Nordic Energy Research

Nordic Hydrogen Valleys

VALUE CHAIN MAPPING ACROSS THE REGION

Contents

Foreword

The Nordic countries are committed to decarbonising their societies. To achieve our goal of becoming a carbon-neutral region, we must build hydrogen value chains that encompass production, processing, distribution and offtake.

The Nordics are uniquely positioned to lead the green transition by integrating hydrogen into our energy systems and fostering a clean hydrogen economy. With our abundant renewable energy resources, world-leading maritime sector and our energy-intensive industries, we can play a key role as producers, processors, users and exporters of hydrogen. Furthermore, our strong history of energy cooperation supports Nordic collaboration on hydrogen solutions as a logical step on the path to decarbonisation.

In this report, Nordic Energy Research maps hydrogen value chains across the Nordic region, showcasing cutting-edge developments and ongoing deployments. This provides decision-makers, investors and society at large with the insights needed to make informed, knowledge-based decisions.

Unlike international mappings of hydrogen value chains, this report and the digital tool developed for this project (available at nordich2valleys.org) are specifically designed to reflect Nordic conditions and regional energy systems. To this end, we have developed our own conceptual definitions of "hydrogen valley" and "hydrogen hotspot", tailored specifically to suit the Nordic context.

I hope that this mapping will inspire the Nordics – and the world – to recognise our hydrogen potential and envision the steps we can take together to make Nordic hydrogen valleys a reality.

Klaus Skytte
CEO, Nordic Energy Research

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The individuals and organisations that contributed to this study are not responsible for any opinions or judgements contained in this study.

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For enquiries regarding the presentation of results or distribution of the report, please contact Nordic Energy Research. Additional materials, press coverage, presentations etc. can be found at nordicenergy.org.

Executive summary

The objective of the project presented in this report was to support the development of Nordic hydrogen valleys, contribute to the exchange of experience among Nordic stakeholders and to promote and enhance Nordic strengths within Nordic hydrogen value chains.

The project reached this objective by providing:

- A Nordic definition of hydrogen valleys and hydrogen hotspots.
- A mapping of hydrogen projects in the Nordic region, including Denmark, Greenland, the Faroe Islands, Finland, Iceland, Norway, Sweden and Åland.
- A categorisation – based on the proposed definitions – of the mapped projects into the categories "hydrogen valleys", "hydrogen hotspots" and "other".
- A user-friendly and versatile prototype digital tool for visualising the results of the mapping work, based on which a more comprehensive digital tool can be developed at a later stage.
- A deeper understanding of the challenges and opportunities for the use of hydrogen and clean fuels in Arctic maritime transport.
- An overview of drivers and barriers for hydrogen valley development in the Nordics, as well as policy recommendations.

Information was gathered through literature reviews, expert interviews and an open project workshop. All data was collected in the spring of 2024, and changes in, for instance, stakeholders' investment plans after May 2024 have not been incorporated. The interviews and the workshop also gave stakeholders an opportunity to provide feedback on draft work and to give suggestions on ways to move forward.

Hydrogen valley mapping and tool development

This project proposed the following definition of Nordic hydrogen valleys and hydrogen hotspots, based on findings by the Mission Innovation Hydrogen Valley Platform and definitions used in relevant EU calls.

Hydrogen valleys are projects that:

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

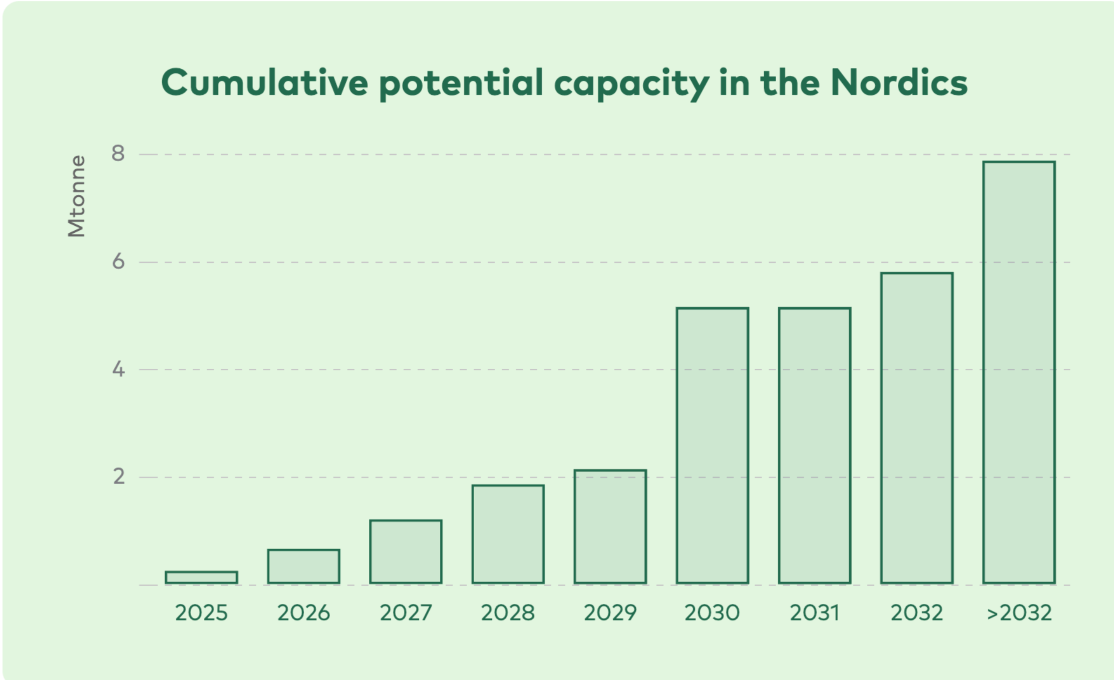
Nordic hydrogen hotspots are projects that do not qualify as hydrogen valleys but fulfil criterion 1 and at least two of criteria 2–5 in the hydrogen valley definition. Use includes both direct and indirect use of hydrogen (e.g. to produce fuels or chemicals).

The project mapped 167 Nordic hydrogen projects and gathered key information in a database, which was subsequently visualised using a digital tool developed within the project. Nine of the mapped projects fulfilled the hydrogen valley definition at the time of the mapping (spring 2024). The mapping results are available at nordich2valleys.org , and a summary is given below.

The digital tool is a publicly available interactive web application that allows users to view and analyse data gathered during the mapping. The tool is managed by Nordic Energy Research and is a prototype from which a more comprehensive tool may be developed at a later stage.

Mapped hydrogen projects, hotspots and valleys per Nordic country. Production capacity refers to the total planned capacity of the mapped projects and includes capacity that is already operational. About 0.2% of the total planned capacity in the Nordics is operational; none of the identified valley projects are operational. Hydrogen projects that cannot be categorised as hotspots or valleys are categorised as "other". Thus, totals do not equal the sum of hotspots and valleys (the difference is especially notable for Norway).

Country	Total number of hydrogen projects	Total planned hydrogen production capacity (ktpa)	Number of hotspots	Planned hydrogen production capacity of hotspots (ktpa)	Number of valleys	Planned hydrogen production capacity of valleys (ktpa)
Denmark	29	3,748	18	2,822	5	237
Faroe Islands	0	0	0	0	0	0
Finland	36	1 126	35	1 126	1	0.5
Greenland	1	153–255	1	153–255	0	0
Iceland	9	112	9	112	0	0
Norway	50	711	24	414	2	10
Sweden	38	1,524	37	1,512	1	12
Åland Islands	4	513	4	513	0	0



Total number of hydrogen projects

167

Current capacity (Mtonnes/year)

0.02

The fourth hydrogen valley criterion was identified as challenging in expert interviews and the open project workshop. This sentiment was confirmed by the mapping; only 25 of the mapped projects supply hydrogen to specific off-takers in multiple sectors, meaning that 142 mapped projects failed to meet this criterion. Of the 25 projects that do supply more than one end-use sector, 16 failed to meet the hydrogen valley definition, mainly because of insufficient project maturity.

Although the total capacity of the mapped projects is significant – about 8 Mt or 270 TWh of hydrogen per year – only about 0.2% of this capacity is operational, with an additional approx. 1% under construction. **Most projects – especially those very large in scale (hundreds of MW or more) – are in the very early stages of development, meaning that project scope, scale and timeline are still subject to change**. **Realistically, most of the mapped projects will never materialise. This means that the developed project database and digital tool will require frequent updates to stay relevant.**

Common characteristics among the mapped projects (regardless of their status) are summarised below.

Projects in Sweden and Finland often aim to use hydrogen for the on-site production of e-fuel/chemicals or to decarbonise existing industrial processes. While Danish projects also commonly use hydrogen for the on-site production of e-fuel/chemicals, Denmark also hosts several large-scale, export-oriented projects aiming to sell hydrogen in potential future European or Global markets. To export hydrogen, Danish projects often plan to use (prospective) hydrogen gas grids. Norwegian projects also cover a variety of end-uses but are distinguished by a focus on utilising hydrogen for ammonia production or as a maritime fuel. The two aspects are sometimes combined, with hydrogen being used to produce ammonia for use as maritime fuel. However, there are also projects producing hydrogen for direct use as maritime fuel or projects producing ammonia for industrial use (e.g. to decarbonise fertiliser production).

It should also be noted that the mapping often failed to identify intended end-users for the Norwegian projects, indicating that the planned hydrogen capacity will be available "on the market" for interested off-takers. In comparison with the previously discussed countries, the majority of Norwegian projects produce hydrogen for use on-site (instead of exporting hydrogen to e.g. the transport sector), meaning they are not in control of the entire value chain. Consequently, final off-takers are sometimes not identified even in advanced stages of project development. One explanation for the difference between Norwegian projects and especially Finnish and Swedish projects may be that the latter focus on the decarbonisation of their own processes, while Norwegian projects have great opportunities for export due to low power prices.

The number of mapped projects in Iceland, Åland, the Faroe Islands and Greenland is too low to draw general conclusions. Most of the mapped Icelandic projects target e-fuel/chemicals production or direct use in transport. This is in line with the Hydrogen and E-fuels Roadmap for Iceland, which identifies hydrogen and e-fuels as key elements in decarbonising Iceland's transport and maritime sectors. Identified projects in Åland are export-oriented, aiming to export hydrogen via prospective Baltic Sea hydrogen infrastructure.

The most common hydrogen derivatives produced by the mapped projects are methanol, ammonia and methane, with the production of e-SAF being less common. Common direct uses of hydrogen include road transport and industrial heating, as well as the decarbonisation of industrial processes by replacing a fossil input (e.g. coal in steel making or fossil hydrogen in refinery processes or ammonia production).

This project has not assessed Nordic strengths and weaknesses in relation to other EU countries. However, the presence of large-scale export projects targeting the European market (especially in Denmark) indicate a position of strength.

Since most of the mapped projects – especially the larger projects – are in the very early stages of development, the scope and timeline of many projects are still very uncertain and subject to change. Consequently, the developed database and the tool will require regular updates, maintenance and development to stay relevant. Given that the tool continues to be developed and updated, it will contribute to knowledge development among Nordic stakeholders and promote and enhance Nordic strengths within Nordic hydrogen value chains.

The potential role of hydrogen in Arctic maritime transport

The potential future role of hydrogen and hydrogen-based fuels for Arctic maritime transport in the Nordic countries was assessed by a review of existing literature and knowledge about relevant projects (including projects covered by the mapping).

In context of this project, "Arctic" is defined as Greenland, Iceland, the Faroe Islands and Northern Norway.

Since 1 July 2024, there has been a ban on the use and carriage of HFO in Arctic waters, although waivers and exemptions could allow continued use and carriage for a few years longer. Nonetheless, this ban can be expected to incentivise the use of alternative fuels in Arctic maritime transport.

The literature and outcomes of projects find hydrogen and hydrogen-based fuels to be among the most promising alternatives to facilitate the decarbonisation of shipping. In addition to their environmental benefits, the isolated power infrastructure in the Arctic makes green hydrogen and hydrogen-based fuels particularly interesting. Wind and PV have huge untapped potential in the region and can be put in use in areas with no grid or low grid capacity. In addition to supplying marine fuel, the scattered communities in the Arctic would benefit from the harnessed power, which would in turn contribute to job and value creation in the region.

The current use of hydrogen in Arctic maritime transport is negligible compared to the use of fossil fuels. Projects producing hydrogen or hydrogen-based e-fuels such as ammonia and methanol are under development in the region, especially in Northern Norway where about 600 thousand tonnes of hydrogen capacity (including natural gas reforming with CCS) is under development, mostly for ammonia production and often aimed at maritime off-takers. Several large-scale e-fuel projects are also under development in Iceland, where maritime activities are an important part of the economy. Because ammonia and methanol are likely future fuels for decarbonised shipping, these projects may pave the way for increased hydrogen use in Arctic shipping, although most projects are still in the early stages of development.

To enable the use of hydrogen and hydrogen-based fuels in Arctic shipping, some barriers need to be addressed. The advancement of regulatory frameworks, bunkering facilities and technical and operational know-how on using these fuels onboard ships would facilitate their adoption.

Drivers, barriers and policy measures for Nordic hydrogen valley development

This project reviewed relevant literature to map the drivers and barriers for hydrogen valley development in the Nordics (and for hydrogen development in general). Expert interviews and a workshop were conducted to complement and rank a list of drivers and barriers developed during the literature review.

Of the identified drivers, the three most important are current and future access to renewable energy production, policy support on a Nordic/EU level and industries' ambitions to use hydrogen for the decarbonisation of their own activities.

In most of the Nordic countries, an important driver for the development of a hydrogen economy is the potential of untapped national resources (e.g. wind power) to create additional value.

The most important barriers that need to be addressed include the overall business case for hydrogen projects, regulatory frameworks, which are not optimal for developing hydrogen projects, and a lack of local energy supply and infrastructure.

The literature review, expert interviews and workshop were also used to identify policy suggestions. One key finding from this work is that stakeholder priorities can differ significantly regarding which policy measures are deemed most important. However, the most prioritised policy measures identified include:

- Defining long-term strategies and targets for the development of hydrogen production and use on the national level, with a view to supporting investments.
- Promoting the development of a cost-effective hydrogen value chain by improving the support schemes for both the demand and supply side. This could support initial development to reduce the cost difference in relation to less sustainable options.
- Supporting the development of hydrogen infrastructure (pipeline and refuelling infrastructure, hydrogen storage) through the creation of partnerships to reduce risk.
- Supporting the promptest possible implementation of more general climate policies at the EU level (such as CBAM, EU ETS, RED III etc.), as a general driver for fossil-free alternatives, including hydrogen.
- Providing support to reduce unnecessary lead times in permitting processes for electricity and hydrogen infrastructure, while establishing suitable regulations to streamline these processes.
- Creating standards to define the origin, quality and life cycle of hydrogen GHG emissions. This should be aligned with the EU's Renewable Energy Directive (RED III) and other relevant regulations.

The respondents of the interviews, who represented national hydrogen associations and project managers involved in the "Nordic Hydrogen Valleys as Energy Hubs" programme, stressed the need for financial support for the entire value chain of early-stage hydrogen projects. This value chain includes energy supply and hydrogen production, as well as hydrogen distribution, infrastructure and utilisation.

Abbreviation list

AIS – Automatic Identification System

CBAM – Carbon Border Adjustment Mechanism

CCS – Carbon Capture and Storage

CEF – Connecting Europe Facility

EIA – Environmental Impact Assessment

EIB – European Investment Bank

EMSA – European Maritime Safety Agency

EU ETS – European Union Emissions Trading System

FEED – Front End Engineering Design

HFO – Heavy Fuel Oil

HYBRIT – Hydrogen Breakthrough Ironmaking Technology

IPCEI – Important Projects of Common European Interest

LHV – Lower Heating Value

LNG – Liquefied Natural Gas

MARPOL – The International Convention for the Prevention of Pollution from Ships

MEPC – Marine Environment Protection Committee

NER – Nordic Energy Research

P2X – Power-to-X

PV – Photovoltaic

PAME – Protection of the Arctic Marine Environment

SAF – Sustainable Aviation Fuel

TCO – Total Cost of Ownership

UI – User Interface

UX – User Experience

Photo: íStock

1. Scope of the project and this report

1.1 Background

Hydrogen can be an important energy carrier for contributing to the decarbonisation of energy-intensive industrial processes and transport. Clean hydrogen is part of a value chain that spans from electricity generation to various end uses and their associated infrastructures and transport.

