017) estimates that Norway, Sweden, Finland and Denmark could deploy a total of 32 GW of cumulative onshore wind energy capacity by 2030. Denmark, Belgium, the Netherlands and Germany have also signed the Esbjerg declaration, an agreement to build 65 GW of offshore wind power capacity and 20 GW of electrolyser capacity for the production of hydrogen by 2030 (Kurmayer 2022).

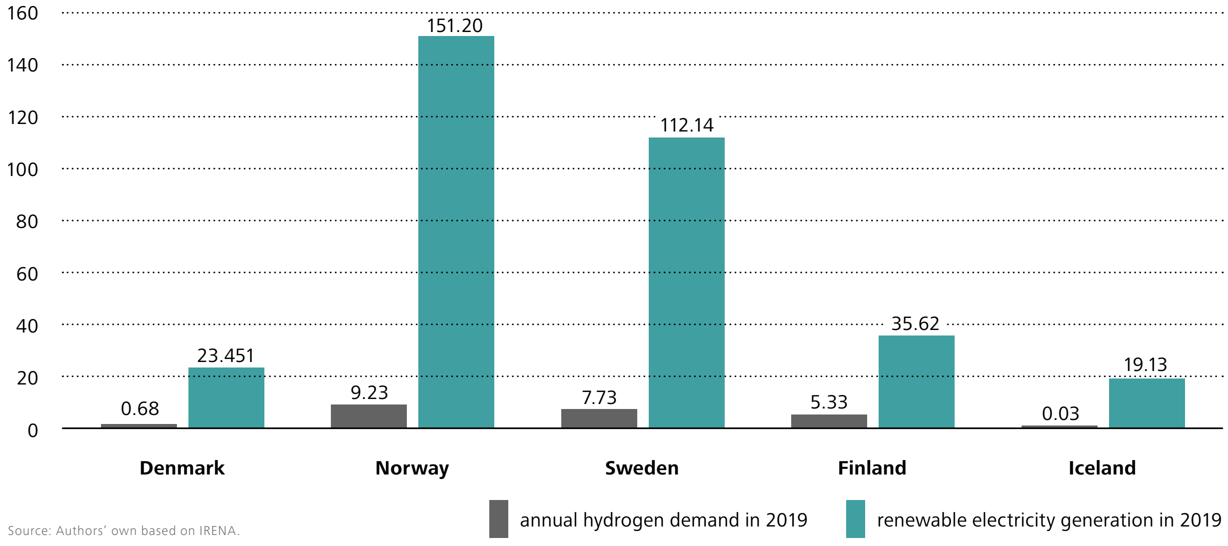
By 2050, Denmark aims to build 35 GW of offshore wind power capacity, more than double the current installed power capacity in the country. Since this expansion of offshore wind power will create a substantial surplus of electricity, the country intends to export electricity to its neighbours and to produce hydrogen to meet the national target of 6 GW of electrolysis capacity by 2030 (KEFM 2021). It is one of the highest targets in Europe, backed by nearly 7 GW of electrolysis capacity at various planning stages in the country today, exceeding its own target (Simonyi and Svendstorp 2022). For Denmark, hydrogen is also key to supporting the integration of its offshore wind potential into the energy system and reducing related investment needs for the development and strengthening of grid infrastructure (IEA 2021).

Also, Norway recently announced plans to develop 30 GW of offshore wind energy by 2040, which will include extending its grid connections to continental Europe (Durakovic 2022; VNG 2022). The fact that renewables already account for over 98 per cent of Norway's electricity generation also suggests that substantial amounts of new offshore wind energy could be used to produce hydrogen (see Figures 4 and 5). Sweden and Finland are also planning for an expansion of their respective offshore wind capacity. As signatories to the Marienborg Declaration, signed by eight Baltic Sea states, they aim to install a combined 6 GW of offshore wind capacity by 2030 (Rystad 2022). Today, Sweden has less than 4 GW of fossil-based capacity, while Finland has slightly more than 5 GW of fossil-based generation capacity.[2] Finally, Iceland, with a 100 per cent share of renewable energy in the power sector, is seeking to further expand remaining hydropower and geothermal potential to fully decarbonise, while developing new, climate-friendly industries.