Work on hydrogen, e-ammonia, e-methanol and other electrofuels (e-fuels) is becoming increasingly important and is expected to play a vital role in the future energy landscape in the Nordic region, in the EU and across the globe. This requires increased electrification and the expansion of power production.

According to the "EU Hydrogen strategy" (COM/2020/301), the production and use of hydrogen will grow significantly towards 2030/2050 and will be an important part a of the EU's strategy for energy system integration. Today, hydrogen constitutes less than 2% of Europe's energy mix.

Many Nordic and international initiatives related to hydrogen and e-fuels are also underway, including the "Nordic Roadmap for Maritime Transport" and the comprehensive Nordic research programme "Nordic Hydrogen Valleys as Energy Hubs – by 2030 and 2040".

The Nordic Committee of Senior Officials for Energy Policy (EK-E) has therefore commissioned a project to map Nordic hydrogen valleys. This will create an overview for relevant businesses, authorities and policy decision makers, aiming to strengthen existing Nordic hydrogen valleys and their associated value chains, while also contributing to the creation and development of new ones.

1.2 Objective

The objective of the project presented in this report was to support the development of Nordic hydrogen valleys, contribute to the exchange of experience among Nordic stakeholders and to promote and enhance Nordic strengths within Nordic hydrogen value chains.

The project reached this objective by providing:

- A Nordic perspective on the criteria and definition of both hydrogen valleys and hydrogen hotspots.
- A comprehensive Nordic overview by mapping existing and potential hydrogen valleys throughout the Nordic region, including Denmark, Greenland, the Faroe Islands, Finland, Iceland, Norway, Sweden and Åland.
- A deeper understanding of the challenges and potential opportunities for the use of hydrogen and clean fuels in Arctic maritime transport.
- A user-friendly and versatile prototype digital tool for visualising the results of the mapping work, based on which a more comprehensive digital tool can be developed at a later stage.
- An overview of drivers and barriers for hydrogen valley development in the Nordics, as well as policy recommendations.

1.3 Project overview

The project was structured into four separate tasks (see Figure 1). *Task 1 Define and map Nordic hydrogen valleys*[1] included the development of a conceptual understanding as well as a definition of hydrogen valleys from a Nordic perspective. Moreover, this task included the actual, comprehensive mapping of data from all Nordic countries about initiatives that could qualify as existing or potential hydrogen valleys. *Task 2 Create a prototype digital tool for mapping*[2] involved developing a prototype for a web-based platform designed to showcase the findings and data collected through the mapping activities. *Task 3 Analyse hydrogen potential in Arctic maritime transport*[3] used the mapping of the valleys relevant to the Arctic maritime sector as a starting point to further explore the potential role of clean hydrogen and other fuels based on clean hydrogen in this sector, looking ahead to 2030 and beyond. Finally, *Task 4 Identify drivers and barriers for Nordic hydrogen valleys*,[4] including a mapping of drivers, barriers and potential policy measures, formed the basis for the development of policy recommendations.

1. Full task name: *Concept creation and mapping of Nordic hydrogen valleys*
2. Full task name: *Creating a prototype digital tool for mapping hydrogen valleys in the Nordic and Arctic regions*
3. Full task name: *Analysing the potential for using clean hydrogen and other fuels based on clean hydrogen in Arctic maritime transport*
4. Full task name: *Identifying drivers and major barriers for the development of Nordic hydrogen valleys*

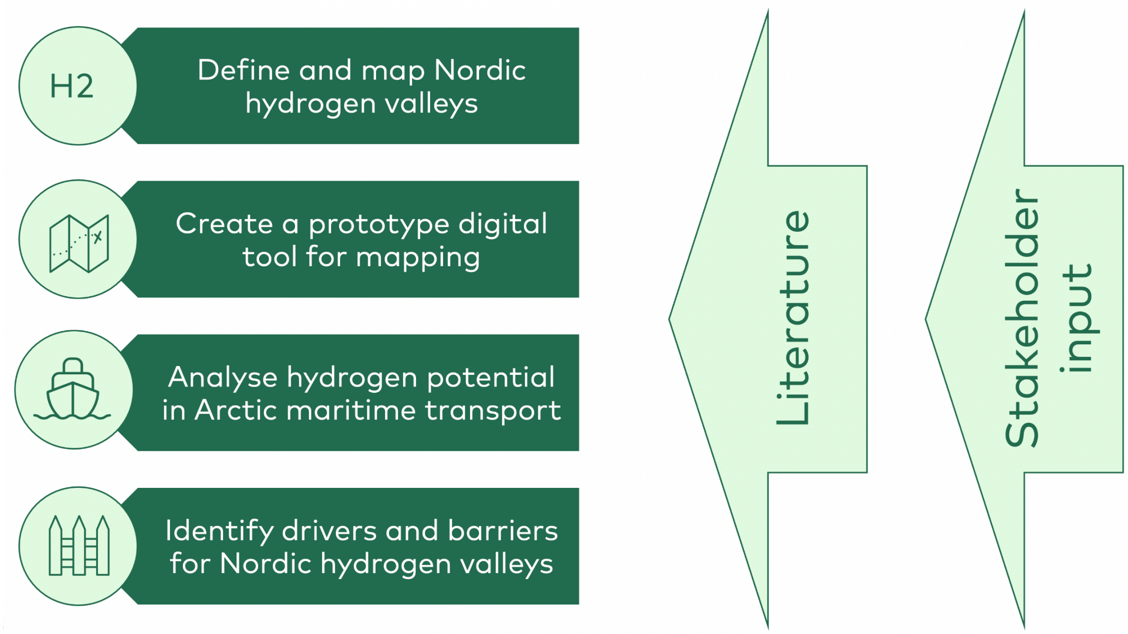


Figure 1. Overview of the four project tasks, including an indication of primary sources of information.

The implementation of all tasks relied on a combination of input from literature (various publicly available data sources) and stakeholder input. Stakeholder input was provided partly through direct interviews with key stakeholders and partly through a stakeholder workshop carried out at an early stage of the project.

The stakeholders interviewed represented national hydrogen associations in Norway, Finland, Sweden and Iceland, a university in Denmark and the five NER Hydrogen Hubs projects (see Appendix B). More than 80 participants registered for the stakeholder workshop, representing additional academic and industry stakeholders as well as authorities and national policymakers (see Appendix C). The input from both the interviews and the stakeholder workshop primarily contributed to the definitions of Nordic hydrogen valleys and hotspots (see Chapter 2) and the identification of the most relevant drivers, barriers and policy measures (see Chapter 6).

The project was carried out by a team that represented various parts of the Nordic region and brought together complementing expertise. The project team consisted of experts in hydrogen, industrial transformation and energy systems from VTT (Finland), SINTEF (Norway) and CIT Renergy (Sweden); experts in the maritime industry from SINTEF Ocean (Norway); and experts in the design and development of digital tools from Boid (Sweden).

1.4 The report and other project deliverables

This report provides an overview of the implementation and key findings from the project. Following this introductory chapter, the structure is clearly aligned with the respective tasks. Chapter 2 includes the background of the concept of hydrogen valleys and the development of Nordic criteria for hydrogen valleys and hotspots, while Chapter 3 describes the actual mapping activities and results. Chapter 3 also includes an extended discussion on the hydrogen activities that are especially relevant to the Arctic maritime sector. Chapter 4 summarises the approach taken in developing a digital tool for visualising the results of the mapping, as well as a discussion of the long-term potential of such a tool. Chapters 5 and Chapter 6 cover the parts of the study that go beyond the direct mapping of projects. Chapter 5 discusses the potential role of clean hydrogen in the Arctic maritime sector. Chapter 6 elaborates on the drivers and barriers for the development of hydrogen valleys, as well as potential policy measures for addressing these. Finally, Chapter 7 highlights key findings and conclusions from the study.

In addition to this report, the project resulted in the development of a comprehensive database of Nordic hydrogen initiatives and a prototype digital tool for this mapping work. The database and the tool were provided as separate deliverables to Nordic Energy Research. The tool has been made available both to stakeholders and to the public via NER's website: nordich2valleys.org

Photo: Unsplash

2. Nordic criteria for hydrogen valleys and hydrogen hotspots

2.1 EU criteria for hydrogen valleys

The *Mission Innovation Hydrogen Valleys Platform* was commissioned by the European Union and launched in 2021 to "[present] comprehensive insights into the most advanced and ambitious Hydrogen Valleys around the globe".[5] A report[6] accompanying the launch highlighted four key characteristics of hydrogen valleys. In an updated version of the report,[7] one key characteristic was added, giving a total of five key characteristics, as illustrated in Figure 2 below. In the following, these five characteristics are discussed as *criteria* for what makes a hydrogen valley.

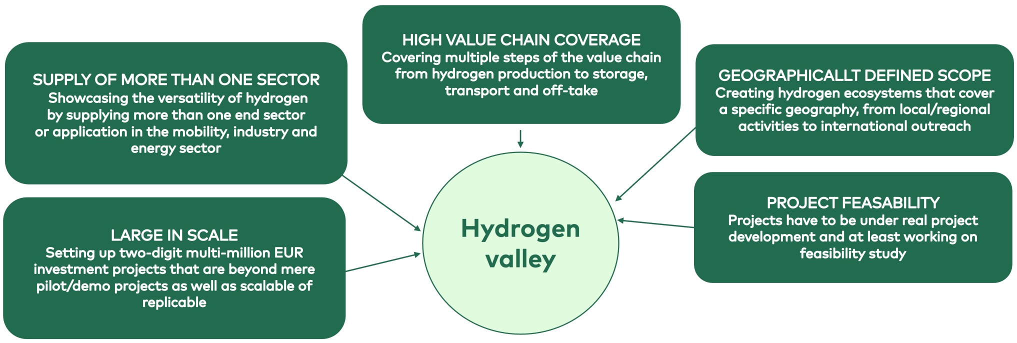


Figure 2. Key characteristics of hydrogen valleys, as identified by the Mission Innovation Hydrogen Valleys Platform (adapted illustration, based on publication from the Mission Innovation report).[8]

5. Clean Hydrogen Partnership – Mission Innovation Hydrogen Valleys Platform. Available: https://www.clean-hydrogen.europa.eu/get-involved/mission-innovation-hydrogen-valleys-platform_en
6. Both Mission Innovation reports are available here: https://h2v.eu/analysis/reports
7. Clean Hydrogen Partnership – Mission Innovation Hydrogen Valleys Platform. Available: https://www.clean-hydrogen.europa.eu/get-involved/mission-innovation-hydrogen-valleys-platform_en
8. Going Global – An update on Hydrogen Valleys and their role in the new hydrogen economy. Available: Hydrogen_Valleys_online_2022.pdf

With reference to the Mission Innovation report, the 2024 Horizon Europe call for hydrogen valley projects summarised the concept as follows (emphasis added **in bold**):

*"Hydrogen Valleys are hydrogen ecosystems that **cover a specific geography** ranging from local or regional focus (e.g. industrial cluster, ports, airports etc.) to specific national or international regions (e.g. cross border hydrogen corridors). Hydrogen Valleys showcase the versatility of hydrogen by **supplying several sectors in their geography** such as mobility, industry and energy end uses. They are ecosystems or clusters where various final applications share a common hydrogen supply infrastructure. Across their geographic scope, Hydrogen Valleys **cover multiple steps** in the hydrogen value chain, ranging from hydrogen production (and often even dedicated renewables production) to the subsequent storage of hydrogen and distribution to off-takers via various modes of transport."*

The definition given by Horizon Europe uses three of the five criteria from the Mission Innovation report (emphasised) but excludes the scale and feasibility criteria. The call does, however, set a different scale criterion (production of at least 500 tpa of hydrogen) and adds the requirement that hydrogen must be produced from renewable sources[9] – although low-carbon hydrogen is permissible during a transition period.

2.2 Nordic criteria for hydrogen valleys and hydrogen hotspots

Summarising the different criteria and definitions used by the EU and described above, the following possible criteria for a definition of "hydrogen valley" can be identified:

1. Hydrogen valleys have a defined geographic scope/coverage.
2. Hydrogen valleys supply several end-use sectors.
3. Hydrogen valleys cover multiple steps of the hydrogen value chain.
4. Hydrogen valleys are large in scale
   a. At least a two-digit MEUR investment (Mission Innovation), or
   b. >500 tpa production (Horizon Europe).
5. Hydrogen valleys are projects that have at least reached the feasibility phase (Mission Innovation).
6. Hydrogen valleys use hydrogen from renewable energy sources (Horizon Europe).

In the present mapping of Nordic hydrogen valleys, the possible criteria listed above were used as a starting point to define Nordic hydrogen valleys. The first three criteria in the list above are used both by Mission Innovation and by Horizon Europe. They are also used in the Nordic hydrogen valley definition proposed by the present project, with only minor adjustments and clarifications. "Several" and "multiple" in criteria 2–3 have been replaced by "at least two" and the "steps of the hydrogen value chain" referred to in criterion 3 are explicitly defined as production, distribution and use.

9. As defined by the Renewable Energy Directive, 2018/2001/EU

Regarding the criterion to supply several end-use sectors, a similar level of integration may be achieved if one end-user has several suppliers. However, because most projects are production-oriented, the number of such projects (end-users with multiple suppliers) is expected to be very low, and they were not included in the proposed definition.

The first criterion does not have strict sub-criteria that must be fulfilled (e.g. aligning with rules for geographically confined hydrogen networks set out in Article 52 of the EU's Directive on common rules for the internal markets for renewable gas, natural gas and hydrogen (EU 2024/1788)). More detailed criteria would make the task of mapping extremely challenging due to the limited public access to project-specific data. Having a specified site of hydrogen production supplying specific end-users is sufficient is sufficient to fulfil criterion 1. The interplay between the first criterion and the second criterion (end-use sectors) is further discussed in Section 3.1.

Regarding the fourth criterion (scale), we find the capacity metric used by Horizon Europe (production capacity) more suitable than the investment metric used by Mission Innovation (investment volume) for the following reasons:

- Investment estimates are uncertain and change as a project matures.
- Investment estimates are often communicated as lump sums without details on the scope and methodology of the estimate, making it very difficult to compare projects. An investment estimate may include costs that are not directly related to the hydrogen value chain.
- For most projects, information on production volumes is more readily available than information on investments, which facilitates mapping.

It should be noted that the Mission Innovation platform considers not only scale, but also project replicability and scalability in its scale criterion. Replicability and scalability are difficult to assess in a definitive way for early-stage projects with very limited information publicly available. Therefore, the mapping only considered production capacity (which is an easily evaluated metric) for the scale criterion. However, we consider all the identified valleys to be either replicable or scalable, although modifications would of course be necessary to allow implementation at other locations.

We consider the fifth criterion suitable since it avoids the inclusion of highly uncertain projects in the "concept stage".

The sixth criterion was not formally included in the proposed definition since it would require an assessment of the electricity used for electrolysis in all mapped projects, which may prove difficult for early-stage projects. However, it can be expected that virtually all included projects use renewable energy.

With the adjustments discussed above, a Nordic definition of a "hydrogen valley" can be given:

Nordic hydrogen valleys are projects that:

1. cover a specific geography in at least one Nordic country,
2. cover at least two steps of the hydrogen value chain (production → distribution → use),
3. have a hydrogen production capacity exceeding 500 tonnes per annum (tpa),
4. supply hydrogen to at least two different end-use sectors,
5. have at least reached the feasibility phase (i.e. are working on a feasibility study).

There are many projects that do not fulfil the requirements to be designated as a hydrogen valley but may develop into a hydrogen valley in the future. Such projects are called **Nordic hydrogen hotspots** in the present report and are defined as:

Projects that fulfil criterion 1 and at least 2 of criteria 2–5 in the hydrogen valley definition.

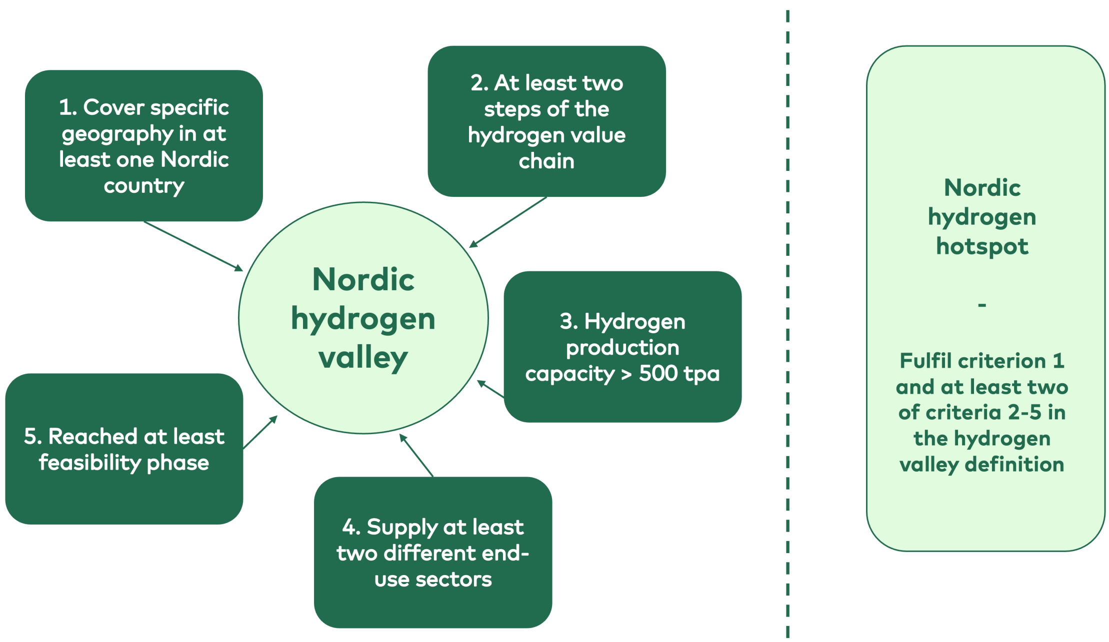


Figure 3. Key characteristics of Nordic hydrogen valleys, as defined in this study.

2.3 Input from workshops and expert interviews

The proposed definition was discussed during the project workshop and in expert interviews, see Appendices A–C.

The proposed definition was generally approved by workshop participants and interviewed experts. The more frequent comments and suggestions are discussed below:

- **"It will be challenging to identify projects that fulfil criterion 4 (at least two end-use sectors)."**
  This concern was raised both in the workshop and in the expert interviews. Indeed, this is the criterion that most of the potential hydrogen valleys in our mapping fail to meet. Nonetheless, showing the versatility of hydrogen is a core aspect of the hydrogen valley concept and the criterion was not removed from the proposed hydrogen valley definition. Moreover, projects that fail only this criterion are still included in the mapping as "hydrogen hotspots".
- **"The colour of hydrogen is important."**
  The issue of hydrogen colour was raised by several workshop participants and experts, but there was no clear consensus regarding which colours to include/exclude. To address this issue, the hydrogen production technology has been specified for all projects included in the database developed by the present project.
- **"The lower capacity limit (500 tpa) is too low."**
  This concern was raised by a few of the interviewed experts. The stated minimum capacity is indeed low and was exceeded by most of the potential hydrogen valleys mapped in this project. Nonetheless, this limit was used throughout the mapping process. The developed database can, however, easily be adjusted to a higher capacity limit as the hydrogen market evolves.

Photo: iStock

3. Mapping and database development

This chapter describes the mapping of hydrogen projects that was performed in the present project. Data from the mapping was gathered in a database and visualised using the digital mapping tool (see Chapter 4). All data was collected in the spring of 2024, and changes in, for instance, stakeholders' investment plans after May 2024 have not been incorporated.

3.1 Scope and method

An Excel database covering Nordic projects for production and/or use of clean- and low-carbon hydrogen was developed. Included projects were evaluated against the Nordic hydrogen valley criteria and sorted into three categories:

- hydrogen valleys,
- hydrogen hotspots,
- other hydrogen projects (potentially interesting hydrogen projects that were identified in the mapping but failed to meet the definition of a hydrogen valley or a hydrogen hotspot).

The database was populated by reviewing existing hydrogen project databases and by complementary literature searches. Reviewed databases include:

Brintbranchen's "Brint i tal"	Danish projects
VTT internal database	Finnish projects (database not publicly available)
Pre-study on transition to hydrogen economy, specifically in Northern Ostrobothnia	Finnish projects
Energi.se Sveriges Vätgasprojekt 2024	Swedish projects
LTU database on hydrogen projects	Swedish projects
Hydrogen and E-fuels Roadmap for Iceland	Icelandic projects
The Norwegian Hydrogen Landscape – The Norwegian Hydrogen Forum[10]	Norwegian projects
IEA Hydrogen project database	Global scope – used for complementary data

For all reviewed projects, the mapping focused on gathering the following information:

Field	Comment
Project name	If an official project name is missing, this field contains the main project stakeholder(s) + the project location.
Location	City or region of implementation.
Stakeholders involved	Entities involved in the implementation of the project.
Production	Which hydrogen production technology is used, if any?
Hydrogen capacity	The full load capacity of the project. To convert electrolyser capacities given as MW_{el} to tpa, 65% LHV efficiency and 8 760 operating hours were assumed.
Distribution	Is hydrogen distributed within the project scope, how?
Utilisation	Is hydrogen utilised within the project scope, for what?
End-use sectors	To which end-use sectors is hydrogen supplied (industry, transport, energy, buildings, export).

10. The database version available *before* the update carried out in June 2024, was used.

Project phase	Indication of the maturity of the project, ranging from "concept" to "operational".
Entry into operation	Year when production started/is scheduled to start.

In addition, information on e.g. investment volume, funding and use of hydrogen storage was identified early on as relevant for the mapping and was gathered when available. However, reliable and consistent information concerning this type of data is difficult to find in publicly available sources. Therefore, it is currently not included in the report or the mapping tool but is available exclusively in the Excel database.

In general, the most challenging part of the mapping process was to determine the project phase (criterion 5) and how the hydrogen is utilised, including the number of end-use sectors (criterion 4). These aspects are discussed below.

Project phase

The fifth hydrogen valley criterion concerns project maturity. To be defined as a hydrogen valley, a project must "have at least reached the feasibility phase (feasibility study)".

Determining the maturity of an early-phase project is often challenging; it can be difficult to determine when an announced project has left the concept stage and entered real project development. Consequently, a project was assumed to fulfil the fifth hydrogen valley criterion if proof of actual project development could be found. Several different indicators were used to determine if this was the case. For example, indications that a project has received or applied for environmental approval, commissioned a FEED study or secured funding can all provide proof that a project has advanced beyond the concept stage and is at least in the feasibility phase. In fact, the mentioned indicators imply that a project has advanced beyond the feasibility phase into later development phases. Conversely, if no proof of actual project development was found, mapped projects were assumed to be in the pre-feasibility/concept phase.

Utilisation and end-use sectors

The fourth hydrogen valley criterion concerns the number of end-use sectors; a hydrogen valley must supply hydrogen to at least two different end-use sectors.

Two distinct project types were identified in the mapping: projects supplying specific end-users via dedicated supply infrastructure and projects exporting hydrogen to the open market via e.g. a future gas grid or ship. The latter project type could potentially supply hydrogen to several end-use sectors. However, a hydrogen valley must cover a specific geography (first criterion). This is not the case for such export-oriented projects where end-users can, in theory, be spread across the globe. In the database, hydrogen export to "the market" is treated as one end-use sector (labelled "Export" in the database).

Conversely, a project was considered to have off-takers in, for instance, the industry or transport sector if it supplies hydrogen to specific off-takers in those sectors via dedicated supply infrastructure.

The production of hydrogen derivatives is always categorised as industrial end-use of hydrogen in the database, regardless of the end-use of the produced derivative.

3.2 Database description and examples

The detailed project information that was gathered during the mapping process is accessible via the developed digital mapping tool and not presented in detail in this report. However, some general trends for each mapped country are discussed below, together with descriptions of *all* identified hydrogen valleys and *a selection of* the identified hydrogen hotspots.

It should be noted that most of the mapped projects – especially the larger projects – are in very early stages of development. This means that the scope and timeline of many of the included projects are still very uncertain and subject to change. Consequently, the developed database will require regular updates and maintenance to stay relevant.

A quantitative high-level summary of the database content is given in Table 1. It is notable that only nine out of 167 mapped projects fulfil the hydrogen valley criteria. In most cases, projects fail to meet the fourth criterion (several end-use sectors). Only 25 of the mapped projects supply hydrogen to specific off-takers in multiple sectors, meaning that 142 mapped projects failed to meet this criterion. Of the 25 projects that do supply more than one end-use sector, 16 failed to meet the hydrogen valley definition, mainly because of insufficient project maturity.

It should be stressed that, although the total capacity of the mapped projects is significant – about 8 Mt or 270 TWh hydrogen per year – only about 0.2% (about 0.2 Mt per year) of this capacity is operational, with an additional approx. 1% under construction.

Table 1. Mapped hydrogen projects, hotspots and valleys per Nordic country. Production capacity refers to the total planned capacity of the mapped projects and includes capacity that is already operational. About 0.2% of the total planned capacity in the Nordics is operational; none of the identified valley projects are operational. Hydrogen projects that cannot be categorised as hotspots or valleys are categorised as "other". Thus, totals do not equal the sum of hotspots and valleys (the difference is especially notable for Norway).

Country	Total number of hydrogen projects	Total planned hydrogen production capacity (ktpa)	Number of hotspots	Planned hydrogen production capacity of hotspots (ktpa)	Number of valleys	Planned hydrogen production capacity of valleys (ktpa)
Denmark	29	3,748	18	2,822	5	237
Faroe Islands	0	0	0	0	0	0
Finland	36	1 126	35	1 126	1	0.5
Greenland	1	153–255	1	153–255	0	0
Iceland	9	112	9	112	0	0
Norway	50	711	24	414	2	10
Sweden	38	1,524	37	1,512	1	12
Åland Islands	4	513	4	513	0	0

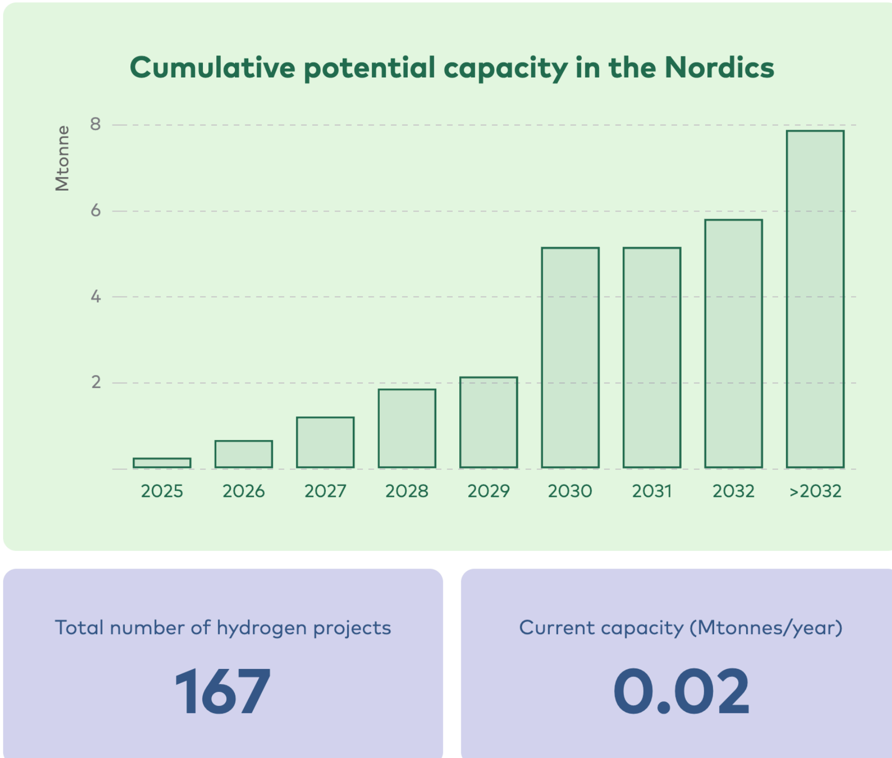


Figure 4. Cumulative potential future production capacity in the Nordics, according to the mapping of this study. Total includes plants without a specified completion year (illustration from nordich2valleys.org).

3.2.1 Denmark

The database contains a total of 29 projects, five of which qualify as hydrogen valleys. The total production capacity of all included projects is 3.7 Mt of hydrogen per year (full capacity utilisation, 65% LHV electrolyser efficiency). The basis of the mapping was Brintbranchen's "Brint i tal", although some projects from that platform have been excluded due to insufficient data availability.

The included Danish hydrogen projects are primarily focused on chemicals or fuel applications (ammonia, methanol, SAF or direct use for heavy-duty road transport). There are also four smaller projects aiming to use hydrogen to increase the methane yield of biogas production, as well as projects aiming to supply green hydrogen to conventional refinery processes. It is also worth mentioning that there are several major export-oriented projects such as the Brintø[11] project (10 GW electrolyser capacity) and the Megaton[12] project (2 GW electrolyser capacity).

While most projects are in early development, six projects are operational or under construction, with the largest being European Energy's Kassø[13] project (approx. 60 MW electrolyser capacity). The fact that most projects are in early development complicates mapping, as project concepts are not yet finalised and may change from one press release to another.

11. COWI, 2022, "Danish Hydrogen Island Could be First of Its Kind" https://www.cowi.com/news-and-press/news/2022/danish-hydrogen-island-could-be-first-of-its-kind-video/
12. GreenGo, n.d., "GreenGo Energy develops 4GW, 8 billion EUR green energy park in Ringkøbing-Skjern municipality" https://www.greengoenergy.com/news/megaton1
13. European Energy, 2023, "European Energy vinder Power-to-X-udbud og påbegynder næste generation af e-fuel-produktion" https://dk.europeanenergy.com/2023/10/27/european-energy-vinder-power-to-x-udbud-og-paabegynder-naeste-generation-af-e-fuel-produktion/

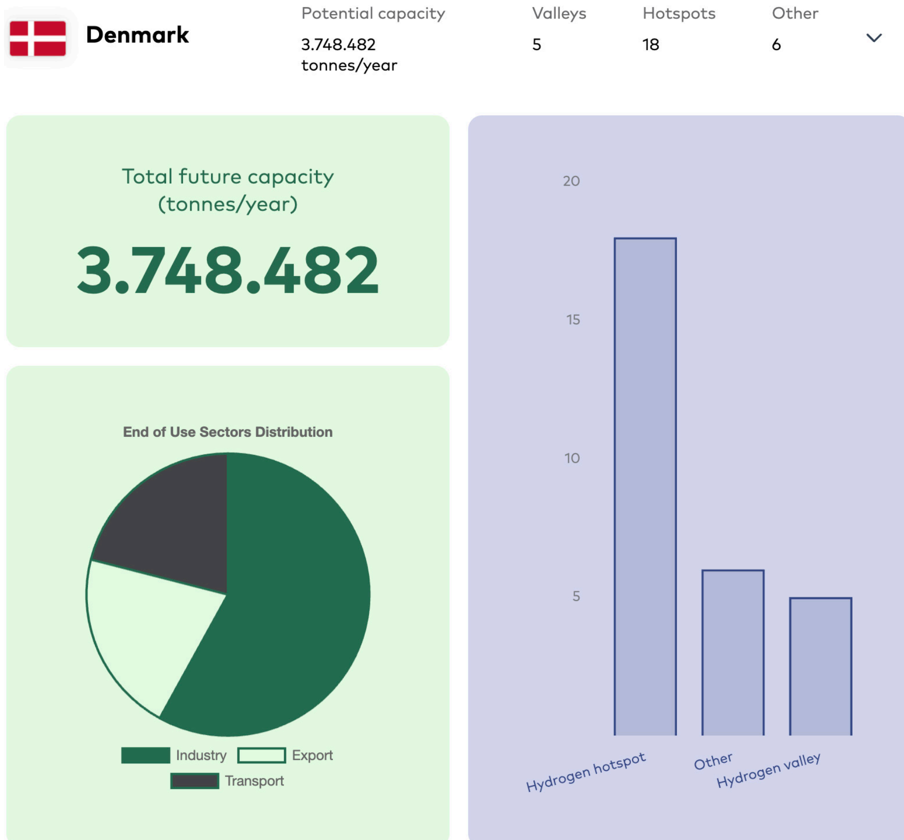


Figure 5. Overview of mapping for Denmark (illustration from nordich2valleys.org).