As these figures indicate, the Nordics have both substantial scope and concrete plans for the generation of surplus renewable energy, which could be dedicated to the production of renewable hydrogen. Moreover, as Figure 5 indicates, only a fraction of current renewable generation would be needed to meet current volumes of hydrogen consumption in the Nordics. In other words, future renewable hydrogen production could be utilised to meet hydrogen demand for decarbonising hard-to-abate end-use sectors as well as exports. Indeed, as pointed out in a recent study (Quitzow et al. 2023b), even after meeting rising demand from decarbonisation, the Nordics all have significant potential to generate surplus renewable energy at prices under 40 euros (€) per MWh in Finland and Denmark, and under €30 MWh in Norway and Sweden. This is significantly below average non-household energy prices in the EU, which increased from €70 in 2020 to €142 in 2022.[3]

2 Based on data provide by IRENA. See https://www.irena.org/Data.
3 Based on data provided by Eurostat. See https://ec.europa.eu/eurostat/databrowser/view/nrg_pc_205_c/default/table?lang=en.

Figure 5
Existing annual H_2 demand and renewable electricity generation in the Nordics in 2019, in GWh



Source: Authors' own based on IRENA.

4

NATIONAL HYDROGEN STRATEGIES AND POLICY OBJECTIVES

All the Nordic states are either actively developing or already implementing hydrogen strategies, recognising their importance for the decarbonisation of hard-to-abate sectors (see Table 1 for an overview). Like the European hydrogen strategy, the Nordic countries strongly emphasise the development of renewable hydrogen. This is hydrogen produced with renewable electricity using electrolysers. Nevertheless, other forms of hydrogen also play a role in some cases. The presence of nuclear energy generation in Sweden and Finland means that these countries are targeting what Sweden's strategy refers to as fossil-free hydrogen, based on renewable and nuclear power generation. Norway, with its abundant reserves of natural gas, is promoting both renewable and low-carbon hydrogen. The latter is produced from natural gas via the traditional process of steam methane reforming[4] with carbon capture and storage (CCS) technologies.

Norway's strategy was published in 2020 and acknowledges a potential role for renewable and low-carbon hydrogen in combination with CCS (NMPE and NMCE 2020). As a natural gas exporter, the government and the state-owned oil and gas company Equinor see low-carbon hydrogen as an important opportunity for value creation from these assets in the future (see Box 1 for more details). In June 2021, the Norwegian government also published a roadmap for hydrogen in its White Paper »Long-Term Value Creation from Norwegian Energy Resources«, building on the existing hydrogen strategy. The roadmap highlights the expectation that hydrogen can be a realistic option for decarbonising maritime transport by 2030, with prospects for greater market adoption via hydrogen hubs and hydrogen research as a short-term goal (Ministry of Petroleum and Energy 2021). While the Norwegian government has not set a specific goal for its hydrogen production capacity, Statkraft, a Norwegian state company and Europe's largest generator of renewable energy, intends to reach a 2 GW electrolyser capacity by 2030 (Buli 2022).

Denmark released its hydrogen strategy in December 2021. The strategy includes the aim of exporting hydrogen derivates and hydrogen-related technologies, as well as the building of 4–6 GW of electrolysis capacity by 2030 via a tender for renewable hydrogen production for DKK 1.25 billion (€0.17 billion). Additionally, southern Denmark is positioned as a hub for renewable energy and sector coupling. Natural gas connections to Europe and the rest of Denmark are identified as possible hydrogen distribution networks (KEFM 2021).

In Finland, a hydrogen roadmap commissioned by Business Finland, a public sector organisation that supports Finnish business, and prepared by VTT, the Technical Research Centre of Finland, was published in 2020. The roadmap recommends the promotion of low-carbon electricity for hydrogen production. It is also estimated that Finland could produce 100 000 to 150 000 tonnes (equivalent to approximately 3 to 5 TWh) of renewable hydrogen per year by 2030 (Laurikko et al. 2020; COWI 2022). The national climate and energy strategy contains a sub-section on hydrogen and e-fuels, which func-

Box 1
The role of low-carbon hydrogen in Norway's hydrogen plans

In light of current natural gas prices across Europe, Bloomberg NEF (2022) reported in 2022 that renewable hydrogen production would be cheaper than low-carbon hydrogen production in eight European countries, including Sweden. In Norway, which has its own gas fields, there is still strong interest in low-carbon hydrogen, however. In fact, Equinor, Norway's state-owned energy company, plans to produce 2 GW of low-carbon hydrogen by 2030 for export to the EU either by pipeline or by ship in the form of ammonia. This would correspond to 10 per cent of the natural gas produced on the mainland. This quantity would be sufficient to meet the hydrogen demand of Germany's current steel production, if converted to hydrogen-based production methods (Collins 2022; Energy Europe 2022).