Hydrogen valleys:

H2 Energy Europe Esbjerg (Njordkraft)[14][15][16]

H2 Energy Europe, a joint venture between Trafigura and H2 Energy AG, is developing a 1 GW electrolyser plant in Esbjerg, Denmark using PEM technology and wind power. The project received environmental approval in January 2024. According to the environmental impact assessment, the produced hydrogen will be transported by pipeline to the Fredericia area (approx. 90 km from the production area) where it will be used as fuel for light-duty and heavy-duty vehicles (transport sector), as well as for industrial applications (e-fuel, e-chemicals or refineries). According to additional information provided by the company, a significant portion of the production may also be exported by pipeline to Germany, depending on the development of distribution infrastructure. In addition, the excess heat will be used in the local district heating network. The project has not yet reached financial close but is slated for completion in 2028.

14. H2 Energy Europe, n.d., "Njordkraft project". https://h2eeurope.com/project/njordkraft/
15. H2 Energy Europe, 2023, "Miljøkonsekvensrapport H2 Energy Esbjerg" https://dagsordener.esbjergkommune.dk/vis/pdf/bilag/3871250d-bde4-4783-a06d-5383b5ae87b9/?redirectDirectlyToPdf=false
16. H2 Energy Europe, n.d., "Denmark's 1GW green hydrogen production facility receives important environmental approval from authorities" https://h2eeurope.com/denmarks-1gw-green-hydrogen-production-facility-receives-important-environmental-approval-from-authorities/

CONVEY – Hirtshals Havn[17][18][19]

The CONVEY project received funding through the Horizon Europe small-scale hydrogen valley call of 2023. The project is being developed by a consortium of ten members led by Norwegian Hydrogen AS and aims to install 5 MW of electrolyser capacity in the port of Hirtshals and to use the produced hydrogen in industry (heating – natural gas replacement) and at a refuelling station for heavy-duty road transport. Excess heat and oxygen will be utilised in aquaculture.

The electrolyser will be powered by local wind production and is planned to produce 550 tonnes of green hydrogen per year, corresponding to approx. 65% capacity utilisation (assuming 65% LHV electrolyser efficiency).

European Energy Måde[20][21]

European Energy is developing several e-methanol projects in Denmark. The Måde project has a different scope: 12 MW of electrolyser capacity will be used to provide hydrogen to the port of Esbjerg – where it will be used to power ships moored in the port – and to a major industrial gas supplier. Excess heat from the electrolyser will be delivered to the Esbjerg district heating network.

The project will be powered by European Energy's wind farm in Måde and is currently under construction.

HySynergy[22][23][24][25]

The HySynergy project is being developed in three phases by a seven-party consortium led by Everfuel. The first phase is currently under construction in Fredericia (scheduled to be operational in 2024) and comprises 20 MW of electrolyser capacity, supplying hydrogen to a neighbouring refinery (Crossbridge Energy) and hydrogen refuelling stations, as well as heat to the local district heating system.

Given that operations in the first phase are successful, the plan is to expand capacity to 1 GW by 2030, implemented over a total of three phases. Later phases will likely also include significant exports of hydrogen via a pipeline to Germany.

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17. Norwegian Hydrogen, n.d., "Project Convey" https://norwegianhydrogen.com/activities/convey_project
18. Port of Hirtshals, 2024, "Norwegian Hydrogen establishes large hydrogen production facility at Port of Hirtshals" https://portofhirtshals.dk/en/currently/news/norwegian-hydrogen-establishes-large-hydrogen-production-facility-at-port-of-hirtshals/
19. European Commission, n.d., "nordiC hydrOgen eNergy VallEY" https://ec.europa.eu/info/funding-tenders/opportunities/portal/screen/how-to-participate/org-details/999999999/project/101137581/program/43108390/details
20. European Energy, 2022, "European Energy underskriver kontrakt med Esbjerg Havn om grøn brint" https://dk.europeanenergy.com/2022/06/28/european-energy-underskriver-kontrakt-med-esbjerg-havn-om-groen-brint/
21. European Energy (LinkedIn-post), 2023, "Måde – The heart of Power-to-X technology testing" https://www.linkedin.com/posts/european-energy-as_green-hydrogen-plant-european-energy-activity-7048565792816193536-E348/
22. Everfuel, 2024, "HySynergy – our flagship project", https://www.everfuel.com/power-to-h/
23. Everfuel, 2024, "Earnings presentation Q4 2023", https://www.everfuel.com/app/uploads/2024/03/20240305_Everfuel-Q4-2023-presentation.pdf
24. Miljøministeriet, 2023, "Miljøgodkendelse for Everfuel Production Fredericia A/S", https://mst.dk/media/gvwnpv43/20230627-everfuel-miljoegodkendelse.pdf
25. Rambøll, n.d., "HySynergy green H2 production plant", https://www.ramboll.com/projects/energy/hysynergy-green-h2-production-plant

Green Hydrogen Hub[26][27][28][29]

The Green Hydrogen Hub Denmark project is being developed by Corre Energy, Eurowind and Gas Storage Denmark. The project will construct

- a 180 MW electrolyser combined with 250 GWh of hydrogen storage,
- a compressed air storage system with a 320 MW generator and a storage capacity corresponding to 84 hours at the generator's rated output.

Compressed air and hydrogen will be stored in salt rock caverns to be used for grid balancing as needed. The hydrogen can be used either for grid balancing (pre-heating air for the compressed air generator) or exported to the (prospective) gas grid in the region. The project achieved commercial close in 2023, with a target for a final investment decision in 2025 and plans to commence operations by 2028.

A selection of projects qualifying as **hydrogen hotspots** is given below:

Høst[30][31][32]

Høst is being developed by Copenhagen Infrastructure Partners and will construct a hydrogen and ammonia plant with 1 GW of electrolyser capacity. The project secured a grid connection in 2023 and expects to reach a final investment decision in 2025, becoming fully operational in 2028/29.

The project would be classified as a hydrogen valley if it supplied more than one end-use sector. While the focus of Høst is ammonia production, the development of a regional hydrogen grid would facilitate the export of a portion of the produced hydrogen, which would elevate the project to hydrogen valley status.

Fjord PtX[33][34]

Fjord PtX is being developed by Copenhagen Infrastructure Partners, Aalborg Forsyning and Reno-Nord. The project aims to build a production plant for SAF using captured CO_2 and hydrogen produced by a 350 MW electrolyser. An important part of the project is the delivery of 200 GWh/year of excess heat to the district heating system, which would replace the district heat production that will be lost when the coal-fired Nordjylland power station is decommissioned. An environmental impact assessment is ongoing, and the SAF production plant is expected to become operational in 2028.

The project would be a hydrogen valley if it supplied hydrogen to multiple end-use sectors. However, the current plan is to use all produced hydrogen on-site for SAF production.

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26. [13] Corre Energy, 2024, "Corre Energy Annual report 2023", https://corre.energy/wp-content/uploads/2024/05/Corre-Energy-BV-2023-Annual-Report.pdf
27. Corre Energy, 2022, "Investor presentation 2022", https://corre.energy/wp-content/uploads/2022/05/Corre-Energy-Investor-Presentation_24-May-2022.pdf
28. Swedish Hydrogen Development Center, 2023, "Danish Outlook", https://www.ri.se/sites/default/files/2023-08/SHDC%20Event%20-%20Danish%20outlook.pdf
29. Green Hydrogen Hub Denmark, n.d, https://greenhydrogenhub.dk/
30. Høst PTX Esbjerg, n.d., "About the project", https://hoestptxesbjerg.dk/about-ptx/
31. Høst PTX Esbjerg, n.d., "Høst signs grid connection agreement" https://hoestptxesbjerg.dk/news/host-underskriver-nettilslutningsaftale-med-energinet/
32. State of green, 2023, "Green hydrogen is Danish hydrogen", https://stateofgreen.com/en/wp-content/uploads/2023/11/sog_greenhydrogen_WP_08_DIGI.pdf
33. Aalborg Forsyning, n.d., "Power-to-X-anlæg skal ligge nord for Aalborg" https://aalborgforsyning.dk/privat/gronne-losninger/energi-og-koling/fjord-ptx/
34. Miljøstyrelsen, 2022, "Indkaldelse af idéer og forslag til afgrænsning af miljøkonsekvensrapport for projekt Fjord PtX ved Aalborg" https://mst.dk/media/rapor5dk/20221115-power-to-x-debatfolder.pdf

3.2.2 Faroe Islands

No projects meeting the criteria for hydrogen valleys were identified in the Faroe Islands, and only one project with planned hydrogen production capacity was found. Salmon producer Bakkafrost has partnered with the Faroese energy company Effo to develop a 100 MW wind farm in a project that will also include hydrogen production capacity, most likely for Bakkafrost's own operations.[35] Note that this project is not included in the mapping, because too little information is available.

35. Bakkafrost, 2024, "Bakkafrost Integrated annual report 2023", https://mb.cision.com/Main/12459/3953950/2701841.pdf

3.2.3 Finland

In Finland, many large-scale hydrogen production projects are currently under development. In the majority of these projects, hydrogen produced via electrolysis is utilised on-site to produce e-fuels and chemicals such as methane, methanol and ammonia, as well as to produce green steel or to be used directly in the transport sector. Although less common, hydrogen exports via transmission pipelines, replacing fossil hydrogen in existing industries, electricity grid balancing and high-temperature heat production are also identified as hydrogen end-uses in the projects.

Sector integration is an important element of Finland's hydrogen production projects. Many of the projects, especially the most advanced ones, incorporate the use of by-product heat from electrolysis for district heating, thereby reducing the use of combustion-based alternatives. As a result, energy companies are often involved in hydrogen projects in Finland, alongside the project developers. Many project developers in Finland, such as P2X Solutions, Ren-Gas Oy, Green North Energy and Plug Power have multiple hydrogen projects in the pipeline across different regions of the country.

The projects with estimated commissioning years are planned to be operational by the 2030s. However, the publicly announced timelines and project stages may not be up-to-date and may involve great uncertainties.

In terms of hydrogen development from a geographical perspective, hydrogen projects in Finland are mainly concentrated in the coastal and southern regions of the country. Several large-scale hydrogen production plans are planned along the west coast, driven by the region's substantial wind power potential. The region of Ostrobothnia leads in both installed and planned onshore wind power capacities in the country.[36] Offshore wind power production with significant capacities is also planned for this area.[37] Additionally, the Nordic Hydrogen Route, a cross-border hydrogen transmission pipeline infrastructure, is set to run around the Bothnian Bay between northern Finland and Sweden,[38] following the west coast and facilitating investment plans. The western coastline also has large-scale biogenic carbon dioxide sources from e.g. the pulp industry in Oulu and Kemi, which could support projects utilising hydrogen in e-fuel production.[39] Furthermore, Finland's only primary steel production plant, located in Raahe, could become a major green hydrogen consumer if the reduction of iron ore is implemented at the site. This demand could occur when the facility is decarbonised, likely in the 2030s.[40] The coastal area is also home to ports and harbours that support plans for exportable hydrogen derivates, such as ammonia. In fact, all green ammonia plants planned in Finland are in the coastal areas, specifically in Kemi, Kokkola, Pori and Naantali.

Southern Finland is another region with numerous hydrogen-related initiatives. The region is the focus area of the EU-funded BalticSeaH2 project,[41] a consortium of 40 partners from nine Baltic Sea countries, which received funding under the Horizon Europe

36. Finnish Wind Power Association, 2023, "Vuonna 2022 eniten tuulivoimaloita valmistui Pohjanmaan maakuntiin" https://tuulivoimayhdistys.fi/ajankohtaista/tiedotteet/vuonna-2022-eniten-tuulivoimaloita-valmistui-pohjanmaan-maakuntiin
37. Finnish Wind Power Association, 2024, "Wind power projects in Finland" https://tuulivoimayhdistys.fi/tuulivoima-suomessa/kartta
38. Gasgrid, 2024, "Nordic Hydrogen Route" https://gasgrid.fi/en/projects/nordic-hydrogen-route-en/
39. Karjunen Hannu, 2022. "Analysis and design of carbon dioxide utilization systems and infrastructures" https://lutpub.lut.fi/bitstream/handle/10024/164753/Hannu%20Karjunen_A4.pdf?sequence=4&isAllowed=y
40. Talouselämä, 2024. "Miksi Luulaja voitti Raahen? SSAB:n Huhtala paljastaa kaksi suurta syytä" https://www.talouselama.fi/uutiset/miksi-luulaja-voitti-raahen-ssabn-huhtala-paljastaa-kaksi-suurta-syyta/b5389237-1e3d-42a9-a3ee-af62f71b66da
41. BalticSeaH2, 2024, "BalticSeaH2 EU-Project" https://balticseah2valley.eu/project/

large-scale hydrogen valley call of 2022. The aim of the project is to build the first significant, cross-border hydrogen valley in Europe. The project's main hydrogen valley is located between southern Finland and Estonia, with replication valleys planned across the Baltic Sea countries. The project includes dozens of individual investments by the partner companies, demonstrating hydrogen economy, including hydrogen production, distribution, storage and end-use (industry, transport, energy, market) throughout the value chain. The investments are published once the companies finalise their investment plans. The hydrogen production potential is projected to exceed 100 ktpa by the end of the project in 2028. Several hydrogen projects led by the consortium partners (P2X Solutions, Helen, Green North Energy and Neste) have already been announced in southern Finland [42] and are described later in this document, as they represent some of the most advanced hydrogen projects in Finland as of today.

Southeast Finland is also a promising region from a hydrogen perspective, with several initiatives ongoing. The region has large point sources of biogenic carbon dioxide from its energy sector and pulp and paper industries. Notably, according to the mapping carried out by the present project, the largest hydrogen production projects in the region by estimated capacity, such as the projects by P2X Solutions in Joensuu[43] and Ren-Gas in Kotka[44] and Mikkeli,[45] are related to hydrogen production for on-site e-fuel production together with a local carbon dioxide source. In addition to significant point sources of biogenic carbon dioxide, the renewable energy potential in southeast and eastern Finland is promising. However, the military air surveillance radars limit wind power construction in the region. To address this, in February 2024, the Ministry of Economic Affairs and Employment and the Ministry of Defence appointed a working group to explore ways to coordinate territorial surveillance and wind power construction in eastern Finland.[46]

Currently, the only hydrogen project in Finland that meets the hydrogen valley criteria outlined in this study, the 3H2 – Helsinki Hydrogen Hub, is in the capital region and is described in more detail below. Several other hydrogen projects have the potential to meet these criteria as they progress beyond the early planning stages or expand their hydrogen supply to multiple end-use sectors. Presently, most hydrogen production projects focus on the on-site production of hydrogen derivatives, categorised as serving a single end-use sector (industry), although products like synthetic methane could benefit both industry and transport. These projects are classified as hydrogen hotspots, and the most advanced among them, based on public announcements, are also described below.

42. BalticSeaH2, 2024. "Investment cases" https://balticseah2valley.eu/investment-cases/
43. P2X, 2022, "P2X Solutions and Savon Voima study the possibility of green hydrogen and e-fuels production in Joensuu" https://p2x.fi/en/p2x-solutions-and-savon-voima-study-the-possibility-of-green-hydrogen-and-e-fuels-production-in-joensuu/
44. Ren-Gas, 2024, "Kotka" https://ren-gas.com/en/projekti/kotka-2/
45. Ren-Gas, 2024, "Mikkeli" https://ren-gas.com/en/projekti/mikkeli-2/
46. Ministry of Defence and Ministry of Economic Affairs and Employment, 2024, "Working group to promote wind power projects in eastern Finland" https://valtioneuvosto.fi/-/1410877/tyoryhma-edistamaan-tuulivoimahankkeita-itaisessa-suomessa?languageId=en_US

It is also worth noting that, while individual projects may not meet the hydrogen valley criteria on their own, certain local clusters of projects could collectively meet the criteria. For example, on the western coast, Kokkola hosts several hydrogen initiatives. Flexens[47] and Plug Power[48] have plans for 350 MW and 1 GW electrolysers for on-site ammonia production, Aliceco Energy and TEH2 aim to produce e-methanol for shipping [49] and Raahen Monivoima plans to work together with local energy company Kokkola Energia on e-methane production to replace fossil fuels in local industries.[50] Hycamite is already constructing a methane pyrolysis facility for hydrogen and solid carbon production at Kokkola Industrial Park[51] and Woikoski has operated a 9 MW alkaline electrolysis unit in the area since 2014.[52] Individually, these projects do not qualify as a hydrogen valley, due to e.g. the end-use criterion, but by leveraging the synergies of these projects, they could potentially form a hydrogen valley in the Kokkola area as the projects proceed.

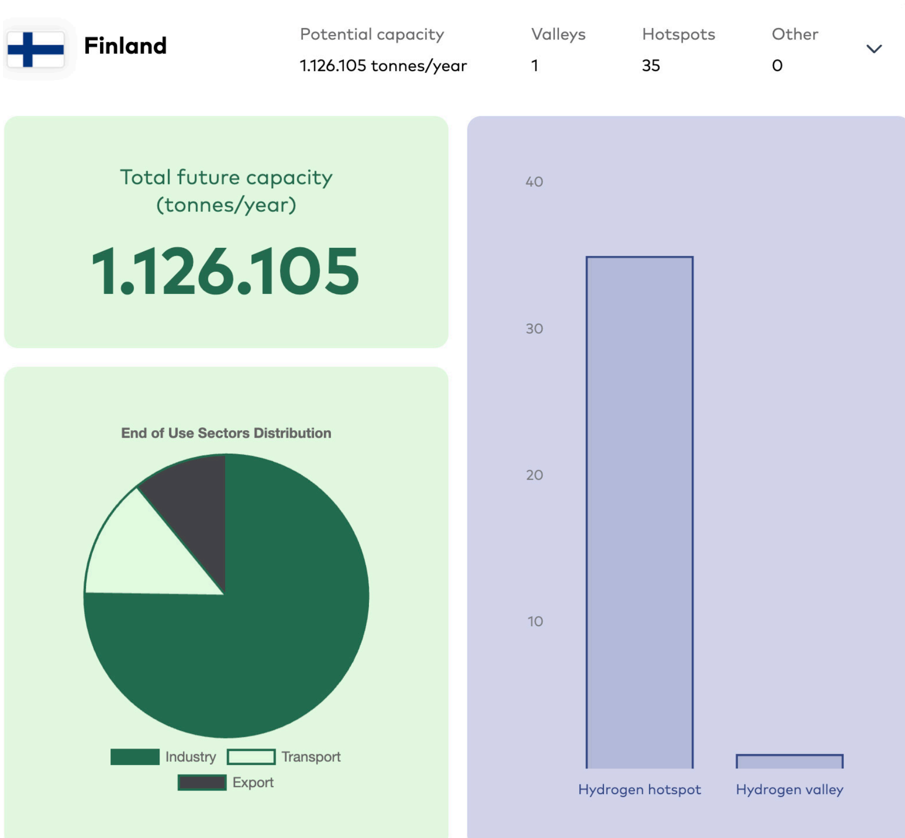

Figure 6. Overview of mapping for Finland (illustration from nordich2valleys.org).

47. Flexens, 2024. "Fuelling Europe's green future in Kokkola" https://www.flexenskokkola.fi/home
48. Plug Power, 2023. "Plug Power Makes Major Strategic Move into Finland's Green Hydrogen Economy with its Proven PEM Electrolyzer and Liquefaction Technology" https://www.ir.plugpower.com/press-releases/news-details/2023/Plug-Power-Makes-Major-Strategic-Move-into-Finlands-Green-Hydrogen-Economy-with-its-Proven-PEM-Electrolyzer-and-Liquefaction-Technology/default.aspx
49. Holopainen, 2023. "Jättimäistä tuotantoa suunnitteilla Kokkolaan: vihreää polttoainetta teollisuuteen ja laivaliikenteeseen" https://yle.fi/a/74-20060254
50. Puhuri, 2023. "The pilot project for Raahen Monivoima's new energy solutions is moving forward" https://www.puhuri.fi/en/the-pilot-project-for-raahen-monivoimas-new-energy-solutions-is-moving-forward-with-the-support-of-a-more-than-5-million-euros-grant-from-tem/
51. Hycamite, 2024. "The largest methane-splitting hydrogen plant in Europe will begin operations this fall" https://hycamite.com/articles/the-largest-methane-splitting-hydrogen-plant-in-europe-will-begin-operations-this-fall
52. Woikoski, 2021. "Woikoski enters collaboration with Neovolt" https://www.woikoski.fi/en/woikoski/news-and-events/news/woikoski-enters-collaboration-with-neovolt.html

Hydrogen Valleys:

3H2 – Helsinki Hydrogen Hub[53]

The 3H2 – Helsinki Hydrogen Hub project, led by the energy company Helen, reached its final investment decision in April 2024. The project aims to construct a 3 MW pilot facility for clean hydrogen production. The facility is intended to supply hydrogen to an on-site refuelling station designed for heavy-duty transport needs. In addition, hydrogen can be delivered to industrial customers. Another key objective is to create necessary expertise for large-scale hydrogen production and to optimise hydrogen production in terms of hydrogen demand, renewable electricity generation and electricity markets. The goal is to begin hydrogen production by 2026 and to launch the refuelling station by 2027. Additionally, surplus heat from the electrolyser will be utilised in the capital region's district heating network.

A selection of projects qualifying as **hydrogen hotspots** is given below. The projects are defined as hydrogen hotspots instead of hydrogen valleys, as they supply hydrogen for only one end-use sector.

P2X Solutions, Harjavalta

P2X Solutions is constructing Finland's first industrial-scale electrolyser unit in Harjavalta, scheduled to be operational in the autumn of 2024.[54] The electrolyser will have a capacity of 20 MW, and the green hydrogen produced will be sold to industrial users (e.g. for xylitol production[55]) and used for on-site synthetic methane production. The electrolyser is being supplied by Germany's Sunfire GmbH, while the methanation unit is provided by Finnish Q Power Oy. The plant aims to generate new knowledge for the green hydrogen sector, with the company applying lessons learned to its two other hydrogen projects in the pipeline, which involve scaling up electrolyser capacity. P2X Solutions is also part of the BalticSeaH2 consortium.

P2X Solutions has also ongoing projects in Joensuu and Oulu. In Joensuu, a production plant will feature a 30–50 MW electrolyser to supply green hydrogen for on-site e-methanol production, processed from biogenic CO_2 captured from the nearby Savon Voima power plant. This plant could be operational by 2026 at the earliest. In Oulu, the company is planning a 100 MW electrolyser and a carbon capture plant for e-fuel production in collaboration with local energy company Oulun Energia. The investment decision is expected in 2025, and the plant could be operational by 2028 at the earliest. Both the Joensuu and Oulu projects will also supply by-product heat to local district heating systems.

53. Helen, 2024, "Helen investoi Helsingin ensimmäiseen vihreän vedyn tuotantolaitokseen" https://www.helen.fi/uutiset/2024/helen-investoi-helsingin-ensimmaiseen-vihrean-vedyn-tuotantolaitokseen
54. PX2, 2024, "Projects" https://p2x.fi/en/project/
55. PX2, 2023, "P2X Solutions and Danisco Sweeteners signed a contract on the delivery of green hydrogen" https://p2x.fi/en/p2x-solutions-and-danisco-sweeteners-signed-a-contract-on-the-delivery-of-green-hydrogen/

Green North Energy, Naantali

Green North Energy is planning its first green hydrogen production project in Naantali, where the hydrogen will be used for on-site green ammonia production for the fertiliser industry. Eventually, as the market develops, ammonia could be supplied to emerging markets such as the shipping industry as well. The planned electrolyser capacity is 280 MW, with an investment of €600 million.[56] The company aims to replicate the hydrogen and ammonia production concept of the Naantali plants in Pori and Kemi, with the feasibility of these locations being examined as part of the BalticSeaH2 project.[57]

Ren-Gas

Ren-Gas Oy has a project portfolio consisting of six hydrogen and e-methane production facilities located in Lahti, Kotka, Mikkeli, Pori, Kerava and Tampere.[58] All projects involve partnerships with local energy producers to ensure an efficient supply of CO_2 and to utilise the by-product heat from the electrolyser in local district heating systems. A feasibility study has been conducted for the entire project portfolio, and the Environmental Impact Assessment (EIA) and permitting processes are underway. The European Investment Bank (EIB) has approved a €230 million framework loan agreement for Nordic Ren-Gas's project portfolio.[59] The EIB will make final investment decisions for each Ren-Gas project separately. In April 2024, a €45 million subsidy grant was awarded to Nordic Ren-Gas's Lahti plant through the European Hydrogen Bank's first competitive bidding process, making it the only Finnish beneficiary.[60] The Lahti plant aims to produce 12 000 tonnes of hydrogen per year and is expected to be operational in 2027.[61]

Neste

As of today, Neste's refinery in Porvoo is Finland's largest consumer of hydrogen. The company is developing a 120 MW electrolyser project aimed at producing green hydrogen primarily for use in the refinery's processes, replacing fossil hydrogen.[62] The investment decision is expected to be finalised in 2024, with potential green hydrogen production starting in 2026. Neste is also collaborating with the local energy company Porvoon Energia to explore the feasibility of utilising by-product heat from the electrolyser in district heating.

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56. Green North Energy, 2024. "Green over gray ammonia. Simple." https://www.greennorth.energy/en/
57. Green North Energy, 2024. "Green North Energy to replicate its Business Finland-funded hydrogen plant concept in Pori and Kemi – aiming for Finland's self-sufficiency in ammonia production" https://www.greennorth.energy/en/news/green-north-energy-to-replicate-its-business-finland-funded-hydrogen-plant-concept-in-pori-and-kemi-aiming-for-finlands-self-sufficiency-in-ammonia-production/
58. Nordic Ren-Gas Oy, 2024. "Projects" https://ren-gas.com/en/projects/
59. Nordic Ren-Gas Oy, 2024. "EIB approves Ren-Gas 230 MEUR financing framework to back its renewable e-methane projects in Finland" https://ren-gas.com/en/news/eib-approves-ren-gas-230-meur-financing-framework-to-back-its-renewable-e-methane-projects-in-finland/
60. Nordic Ren-Gas Oy, 2024, "Nordic Ren-Gas Wins in the First EU Hydrogen Auction with EUR 45 million Bid" https://ren-gas.com/en/news/nordic-ren-gas-wins-in-the-first-eu-hydrogen-auction-with-eur-45-million-bid/
61. Nordic Ren-Gas Oy, 2024, "Lahti" https://ren-gas.com/en/projekti/lahti-2/
62. Neste, 2023. "Neste moves forward in its renewable hydrogen project in Porvoo, Finland" https://www.neste.com/news/neste-moves-forward-in-its-renewable-hydrogen-project-in-porvoo-finla

3.2.4 Greenland

In Greenland, there are no projects that meet the criteria for hydrogen valleys, and only one project with planned hydrogen production capacity was identified.

However, Greenland's Minister of Agriculture, Self-Sufficiency, Energy and Environment has announced (in May 2022[63]) an ambition to make an estimated 800 MW of hydropower reserves available for hydrogen production. Licenses will be awarded through a tendering process, but no projects directly associated with this ambition have been identified in the mapping for the present report.

In addition to the Greenlandic government's ambitions, H2Carrier is planning to implement one of its "P2XFloater" projects in Greenland. The project will include a floating e-ammonia factory with a planned rated power of 900–1 500 MW, as well as a 1.5 GW onshore wind farm developed in a collaboration between H2Carrier and Greenlandic power developer Anori.[64][65]

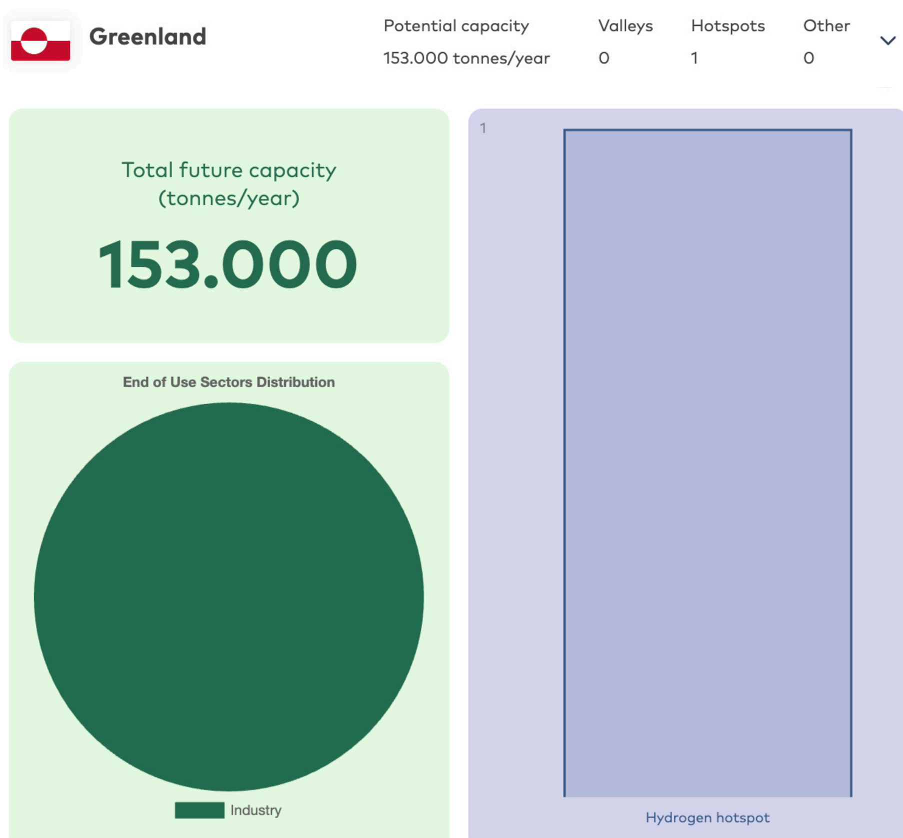

Figure 7. Overview of mapping for Greenland (illustration from nordich2valleys.org).