The strong position of low-carbon hydrogen as a so-called transition fuel is also evident in a strategic partnership between Equinor and Germany's utility RWE, signed in early 2023. This partnership is contingent on the development of a hydrogen pipeline between Germany and Norway, as well as the development of hydrogen downstream infrastructure in Germany. A key target of this strategic partnership is to position Norway as a key supplier of hydrogen to Germany and Europe. As part of this process, low-carbon hydrogen has been given a key role in ensuring the ramp-up of the hydrogen economy with the goal of moving to renewable hydrogen later on. Equinor and RWE will also jointly develop offshore windfarms to enable the production of green hydrogen in the future (Equinor 2023).

4 Steam methane reforming involves the separation of hydrogen from natural gas molecules, resulting in emissions of residual CO2.

tions as a national hydrogen strategy. Here, the focus is on prioritising the needs of Finnish industry, transport and the energy system, with export as secondary goal (TEM 2022). In February 2023 the Finnish government adopted a resolution on hydrogen, outlining the goal of becoming a European leader in the hydrogen economy capable of producing 10 per cent of the EU's emission-free hydrogen by 2030 (TEM 2023).

Iceland and Sweden have not yet finalised their official government hydrogen strategies, but other quasi-government and public-private organisations have developed hydrogen roadmaps or strategy proposals. In 2020, Icelandic New Energy, a public-private entity that supports Iceland's energy transition, released a hydrogen vision for 2030. It seeks to develop hydrogen and fuel cell technologies to help reduce GHG emissions in maritime and other heavy-duty transport. The vision is conceptualised as a living document to be updated and followed by a 2050 Hydrogen Roadmap for Iceland in 2025 (Icelandic New Energy 2020).

In Sweden, a first proposal for a national hydrogen strategy was prepared by Fossil Free Sweden, a government-backed initiative founded in 2015 and comprising various stakeholders (Fossil Free Sweden 2021). Following this, the Swedish Energy Agency drafted a national hydrogen strategy, proposing to deploy 5 gigawatts of electrolyser capacity by 2030 and 15 gigawatts by 2045. These goals require up to 60 TWh of additional electricity by 2030 and 126 TWh by 2045. The focus in both documents is on electricity-based hydrogen from renewables and nuclear, (also referred to as fossil-free hydrogen in Sweden) reflecting the Swedish electricity mix. Sweden intends to prioritise refining industrial products domestically rather than exporting hydrogen to Europe in the short to medium term, although it also remains open to the prospect of hydrogen exports (FCH 2020; Kander et al. 2020). The prioritisation of domestic use reflects the energy needs of Swedish heavy industry, such as steel, and the dual challenge of decarbonising industry and electrifying society as a whole.

Table 1
National hydrogen strategies and official hydrogen targets in the Nordic countries

		Key points
Non-EU Nordic states	Norway	**Strategy (2020)** • Both renewable and low-carbon hydrogen are supported. • Hydrogen is most relevant for use in the maritime, heavy transportation and industrial sectors. • The aim is to increase the number of pilot and demonstration projects in Norway. • Emission quotas are seen as an effective tool for incentivising low-emission technologies. **Roadmap (2021)** • Hydrogen hubs and hydrogen research are the main short-term ambitions. • By 2030, hydrogen will be established as a realistic alternative in the maritime sector, with prospects for wider market adoption. • Establishment of a hydrogen and ammonia research centre to enhance research and development.
Non-EU Nordic states	Iceland	• Virtually all Icelandic energy comes from renewable sources. Thus, electrolysers would generate all hydrogen. • Hydrogen and fuel cell technologies are considered a means of reducing the transport-related GHG emissions gap. • To kickstart deployment, grants for early adopters are proposed. • Benefit schemes for zero emission technologies should be available for taxis and other vehicles of high utilisation. • Maritime transport applications should receive incentives for synthetic fuels.
EU Nordic states	Denmark	• Renewable hydrogen and its derivatives (referred to as Power-to-X*****) are promoted within the context of the Danish Climate Act. • The aim is to develop exportable Danish Power-to-X products. • Strengthening Denmark's regulatory framework and infrastructure to enable a Power-to-X industry to thrive. • Improvement of Power-to-X's integration with Danish energy.
EU Nordic states	Finland	**Roadmap (2020)** • Strengthening the electricity grid and increasing the amount of low-carbon electricity. • In order to achieve industrial-scale storage, storage-related R&D should be initiated. • Ensuring that national safety regulations do not restrict use of renewable hydrogen. • Raising hydrogen's status in all public education. • Future hydrogen-using industries to be inventoried. • Implementing national hydrogen policies in energy, industry, and transportation. **Strategy (2022)** • Focus on clean hydrogen, i.e. electricity-based hydrogen from renewables or nuclear power. • Boosting direct use of clean hydrogen and e-fuels in Finnish industry, transport and energy system. • Long-term aim of exporting technological solutions, hydrogen and e-fuels as a long-term possibility.
EU Nordic states	Sweden	• Hydrogen is identified as a means of achieving fossil-fuel independence. • The use of hydrogen should be based on its economic efficiency and its ability to provide the greatest benefits to the system. • Strengthening security of supply is essential. • Sweden aims to establish itself as an international leader in the production and use of fossil-free hydrogen. • Sweden is looking to export climate-smart products and services.

* Power-to-X refers to the use of clean electricity to produce hydrogen and synthetic fuels, which can replace fossil fuels as feedstocks and energy sources.

5

CURRENT HYDROGEN PRODUCTION AND USES

Norway can build on extensive experience with the hydrogen value chain, including both fossil-based (see also Box 1) and electricity-based hydrogen production. Currently, hydrogen is produced almost exclusively by reforming natural gas without carbon-capture technologies. Industrial consumers, mainly in the fertiliser and refinery industries, produce their hydrogen on-site. The Norwegian industrial sector produces approximately 225 000 tonnes (equivalent to approximately 7 TWh) of hydrogen a year, 80 per cent of which is produced by Yara at Herøya and Equinor at Tjeldbergodden (Damman et al. 2020; Hasaas et al. 2021). Each of these plants is equipped with its own gas reformer, which produces all the hydrogen required. The rest of the hydrogen produced in Norway is primarily a by-product of gasoline production at the oil refineries at Mongstad and Slagentangen. In addition, NEL, a leading supplier of electrolysis technology, is headquartered in the country (COWI 2022; NMPE and NMCE 2020; Nordic Energy Research 2021). It is expected that fossil-based hydrogen used in the refining and chemical industry can be replaced with renewable or low-carbon hydrogen (COWI 2022). A further future use-case is in heavy road transport, although this will require the development of a hydrogen fuelling stations along major roads and in ports (COWI 2022). There are also plans to construct the world's first zero emission hydrogen vessel, the Topeka Hydrogen Project, funded by Enova, to transport hydrogen to filling stations for land transport and local ferries (COWI 2022).

In Denmark, currently there are only a few industry-scale use cases for hydrogen. However, several government-supported projects are already under way in support of hydrogen production and related derivatives. For example, there is a 20 MW electrolyser near the refinery in Fredericia, with the possibility of expansion to 1 GW in the future, and a 12 MW hydrogen and methanol plant near Skive (COWI 2022; IEA 2021; Ihonen et el. 2020).

Sweden produces around 180 000 tonnes of hydrogen per year (equivalent to about 6 TWh), 99 per cent of which is used in the chemical and refinery industries, and the remaining 1 per cent as vehicle fuel and in the metallurgical industry. Hydrogen is produced from fossil fuels (67 per cent), industrial residue streams (30 per cent) and electrolysis (3 per cent) (Fossil Free Sweden 2021).

Current hydrogen production in Finland relies on natural gas and is used mainly in the oil refining and biofuels sectors (Sivill et al. 2022). Total dedicated hydrogen production in Finland is estimated at 140 000–150 000 tonnes per year (equivalent to about 4.7 to 5.0 TWh).