63. EnergyWatch, 2022, "Greenland to make reserves available for hydrogen development", https://energywatch.com/EnergyNews/Cleantech/article14006223.ece
64. H2Carrier, n.d., "Our Projects", https://www.h2carrier.com/projects-6
65. Hydrogeninsight, 2023, "Plan unveiled to produce green hydrogen and ammonia on a ship connected to a 1.5GW wind farm in Greenland" https://www.hydrogeninsight.com/innovation/plan-unveiled-to-produce-green-hydrogen-and-ammonia-on-a-ship-connected-to-a-1-5gw-wind-farm-in-greenland/2-1-1383080

3.2.5 Iceland

In April 2024, the Ministry of the Environment, Energy and Climate published a report entitled "Hydrogen and E-fuels Roadmap for Iceland".[66] The roadmap identifies hydrogen and e-fuels as key elements in decarbonising the transport and maritime sectors in Iceland, which are among the primary consumers of fossil fuels in the country. The country has two operational electrolyser units. Carbon Recycling International has a 6 MW unit that has been producing hydrogen since 2012 for renewable methanol production using carbon dioxide from a nearby geothermal power station.[67] The other electrolyser unit is owned by ON Power and has a capacity of 0.7 MW. It produces hydrogen at the Hellisheiði Geothermal Power Plant for transport as part of the European Union's Hydrogen Mobility Europe development project.[68] According to a press release published in April 2024,[69] five Icelandic companies have signed a letter of intent to purchase hydrogen-powered MAN hTGX heavy-duty freight trucks, which will utilise hydrogen produced at the Hellisheiði site. According to the press release, the trucks are equipped with hydrogen combustion engines, which means that maintenance and care will be similar to the vehicles companies already operate. Additionally, these trucks offer a range of 600 kilometres. The companies buying the first trucks are BM Vallá, Colas, MS, Samskip Iceland and Terra. In connection with the letter of intent, Blær is constructing a new hydrogen refuelling station capable of serving both trucks and passenger cars. Delivery of the first trucks is expected in the spring of 2025.

Based on the project mapping, Iceland has no projects that meet the criteria for hydrogen valleys. However, the Hydrogen and E-fuels Roadmap for Iceland lists a selection of ongoing hydrogen-related projects that qualify as hydrogen hotspots.[70] As these projects are in the early stages of development, only limited details are available. The following selection of Icelandic projects, identified as hydrogen hotspots, includes the ongoing initiatives that have provided estimates of their hydrogen production capacity.

A selection of projects qualifying as **hydrogen hotspots** is given below:

Green ammonia production by Green Fuel and Topsoe[71]
Green Fuel plans to establish a hydrogen and ammonia production facility at the Bakki industrial site near Húsavík in northeast Iceland. The facility is expected to have a capacity of 100 MW and will focus on producing green ammonia for export and domestic maritime use. This production could potentially power a third of the Icelandic fishing fleet, with an annual ammonia output of 105 kt or 300 t per day.

66. Ministry of the Environment, Energy and Climate, 2024, "Hydrogen and E-fuels Roadmap for Iceland" https://www.government.is/library/Files/240102_URN_RoadmapForIceland_V6.pdf
67. Ministry of the Environment, Energy and Climate, 2024, "Hydrogen and E-fuels Roadmap for Iceland" https://www.government.is/library/Files/240102_URN_RoadmapForIceland_V6.pdf
68. OR, 2022, "Geothermal Park at Hellisheiði" https://annualreport2022.or.is/umhverfismal/jar%C3%B0hitagar%C3%B0ur-skipulag%C3%B0ur-%C3%A1-hellishei%C3%B0i/
69. Icelandic New Energy, 2024, "An important step in decarbonizing HD transport in Iceland" https://newenergy.is/en/2024/05/03/an-important-step-in-decarbonizing-hd-transport-in-iceland/
70. Ministry of the Environment, Energy and Climate, 2024, "Hydrogen and E-fuels Roadmap for Iceland" https://www.government.is/library/Files/240102_URN_RoadmapForIceland_V6.pdf
71. Ministry of the Environment, Energy and Climate, 2024, "Hydrogen and E-fuels Roadmap for Iceland" https://www.government.is/library/Files/240102_URN_RoadmapForIceland_V6.pdf

SAF production by IdunnH2[72]

IdunnH2 and Icelandair have signed a memorandum of understanding for IdunnH2 to supply the airline with up to 45 ktpa of SAF produced from green hydrogen. The electrolyser for hydrogen production will have a capacity of up to 300 MW and is planned to be situated near Keflavík Airport. The estimated total annual SAF capacity is 65 ktpa, and the facility is expected to be operational by the end of 2027.

Green Energy Park "Orkugarður Austurlands"[73]

The municipality of Fjarðabyggð, Icelandic power company Landsvirkjun and Copenhagen Infrastructure Partners (CIP) have partnered to explore the development of a 250 MW hydrogen production facility for ammonia production at the Green Energy Park in Reyðarfjörður. The facility is expected to produce 200 kt of ammonia annually. Letters of intent have been signed with several off-takers and power suppliers, including Skeljungur, the municipality of Fjarðabyggð, Síldarvinnslan, Atmonia and Arctic Hydro. The project is expected to be operational by 2028 or 2029.

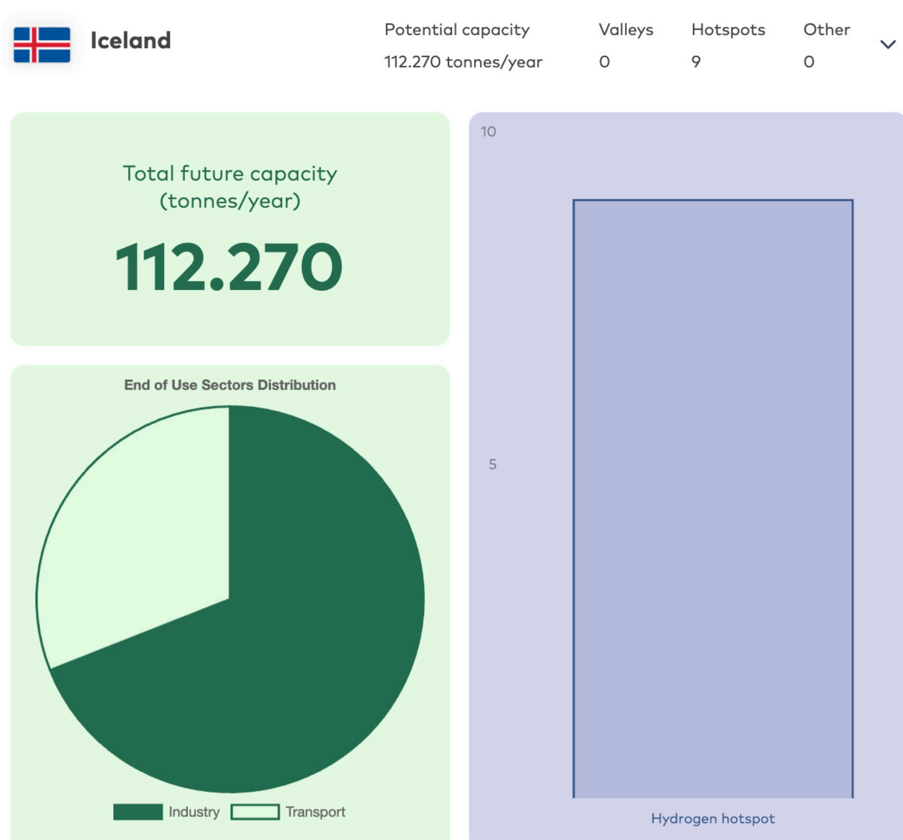

Figure 8. Overview of mapping for Iceland (illustration from nordich2valleys.org).

72. Ministry of the Environment, Energy and Climate, 2024, "Hydrogen and E-fuels Roadmap for Iceland" https://www.government.is/library/Files/240102_URN_RoadmapForIceland_V6.pdf
73. Ministry of the Environment, Energy and Climate, 2024, "Hydrogen and E-fuels Roadmap for Iceland" https://www.government.is/library/Files/240102_URN_RoadmapForIceland_V6.pdf

3.2.6 Norway

There are a lot of plans for hydrogen production all over Norway, ranging from Berlevåg in the north to Kristiansand in the south. Very few of these sites are in operation, and even fewer are larger than 1 MW. The largest plants in operation are Yara's 24 MW electrolyser at Herøya (see more below) and Norwegian Hydrogen's 3 MW electrolyser in Hellesylt. There is a great uncertainty in the data collected for projects where investment decisions have not been made. Despite the overall trend indicating a proliferation of initiatives, there is often a lack of end users and thus no business case for final investment decisions. This is exemplified by the fact that even projects planned to be realised within the next two years seem to lack investment decisions. At this point, none of the already realised projects for green or blue hydrogen production in Norway satisfy all hydrogen valley criteria. However, several planned projects will satisfy the hydrogen valley criteria if realised. It is also clear that the progress of the planned projects varies significantly.

The number of end-use sectors is a difficult criterion to determine, as several of the planned production sites in Norway focus on the transport sector, more specifically maritime transport. However, there is a lack of other interested off-takers, and the projects would likely sell hydrogen (or its derivatives) to any interested party.

The overview produced by Mission Innovation and the Clean Hydrogen Partnership[74] indicates that there are three (potential) Norwegian hydrogen valleys: H2 Valley Mid-Norway, Hydrogen Hub Agder and HyFuel AS. H2 Valley Mid-Norway has an estimated hydrogen production of around 6 000 tonnes per year but does not show up clearly when mapping projects because it is a collection of several projects covering the entire value chain in Central Norway. Hydrogen Hub Agder expects to produce 3 000 tonnes per year in Kristiansand, and HyFuel is focusing on hydrogen production in Florø.

74. https://h2v.eu/hydrogen-valleys?populate=&field_ch_1_q_10_value=NO

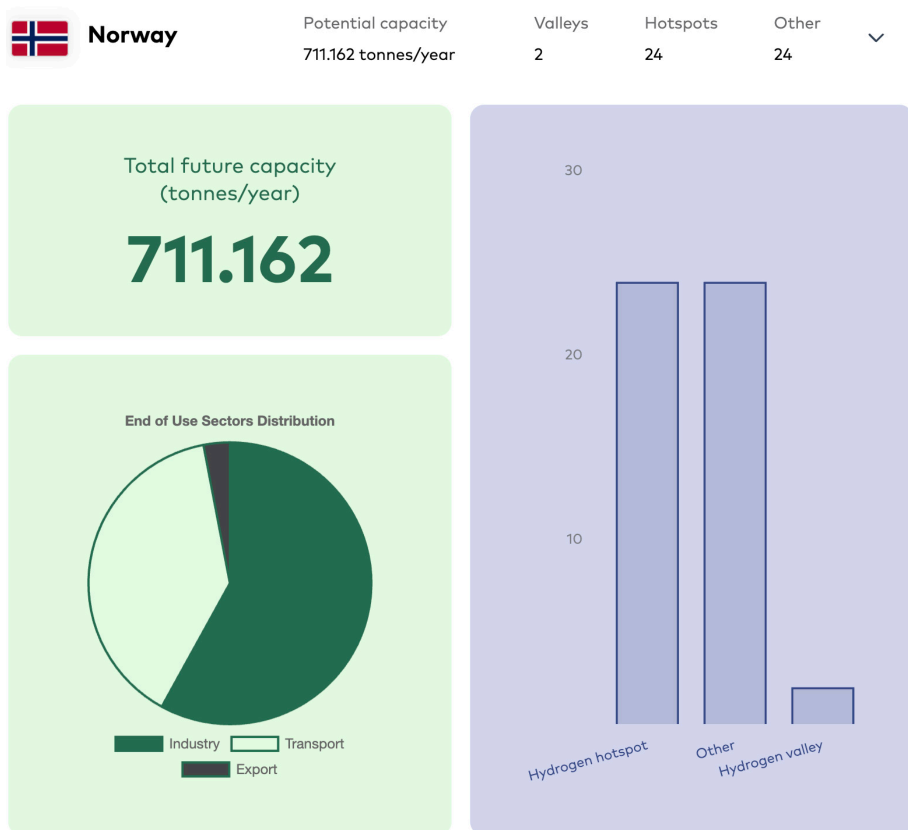

Figure 9. Overview of mapping for Norway (illustration from nordich2valleys.org).

Planned hydrogen valleys where investment decisions have been made:

Glomfjord Green Ammonia

In this project, Neptun Glomfjord Green Ammonia AS plans to build a 20 MW electrolysis plant with additional ammonia production, which will produce green ammonia for both maritime and industrial use from 2027. Hydropower will be the plant's main source of energy, and production will be located at the Glomfjord Industrial Park in Northern Norway. The project initially received funding from Enova in 2022, and the investment decision for the project was made on 31 January 2024.[75]

Hydrogen Hub Agder

This project is run by Greenstat ASA, which plans to build a 20 MW electrolyser (with an option for an additional 40 MW) in Kristiansand. The produced hydrogen will be available for both industry and maritime transport. As with Glomfjord Green Ammonia, the project received funding from Enova in 2022, and the investment decision was made on 31 January 2024.[76]

75. https://www.oceanhywaycluster.no/news/greenstat-agder-hydroge-hub
76. https://www.oceanhywaycluster.no/news/greenstat-agder-hydroge-hub

Other important projects
In addition to the two projects above, there are several other projects that will become hydrogen valleys if realised. One of these is the Narvik Green Ammonia[77] project where up to 600 MW of installed capacity is planned. This project envisions off-takers in the maritime marked, but this is still uncertain. Another interesting project is Fuella's plans for Ammonia production at Skipavika close to Bergen,[78] which was awarded close to NOK 1 billion from the European Hydrogen Bank this year. They plan to install 130 MW of capacity and are expected to make an investment decision later this year.

In addition to the individual planned projects that qualify as hydrogen valleys, there are some geographical areas that can be singled out as promising hotspots for hydrogen production. Torghatten Nord and green hydrogen producer GreenH have formalised a 15-year hydrogen supply agreement for the Lofoten ferries. A production plant with a capacity of 6–10 tonnes per year is planned, and a final investment decision is expected by the end of 2025. Herøya is one of these areas, where Yara already has launched a 24 MW electrolyser for their fertiliser production,[79] with plans to expand capacity to 450 MW if conditions are favourable.[80]

Another interesting area is the Varanger Peninsula in Finmark. Several stakeholders are looking to produce hydrogen and ammonia, mainly for the maritime transport sector.

A third area is the county of Nordland, where multiple stakeholders in various locations (Narvik, Glomfjord, Bodø, Mosjøen, Mo i Rana etc.) are looking to produce hydrogen and ammonia both for industry and for the transport sector (approx. 75 000 tonnes of hydrogen a year).

In the southernmost part of Norway (Rogaland and Agder), there are also a significant number of hydrogen production projects that could be seen as one large hydrogen valley with an estimated production capacity as high as 150 000 tonnes per year.

77. https://www.narvikgreenammonia.com/
78. https://www.narvikgreenammonia.com/
79. https://www.yara.com/corporate-releases/yara-opens-renewable-hydrogen-plant-a-major-milestone/
80. https://www.nrk.no/vestfoldogtelemark/full-elektrifisering-pa-yara-i-porsgrunn-lagt-pa-vent-1.16967726

3.2.7 Sweden

Most of the hydrogen production projects in Sweden are in the early stages, either undergoing feasibility studies, working through a permitting process or awaiting investment decisions. The large-scale projects are largely tied to industrial plants involved in steel production, electrofuels production or fertiliser production. While existing hydrogen production primarily relies on steam methane reforming of natural gas, upcoming projects feature two Nordic hydrogen hotspots focused on producing hydrogen through the gasification of biomass/waste, with the remaining projects centred around hydrogen production via electrolysers.

For projects that disclose the origin of their electricity, wind power and hydropower are the main contributors. This also has a major influence on the location of the hydrogen hotspots/valleys. Very few of the projects have so far communicated their plans for hydrogen storage.

The hydrogen valley criterion that most projects fail to meet is the requirement for "multiple end-use sectors". Other factors that justify exclusion include a non-specific geographical location of the project, production capacity below 500 tonnes per year or insufficient project information.

The technology used for electrolysis is a mix between alkaline electrolysers and proton exchange membranes (PEM), with some existing projects including chlor-alkali electrolysers. While most large-scale projects have not yet disclosed their choice of technology, those that have done so have chosen alkaline technology.

Of listed Nordic hydrogen valleys and hydrogen hotspots in Sweden, only a few projects have thus far outlined their planned use for excess heat and oxygen from the electrolysers. One example of a project utilising both excess heat and oxygen is Ovako, which employs the excess oxygen in steel furnaces and uses the excess heat to warm its own premises and supply district heating.

Several of the projects are planning to produce hydrogen or e-fuels for use in the shipping sector, which aligns with Task 3 of the mapping project. Most notable are the Flagship projects, the SouthH2Port project and the project in Ljusne-Vallvik involving European Energy & Svea Vind Offshore.

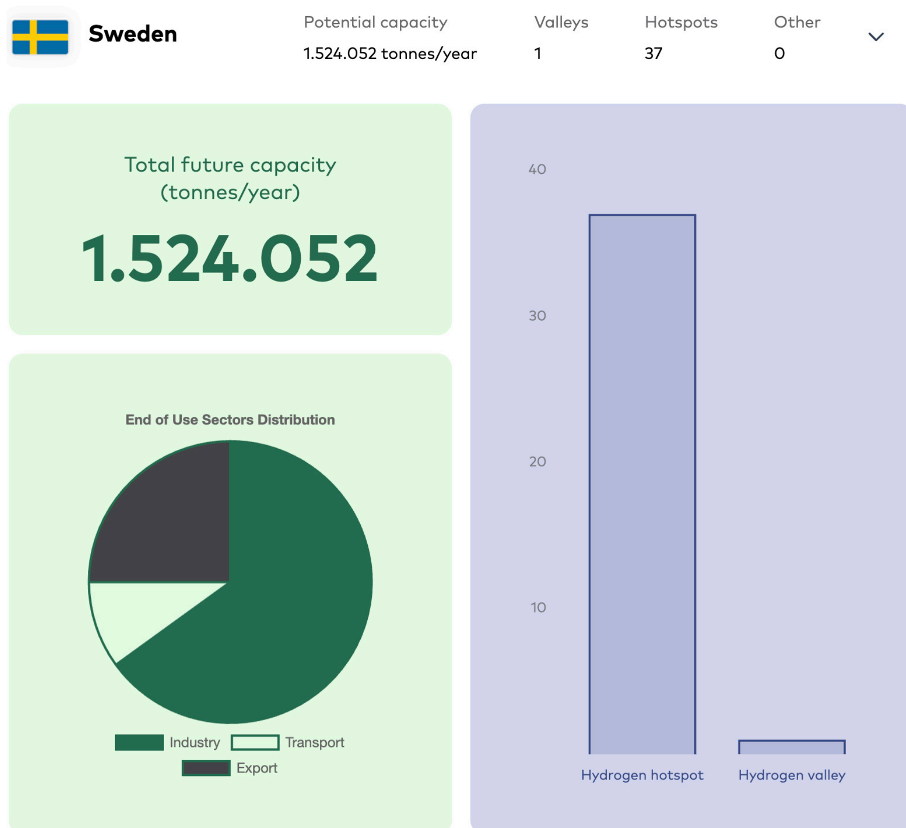

Figure 10. Overview of mapping for Sweden (illustration from nordich2valleys.org).

Hydrogen Valleys:

BotnialänkenH2 with possible upscaling

This project, led by Uniper in collaboration with the Port of Luleå Hamn, ABB, Luleå Energi and ESL Shipping (the project's first customer), aims to establish a hydrogen hub in Luleå that utilises wind power to produce hydrogen through use of electrolysers. The hydrogen will have multiple possible off-takers, including the regional process industry (e.g. the steel industry), electrofuel production for the shipping sector and opportunities for export.[81] The initial capacity of the project will be 12 000 tonnes of hydrogen per year,[82] with a potential for upscaling to 60–65 000 tonnes of hydrogen per year.

The plan is to use the port of Luleå for intermediate storage and to integrate the excess heat from the electrolysers in the city of Luleå's district heating network. Provided that the project secures funding through the EU's Important Projects of Common European Interest (IPCEI) scheme, the plant is scheduled to be operational in 2027.

A selection of projects qualifying as **hydrogen hotspots** is given below:

81. https://www.uniper.energy/sweden/about-uniper-sweden/hydrogen-sweden
82. https://www.uniper.energy/media/2179/download?inline

HYBRIT (Hydrogen Breakthrough Ironmaking Technology)
This is a collaborative project conducted as a joint venture between SSAB, LKAB and Vattenfall. Its goal is to produce fossil-free steel employing direct reduction of iron ore pellets to produce sponge iron, utilising hydrogen produced from electrolysers. A pilot plant with a capacity of 4.5 MW is already operational, featuring hydrogen storage in rock caverns in Luleå.[83] The demonstration plant in Gällivare is planned to be operational in 2027, with a capacity of 500 MW.[84]

H2 Green Steel
In Boden, H2 Green Steel is planning to build a large-scale green steel plant with a capacity of 800 MW, using the same technology as the HYBRIT project. The ambition is to start production in 2025, with full-scale production by 2030.[85]

Hofors rolling project
In 2023, a 20 MW electrolyser was installed at Ovako's industrial site for steel production in Hofors, where the hydrogen is used to reheat steel (replacing LPG as the energy source). The investment was made in partnership with Volvo Group, Hitachi Energy, H2 Green Steel and Nel Hydrogen.[86]

FlagshipONE
Located in Örnsköldsvik, FlagshipONE, plans to be operational in 2025, with a targeted production of 50 000 tonnes of e-methanol per year, utilising green hydrogen and biogenic CO_2 captured from a neighbouring combined heat and power (CHP) plant. The project is a collaboration between Liquid Wind and Ørsted. Liquid Wind is also involved in two other Flagship projects in Sweden (Umeå and Sundsvall).[87]

Power2Earth
Power2Earth is a collaboration among Fertiberia, Nordion Energi and Lantmännen aimed at producing mineral fertiliser in Jokkmokk using a 640 MW electrolyser, with a planned production start in 2028.[88] The hydrogen will be produced next to a hydropower plant in Letsi and transported to the fertiliser production site by pipeline.

83. https://group.vattenfall.com/press-and-media/pressreleases/2019/hybrit-orders-norwegain-electrolyzers-for-fossil-free-steel-production-in-lulea
84. https://lkab.com/press/hybrit-far-stod-fran-eus-innovationsfond/
85. https://www.h2greensteel.com/articles/on-course-for-large-scale-production-from-2025
86. https://www.ovako.com/en/about-ovako/our-hydrogen-plant/
87. https://www.siemens-energy.com/global/en/home/press-releases/blueprint-commercial-e-fuel-production-being-built-siemens-energy-technology.html
88. https://www.nyteknik.se/energi/stor-kartlaggning-hoppet-bubblar-for-vatgasskiftet-men-inte-elektrolysorerna/4256181

3.2.8 Åland Islands

The Åland Islands present an interesting opportunity from a hydrogen perspective, due to the substantial potential for large-scale offshore wind power. More than 10 GW of offshore wind power capacity is currently under development, with 8 GW in the environmental impact assessment process.[89] Furthermore, the Baltic Sea Hydrogen Collector project aims to establish offshore hydrogen pipeline transmission infrastructure connecting Finland and Sweden to Germany, via the Åland Islands and other potential energy islands in the Baltic Sea by 2030.[90] This initiative seeks to harness the potential of offshore wind power in the Baltic Sea and facilitate hydrogen transmission and export. Project partners include Gasgrid Finland and Nordion Energi, as well as the industrial companies OX2 and Copenhagen Infrastructure Partners.

While no projects in the Åland Islands qualified as hydrogen valleys, a few projects that qualify as **hydrogen hotspots**. As the large-scale projects advance in project maturity, they have the potential to fulfil the criteria for a hydrogen valley.

Mega Grön Hamn
The Mega Grön Hamn project, led by OX2 and the Bank of Åland, aims to establish a hydrogen hub featuring an electrolyser capacity of 3 000 MW.[91] The produced hydrogen will be utilised for on-site e-fuel production for the shipping industry, future local archipelago transport services, industrial processes in Åland and export via the Baltic Sea Hydrogen Collector. In terms of sector integration, the by-product heat from electrolysis will be utilised in various local manufacturing activities, while the generated oxygen will contribute to water oxygenation. As the project advances, it has the potential to evolve into a hydrogen valley.

Åland Energy Island
Flexens, Lhyfe and Copenhagen Infrastructure Partners (CIP) have joined forces to develop and build a large-scale hydrogen production facility in the Åland Islands alongside gigawatt-scale offshore wind power production.[92] While the specific end-use sectors for hydrogen have not been detailed, the goal is to integrate hydrogen into Åland's energy system and export it both to the Baltic Sea region and to Europe. This approach is anticipated to encompass a variety of sectors for hydrogen utilisation. The specific design of the Åland Energy Island project will be developed in close collaboration with local government and other stakeholders.

Energy Parks Möckelö and Hellesby
OX2 Åland plans to establish two energy parks in Åland.[93] The first, located at Möckelö in Jomala, will feature a solar park, a 3 MW electrolyser, a hydrogen refuelling station and a large-scale battery storage facility. The hydrogen refuelling station is designed to supply hydrogen to passenger cars and heavy-duty vehicles, with plans to expand its applications in the future. The battery storage system will serve a dual purpose by facilitating electric vehicle charging and supporting grid balancing efforts.

89. Finnish Wind Power Association, 2024, "Wind power map" https://tuulivoimayhdistys.fi/en/wind-power-in-finland/map
90. Baltic Sea Hydrogen Collector, 2024. "Baltic Sea Hydrogen Collector – Unlocking the hydrogen potential in the Baltic Sea" https://balticseahydrogencollector.com/about-the-project/
91. Ålandsbanken, 2023. "OX2 and the Bank of Åland plan a Mega Green Port project in Åland" https://www.alandsbanken.com/news/ox2-and-the-bank-of-aland-plan-mega-green-ort-project-in-aland
92. Flexens, 2023. "New partnership to develop large-scale integrated renewable energy system on Åland" https://flexens.com/new-partnership-to-develop-large-scale-integrated-renewable-energy-system-on-aland/
93. OX2, 2024, "Energy Park Åland" https://www.ox2.com/sv/aland/projekt/energypark-aland/

In addition to Möckelö, OX2 Åland is developing another energy park in Hellesby, Hammarland. This facility will include a solar park, battery storage and hydrogen production facilities primarily intended for industrial processes. Specific details on the electrolyser capacity have not yet been disclosed. Construction for both energy parks is scheduled to begin in 2025. Both sites aim to effectively utilise oxygen and by-product heat.

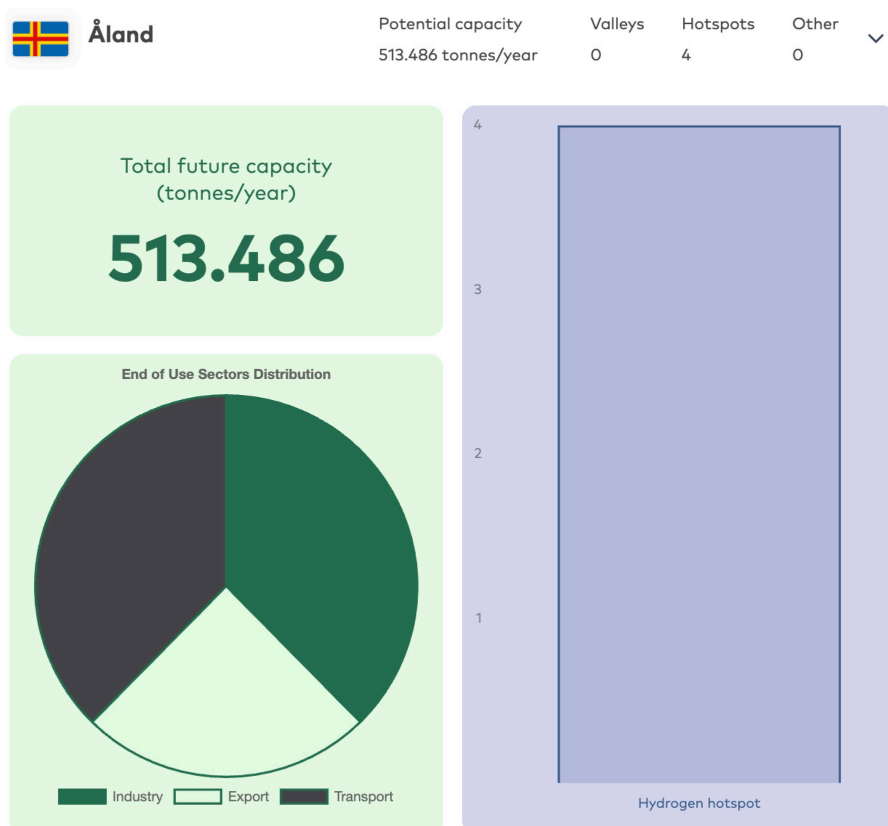

Figure 11. Overview of mapping for Åland Islands (illustration from nordich2valleys.org).

3.3 Projects relevant to the decarbonisation of Arctic shipping

This section highlights mapped projects that are relevant to the decarbonisation of Arctic shipping, i.e. projects in the Arctic region that produce hydrogen or other electrofuels. The future role of clean hydrogen in Arctic shipping is discussed in Chapter 5 of this report.

3.3.1 Faroe Islands

Only one project with planned hydrogen production capacity was identified in the Faroe Islands. According to Bakkafrost's 2023 annual report, some of the produced hydrogen may be used for the company's larger vessels in the region, which will contribute to the decarbonisation of Arctic shipping.

3.3.2 Greenland

All developments and projects described for Greenland above have the potential to contribute to the decarbonisation of Arctic shipping. In particular, H2Carrier's P2XFloater project aims to produce large quantities of e-ammonia, which is a possible future fuel for maritime applications.

3.3.3 Iceland

Iceland has abundant renewable energy resources, making it an ideal location for the production of hydrogen and e-fuels. Hydrogen and e-fuels are expected to help to decarbonise various sectors in Iceland, including the maritime and road transport sectors. The Hydrogen and E-fuels Roadmap for Iceland lists several early-stage hydrogen projects,[94] many of which are linked to the maritime sector due to Iceland's significant maritime activities. One example is a project planned by Green Fuel and Topsoe, which aims to produce green ammonia in Iceland. The plant is planned for the Bakki Eco-Industrial Park, near Húsavík in northeast Iceland, and is expected to produce around 300 tonnes of ammonia daily with a 100 MW electrolyser for export and domestic maritime purposes.

3.3.4 Northern Norway

There are currently 10–15 projects with plans for large-scale hydrogen, ammonia and methanol production from water electrolysis in Northern Norway, in addition to one (Barents blue) that is focused on hydrogen from steam methane reforming and CCS. If all of them are realised, hydrogen production in this area will be close to 600 000 tpa, of which most will be used for ammonia production.

Energy costs are generally lower in the northern parts of Norway due to the segmentation of the Norwegian energy marked and greater availability of power compared with southern Norway. Although the hydrogen projects in Northern Norway are spread across Finnmark, Troms and Nordland, there are some areas with a higher density of projects. In

94. https://www.government.is/library/Files/240102_URN_RoadmapForIceland_V6.pdf

many cases, this is linked to the availability of energy for hydrogen production. In Finnmark, the Varanger Peninsula is home to several of the planned projects that intend to use wind power to produce hydrogen and ammonia. Green Ammonia Berlevåg is one of these projects, with a plan to produce 100 000 tpa of hydrogen for ammonia production. H2Carrier's P2XFloater is set to be used for ammonia production in multiple locations on or close to the Varanger Peninsula. Another important project in Finmark is Barents Blue, where the long-term plan is to reform natural gas from the Melkøya LNG plant to produce as much as 1 000 000 tonnes of ammonia per year from blue hydrogen.

Another prominent hydrogen hotspot in Northern Norway is the county of Nordland, where several projects aim to produce a total of 75 000 tonnes of hydrogen per year.

Photo: iStock

4. A digital mapping tool for hydrogen valleys in the Nordics

The digital mapping tool is a web-based platform designed to showcase the findings and data collected throughout the project. The objective was to develop a prototype that serves as the initial step towards creating a more sophisticated and refined platform in the future.

4.1 Scope and method

4.1.1 The user experience (UX)

To create a foundation for the design and ensure that the tool functions effectively, we must first understand the needs and preferences of the end-users. A common process for UX design work is the Double Diamond, which is a structured design approach developed by the British Design Council, consisting of four phases: Understand, Define, Develop and Deliver. It emphasises divergent thinking to explore multiple possibilities in the Understand and Develop phases, and convergent thinking to narrow down and refine ideas in the Define and Deliver phases, ultimately leading to well-crafted solutions.