Iceland has been actively supporting research and demonstration projects. These include the hydrogen refuelling station for vehicles operated from 2003 to 2012 at Skeljungur. This was the first hydrogen refuelling station operated at a public gas station in the world (COWI 2022).

6

HYDROGEN TRANSPORT AND STORAGE INFRASTRUCTURE

Currently, there are no dedicated hydrogen transport solutions in the Nordic region that are fully optimised for the local market (Ihonen et al. 2021). As a result, the distribution of hydrogen produced in the Nordic states takes place mostly by road in compressed form (Lahnaoui et al. 2019). Additionally, the region's excellent port infrastructure means that hydrogen can also be distributed globally through ocean freight. Nordic port infrastructure, with facilities that are capable of accommodating international transport, is more than adequate for adaptation to maritime-based distribution (Nordic Energy Research 2022).

Pipelines represent the most promising channel for hydrogen distribution because of their cost-efficiency. Because Norway does not have a domestic natural gas pipeline network that it can easily convert to hydrogen, for now clean hydrogen is most likely to be produced in close proximity to its end users (NMPE and NMCE 2020). Sweden also lacks a national pipeline network that could be used for transporting hydrogen. There is an extensive pipeline network between Sweden and Denmark that can be retrofitted, however (Sivill et al. 2022; Figure 8). A large gas pipeline network that connects Norway with Europe could also be retrofitted to carry clean hydrogen, thereby providing Norway with a significant export opportunity. Similarly, Finland has a natural gas pipeline that has a connection with the Baltic countries that could be converted for hydrogen transportation (EHB 2022).

As regards storage, Vattenfall and LKAB have already built hydrogen storage facilities in rock caverns in northern Sweden (Bellini 2022). High sealing capabilities, low investment cost and high storage capacity make salt caverns a more flexible and efficient option for hydrogen storage (Caglayan et al. 2020). The presence of salt caverns in Denmark and Norway make them the fourth and fifth most suitable countries in Europe for hydrogen storage, respectively (Nordic Energy Research 2022). In contrast with Danish caverns, however, Norwegian caverns are offshore in the North Sea, so integrating them into the energy system may be more challenging and expensive (Hassanpouryouzband et al. 2021). Additionally, hydrogen applications will have to compete with hydropower, which can be adjusted and stored in Norway's hydroelectric dams. As already indicated, the Norwegian energy system has a large hydroelectric capacity compared with other European countries (Figure 3) and is flexible. For this reason hydrogen is less valuable in Norway as a source of renewable energy storage than in other countries (IEA 2021). Denmark also has additional potential in hydrogen storage because of its natural gas storage facilities. Of the approximately 100 underground gas storages around the world, two are owned and operated by Energinet.dk in Denmark. The two facilities are currently operated as a joint storage point for methane in the Danish natural gas network and help to ensure stable supplies of natural gas all year round (Energinet Denmark 2022). As a result, national gas storage alone can store up to 11 TWh measured in power-to-gas (Energynet Denmark 2015).

7

KEY HYDROGEN PROJECTS IN THE NORDICS

The hydrogen project landscape in the Nordics has been developing dynamically, with the planning and development of various hydrogen related initiatives.

Sweden has several ongoing major hydrogen projects and plans. **HYBRIT** (Hydrogen Breakthrough Ironmaking Technology), a joint venture by SSAB, LKAB and Vattenfall, is a key project and focuses on fossil-free steel production, in which hydrogen plays a key role (Nurdiawati and Urban 2022). Reducing steel industry emissions is of key importance if Sweden is to achieve its goal of carbon neutrality by 2045. The Swedish steel industry emitted 5.77 Mt of CO2 in 2021, or 12 per cent of the national total.[5] Decarbonising the steel sector is also globally important, given that the steel industry is responsible for approximately 7 per cent of global emissions (Kushnir et al. 2020). Enabling a fossil-free steel-industry is also the focus of the **H2 Green Steel** project and **Ovako's** hydrogen plant at the Hofors steel mill (Ovako 2023; Sivill et al. 2022).

In Norway, transitioning the economy away from its dependence on oil and gas has been a key focus in ramping up the hydrogen economy. In addition to hydrogen, the export of basic materials and industrial feedstocks, including ammonia, methanol, steel and cement, is seen as a possible development trajectory (Cloete et al. 2022). While low-carbon hydrogen is one possible option for the Norwegian hydrogen economy, the overall pace of renewables uptake and the EU stance on low-carbon hydrogen could limit the future use cases for low-carbon hydrogen exports (Damman et al. 2022). Another project in Norway is **Barents Blue Ammonia**, focusing on clean ammonia production, including offshore CCS (Sivill et al. 2022). The **Aurora liquid hydrogen** project represented another major endeavour, focusing on the production of liquefied hydrogen to decarbonise shipping, including the supply of the **Topeka Hydrogen Vessel** (Sivill et al. 2022). But project partners Equinor, Air Liquide and Eviny decided to terminate the project in 2023, after suspending it in 2022. The project partners cited insufficient orders from offtakers and the need for further support schemes for hydrogen as a shipping fuel (Hydrogen Insight 2023).

Several projects are under development in Finland (Sivill et al. 2022). **Neste** is planning a 120 MW renewable hydrogen production facility in Porvoo (Neste 2023). This green hydrogen is intended to replace fossil feedstocks in the refinery processes. **Flexens Kokkola** represents the largest planned electrolyser project to date, a 300 MW facility on the west coast to produce renewable hydrogen and ammonia starting in 2027 (Flexens Kokkola 2022). The Norwegian company **Blastr Green Steel** is developing a green steel plant in Finland with an integrated hydrogen production facility (Business Finland 2023). In addition, **BotH2nia** serves as an umbrella brand to facilitate and enable hydrogen-related activities in the Gulf of Bothnia and the Baltic Sea, bringing together diverse stakeholders from business, research institutes, investors, municipalities and cities (Both2nia 2023).

In Iceland, earlier key projects focused on the transport sector, such as the **ECTOS (2003–2007)** project. The objective of ECTOS was to demonstrate the role hydrogen technology can play in public transport by using fuel cell-powered busses in the public transport system in Reykjavik (New Energy 2023). A current key project is **Green Fuel Iceland**, focused on the use of renewable ammonia in maritime transport. As part of the Green Fuel Iceland project renewable hydrogen will be produced and then converted to green ammonia to be used in maritime transport applications. The project is located at Bakki industrial park and the large-scale production of ammonia will be ramped up in two phases: a first 30 MW unit operational by 2025, followed by a 70 MW unit by 2027 (Green Fuel Iceland 2023).

In Denmark the focus has been on the production of renewable hydrogen. The potential production capacity of planned projects exceeded 7 GW in 2021 (Sivill et al. 2022). Among key projects driving Danish development are **Greenlab Skive**, **Hysynergy** and **H2Energy Europe**. **GreenLab Skive** is a circular energy park focusing on P2X solutions aiming to reach a capacity of 12 MW by 2023, with plans to start building an additional 100 MW in 2024. It also functions as a technology enabler and national research facility supporting the development of P2X solutions in Denmark (GreenLab 2023). **Hysynergy** is also focused on renewable hydrogen production, targeting 1 GW by 2030 (Everfuel 2023). **H2Energy Europe** intends to build a 1 GW electrolyser to supply renewable hydrogen for use in trucks and other heavy road transport (H2Energy 2023).

5 See https://www.statistikdatabasen.scb.se/pxweb/en/ssd/START__MI__MI1301

8

HYDROGEN COOPERATION IN THE NORDIC REGION AND ITS NEIGHBOURHOOD

The Nordic states can build on strong existing energy-related cooperation. The joint political will to cooperate on clear strategic objectives has been highlighted as a central driver of cooperation in renewables and the common Nordic electricity market in order to build »the smartest energy system in the world« (Ollila 2017: 10). In this context, the importance of Nordic cooperation across energy markets and systems is highlighted, while also stressing the national responsibilities of each Nordic country. Here hydrogen is identified as a possible contribution to the diversification of energy sources and as a storage medium (Nordic Energy Research 2023). Efforts to develop hydrogen cooperation in the Nordic region are long-standing and aim to support the setting of R&D priorities and the creation of effective framework policies (Eerola 2004). Hydrogen also features prominently in the Nordic Co-operation Programme on Energy Policy 2022–24,[6] which calls for closer collaboration on hydrogen strategies and identifies renewable hydrogen as one area of particular interest for energy research. It aims to contribute to achieving the overarching goal of achieving a green, competitive and socially sustainable Nordic region by 2030 (NCM 2021).

The Nordic countries have also been active in setting up a variety of hydrogen-specific cooperation projects and partnerships. They have established a Nordic Hydrogen Partnership for the purpose of intraregional mutual support and cooperation to promote the transformation of the transport sector. Initially named the Scandinavian Hydrogen Highway Partnership, it was renamed the Nordic Hydrogen Partnership to reflect the organisation's widened scope. As part of one of the first global hydrogen economy partnerships, strong public and private support bases have been established to facilitate collaboration across borders, attract investment and implement tax exemption schemes. Likewise, the Nordic Hydrogen Partnership seeks to make Sweden, Finland and Denmark the first European states in which hydrogen is widely available and used in a refuelling network (NHP 2021). The Nordic Hydrogen Corridor (2017–2022) is a study and pilot deployment of eight hydrogen refuelling stations, hydrogen production units and fuel cell electric vehicles aimed at supporting emission-free transport between the mainland capitals of the Nordic countries and from there to Germany and other EU countries. The project is a cooperation between Everfuel, Statkraft, Hydrogen Sweden, Toyota and Hyundai (NHC n.d.).

There is also cooperation under the umbrella of the European Hydrogen Backbone, via the Nordic-Baltic Corridor and the North-Sea corridor. A key project to support the development of cross-border infrastructure is the Nordic Hydrogen Route. This is a cooperation project between Gasgrid Finland and Nordion Energi to build cross-border hydrogen infrastructure in the Bothnian Bay Region, the northernmost part of the Gulf of Bothnia, located between Finland and Sweden. It targets a first set of operational pipelines by 2030 and a total of 1 000 km of pipelines by 2050 (Nordic Hydrogen Route 2023). The scope of this project is in line with the identified need to further develop infrastructure and connectivity in the Nordic region to support the ramp up of the hydrogen economy.

Cooperation initiatives are also being developed with countries beyond the Nordic region. The German government has deepened cooperation efforts with both Denmark and Norway. In the case of Norway, developing cooperation on hydrogen is embedded in wider efforts to strengthen cooperation on developing green industry and lowering emissions. The German-Norwegian cooperation builds on developing necessary infrastructure to enable large-scale transport of hydrogen from Norway to Germany and CO2 transport from Germany to Norway. In addition, the cooperation is focused on developing a European hydrogen market and value chains. Norway has actively promoted exports of low-carbon hydrogen as a transitional fuel, while also ramping-up of renewable energy production (Government of Norway 2023). In this vein, Norway's Equinor recently signed a cooperation agreement with Germany's RWE for the development of low-carbon hydrogen exports (see Box 1 for more details). In acknowledgement of this reality, Germany recently accepted the potential role of low-carbon hydrogen as a transitional fuel. In its revised hydrogen strategy, it explicitly states the possibility that low-carbon hydrogen could be acceptable in the context of government-supported demand-side schemes to promote the use of hydrogen (Government of Germany

6 The Nordic Co-operation Programme on Energy Policy was adopted by Nordic energy ministers within the context of the Nordic Council of Minsters, the forum for inter-governmental cooperation in the region. The »Vision for Nordic co-operation« was agreed in 2019. This vision states three strategic priorities – a green Nordic region, a competitive Nordic region, and a socially sustainable Nordic region – to guide the work of the Nordic Council of Ministers. For more details see: https://www.norden.org/en/declaration/our-vision-2030

2023). Cooperation between Germany and Denmark builds on linking Danish production and German demand for renewable hydrogen. The Danish-German joint declaration on hydrogen focuses on developing a large-scale transmission interconnector for renewable hydrogen by 2028 (BMWK 2023).

Another example is the BalticSeaH2 project to develop a hydrogen valley around the Baltic Sea, with the main valley located between Finland and Estonia. The project involves the participation of 40 partners from nine Baltic countries (Finland, Estonia, Latvia, Lithuania, Poland, Germany, Denmark, Norway and Sweden) and focuses on demonstration and investment projects aimed at producing 100 000 tonnes of hydrogen annually within five years (CLIC 2023). Cooperation between the Nordics and the Baltic region is also unfolding as part of the Nordic-Baltic Hydrogen Corridor, developing infrastructure from Finland via Estonia, Lativia, Lithuania and Poland to Germany by 2030. This project is in the preliminary study phase and aims to develop hydrogen infrastructure to support the creation of a hydrogen market area, as well as diversification of energy supplies and the energy transition (Gasgrid 2022).

9

CONCLUSIONS

The Nordic countries share ambitious climate and energy policy targets under the umbrella of national decarbonisation goals. Hydrogen strategies are being actively developed in the Nordic countries in line with their national energy and climate targets. Their potential for the generation of renewable energy also positions them as important players within the EU's hydrogen economy. Renewable hydrogen could play a key role not only in achieving the Nordic countries' ambitious energy and climate goals by supporting the decarbonisation of hard-to-electrify sectors, but also in positioning them as providers of hydrogen technologies, producers of green industrial products and, potentially, as exporters of renewable hydrogen.

They can build on a strong existing framework for renewables, a strong enabling environment for innovation, a very good investment climate, and the leading role Nordic countries have taken in the diffusion of renewable energy technologies globally. This includes biomass technologies in Finland and Sweden, hydropower developments in Norway, wind power in Denmark, and geothermal power in Iceland. In Sweden and Finland, renewable electricity generation is complemented by nuclear power, which represents a second pillar for decarbonising the energy sector.

The momentum for ramping up hydrogen is supported by a broad portfolio of demonstration and R&D projects, although they have not been without challenges, as the case of the Aurora Liquid project shows. This highlights the rapidly moving environment within which hydrogen strategies and policies are operating. Open questions also remain regarding the respective roles of fossil-based and of renewable hydrogen in the system, especially given Norway's abundant gas resources and carbon storage potential for low-carbon hydrogen production. While EU hydrogen policy remains strongly focused on renewable hydrogen, Germany recently acknowledged the potential role of low-carbon hydrogen within its revised hydrogen strategy, indicating its willingness to endorse cooperation with Norway in the field (Government of Germany 2023).

Overall, however, the Nordic countries' potential export-orientation needs to be seen in the perspective of national needs and priorities. In all the Nordic countries, hydrogen is viewed as an important vehicle for decarbonising domestic industry and transport. Despite their potential to generate surplus renewable electricity, exports of renewable hydrogen and its derivatives feature as a clear policy goal only in Denmark. As indicated, Norway has a strong interest in retaining value creation in the natural gas sector and is therefore emphasising low-carbon hydrogen exports. Sweden, Finland and Iceland are focused on the use of hydrogen mainly for domestic decarbonisation.

Another key point is the development of infrastructure in tandem with current and expected needs for the hydrogen economy. Here, the lack of domestic gas infrastructure in Sweden and Norway has been noted. Cooperation projects to develop this infrastructure are ongoing under the European Hydrogen Backbone project. Here, Sweden and Finland have been active in developing cooperation to build new pipeline infrastructure. In tandem with this, the Nordic countries are active in anchoring hydrogen in their overall cooperation in the energy sector. This dual focus on cooperating on both projects and the regulatory aspects underlying the integration of hydrogen into the energy system is a key strength and can build on established energy cooperation mechanisms in the Nordics.

Overall, the Nordic countries are well positioned to draw on their existing strengths in their efforts to integrate hydrogen into their energy systems both nationally and regionally. Active engagement across the Nordics and with their European neighbours will play a crucial role in realising the potential contribution that the Nordic region can make to EU efforts to decarbonise and build a competitive hydrogen economy.

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HYDROGEN IN THE NORDICS

Drivers of European Cooperation?

Building on their strong renewables potential, the Nordics are ambitiously pursuing hydrogen strategies for the decarbonization of industry and transport.

The Nordics could play a pivotal role in Europe's emerging hydrogen economy: as technology providers, as producers of green industrial products and as exporters of hydrogen.

Engagement between the Nordics and their European neighbours should be enhanced in order to mobilise their potential for mutually beneficial cooperation.

For now, only Denmark is actively pursuing renewable hydrogen exports, while Norway is promoting the export of low-carbon hydrogen, drawing on its natural gas reserves and carbon storage potential.

For further information on this topic:
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