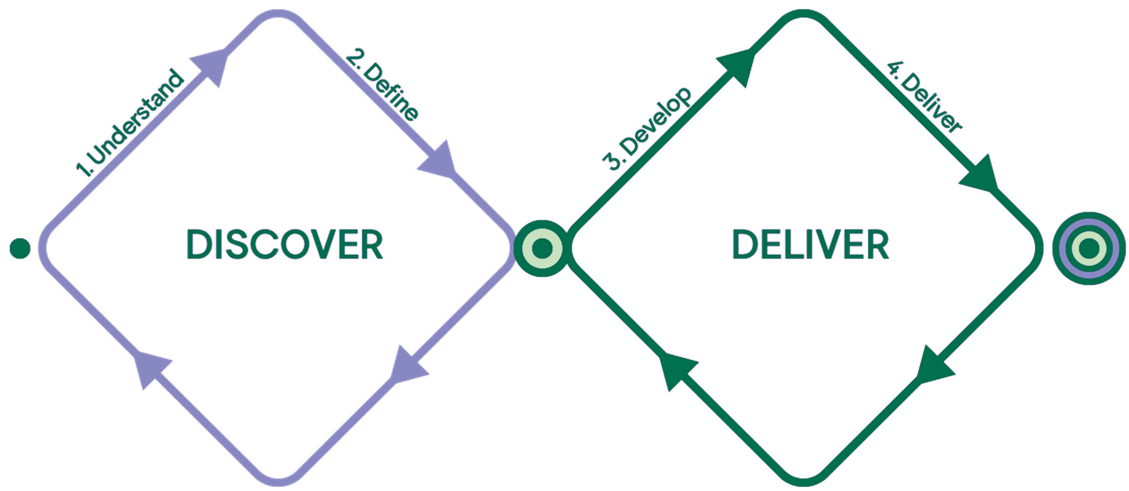

Figure 12. The design process "Double Diamond".

As a part of the Discover process a benchmarking study was conducted to map existing tools and information sources that communicate hydrogen projects and initiatives on a global or local level.

The following sources were examined.

Online tools

- live.stateofgreen.com/green-together/#/challenges
- live.stateofgreen.com/green-together/#/denmark
- ek.fi/en/green-investments-in-finland
- thehydrogenmap.com
- hydrogeninsight.com/innovation
- h2v.eu/hydrogen-valleys
- iea.org/data-and-statistics/data-tools
- ltu.instante.se
- h2.live

Information and statistics

- hydrogen.no/faktabank
- renewables.digital
- hydrogencouncil.com
- clean-hydrogen.europa.eu
- cris.vtt.fi
- hydrogeneurope.eu
- Handlingsplan – Regional samverkan kring vätgas

4.1.2 Design principles

Based on market research and input from a workshop with participants from across the Nordic region, a set of design principles for the tool was developed. These principles were used to provide direction for the design work in the Deliver phase.

The design principles were:

- **A Nordic perspective.** The tool is distinguished by focusing on hydrogen development within the Nordic region, and the aim is to clearly represent and maintain this perspective throughout the platform, highlighting the unique context and contributions of the Nordics.
- **Let the information shine.** By distributing information across separate pages, we enhance search engine optimisation and create multiple entry points to the site. This approach not only optimises visibility but also allows users to navigate the content more efficiently.
- **Show what we know.** It is crucial to have a pragmatic approach to presenting the data generated throughout the project.

4.1.3 Tool structure

The aim was to develop a structured and flexible tool that shows information from the hydrogen valley database in a compelling manner. By distributing information across separate pages, we highlight different perspectives without overwhelming users. This approach allowed us to craft unique content for each view, facilitating easier content sharing and enhancing the user experience. Additionally, this structure improves the site's search engine optimisation (SEO) because each page has a unique URL, enabling users to access the tool from various entry points, depending on their search criteria.

The tool is organised into the following page types:

- **Landing page/Homepage**: The main entry point, which provides an overview and guides users deeper into the site.
- **Map page**: Visual representations of data with geographic contexts.
- **List page**: Tabular data for easy filtering and data overview.
- **Statistics page**: Aggregated data and analytics.
- **Regional pages**: Focused content that pertains to specific regions.
- **Information pages:** Detailed information on various topics such as data definitions, about the project, privacy policy etc.

4.1.4 Data architecture

The data architecture plays a vital role in organising and presenting information effectively within the application. To fully understand the information available, the data in the hydrogen valley database (Excel) was broken down and divided into two categories:

- **Descriptive data**: Project name, links, description etc. These data points provide context for the hydrogen valley/hotspot.
- **Segmentation data**: These data points represent a finite range or set of possible values and are typically used in queries to segment data. Examples of segmentation data include production capacity, year of completion, country etc.

Based on this, data prioritisation for the UI was discussed with project partners and the steering committee.

4.1.5 User interface (UI) design

The focus of UI design activity was on creating a comprehensive and user-friendly interface, informed by insights obtained during the UX research. To verify the concept prior to developing the software, the UI was presented as an interactive prototype.

4.1.6 System setup

This activity focused on exploring the technical frameworks and infrastructure necessary to support the tool. The technical planning involved defining necessary functionality and data storage requirements, as well as evaluating existing technical systems and resources that could impact the new setup.

In general terms, the system includes of the following primary components:

- **A web server**: Acts as the gateway for handling requests and responses between the user and the server.
- **A frontend application**: This is the user interface through which end-users interact with the tool.
- **A database**: Serves as the central repository for storing all the data the tool needs to function efficiently.
- **A backend application**: This component manages data provisioning for the frontend by handling database connections and data processing.

4.2 The prototype tool

The final concept was designed iteratively by looking at the available data and the defined information structure and finding a visual style coherent with the communication guidelines provided by Nordic Energy Research. Development of the actual tool was accelerated as soon as the concept was finalised. The development process itself was also carried out in iterations, and during this process, adjustments were made to translate the concept into the implemented product. The tool presents the database content via several different visualisation views (or pages), briefly described below.

4.2.1 Landing page

- Provides a brief introduction to the purpose and content of the tool.
- Summarises data points for the entire Nordic region.
- Summarises data for each country within the Nordic region.
- Promotes further exploration by providing links to prioritised sections (map) of the tool.

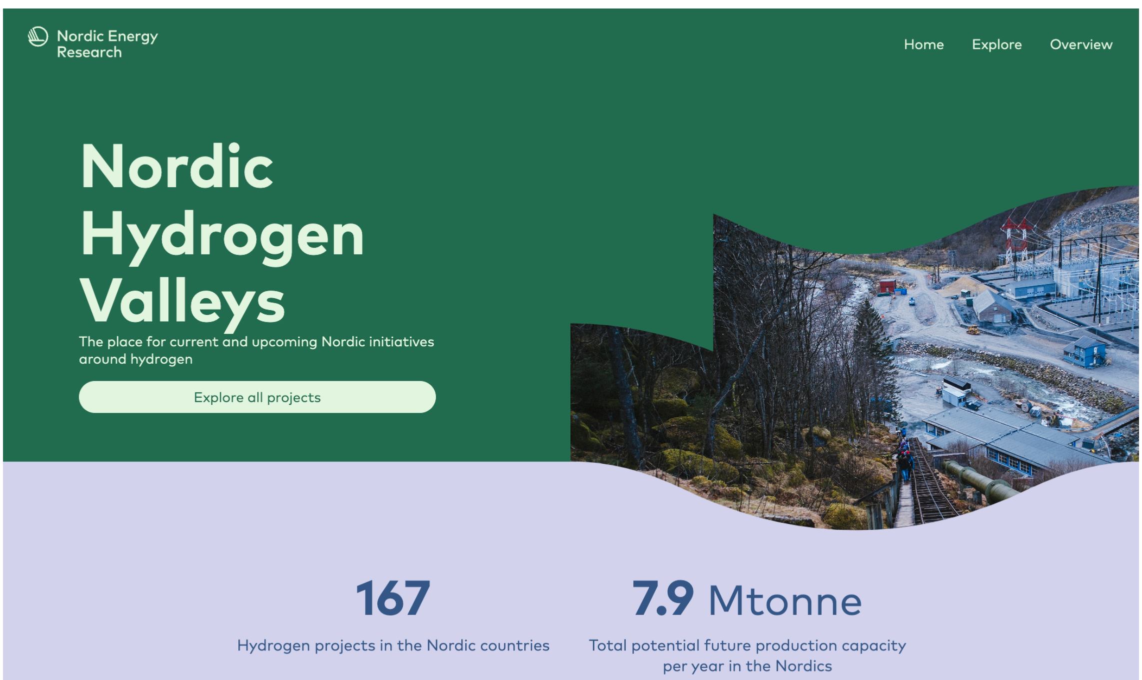

Figure 13. The landing page (illustration from nordich2valleys.org).

4.2.2 Explore page

- Map view that provides a geospatial overview of each project and type (hotspot or valley).
- Easily view each project by clicking on the markers on the map.
- Data filters for viewing the data from different perspectives.
- Table view for exploring the projects from a data perspective.

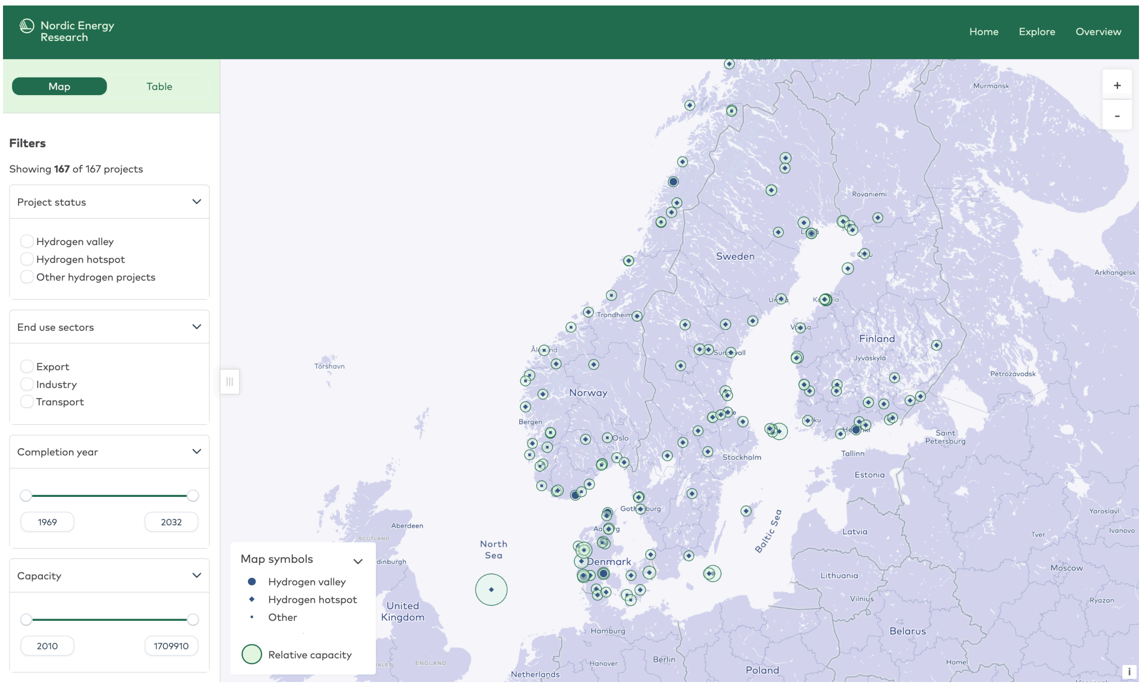

Figure 14. The explore page, in map view (illustration from nordich2valleys.org).

4.2.3 Overview page

- Focuses on the Nordics from an aggregated perspective, as well as from the perspective of each country.

For examples from the overview page, see Figures 4-11.

4.2.4 Project page

- Presents the available data for each project in a clear and visually appealing manner. The data presented here mirrors the content that is displayed when clicking on a project marker in the map on the explore page.

Figure 15. Example of the information provided on a project page (illustration from nordich2valleys.org).

4.2.5 Content pages

- Content pages are a flexible format for displaying information. Pages can consist of data definitions, project descriptions, contact information etc.

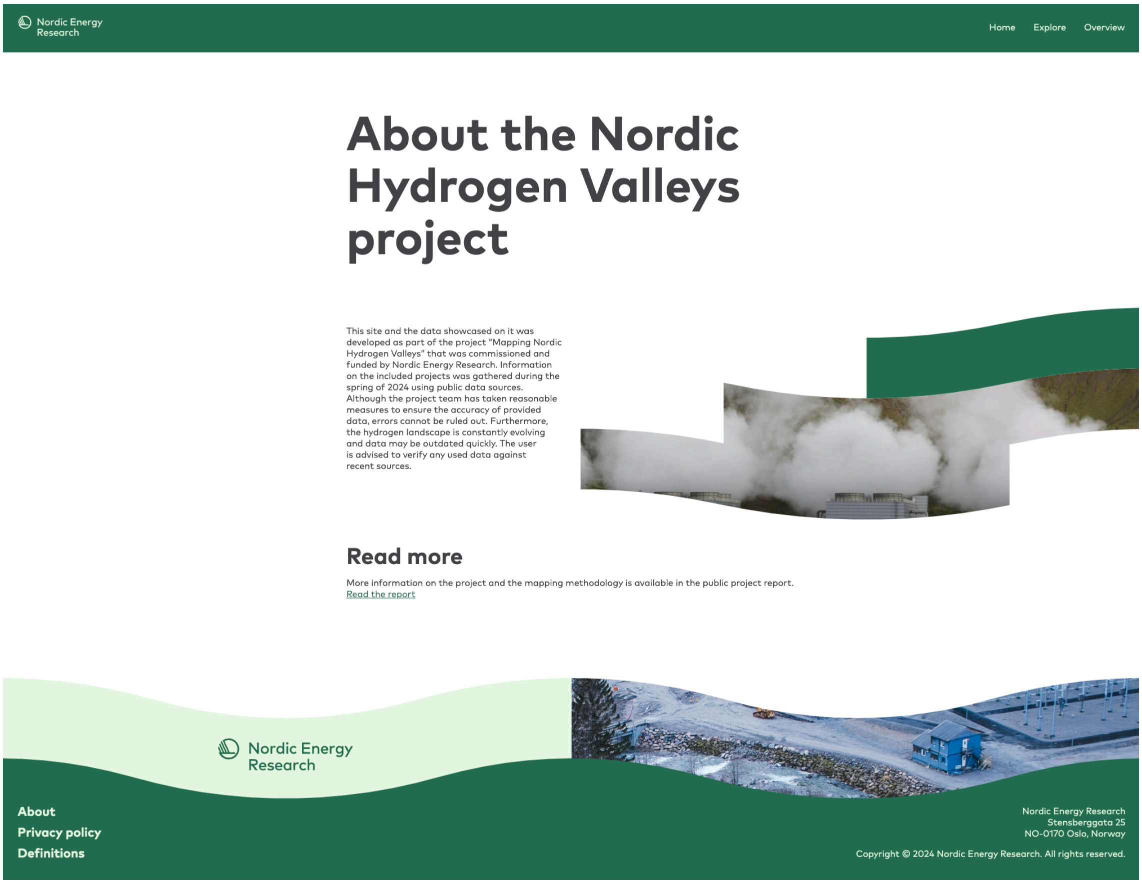

Figure 16. The content page "About" (illustration from nordich2valleys.org).

4.3 Future tool development

The digital tool, as a publicly available interactive web application, allows users to view and analyse data gathered during the mapping process. It is thus essential for the mapping to indicate any true added value for Nordic stakeholders. However, the tool is currently only a prototype and will require further development to be fully quality assured and become a more comprehensive tool.

The development process moving forward may include the following steps:

- Investigate and implement new ways of aggregating relevant data based on the data collected during the project.
- Test the tool with relevant stakeholders, gather their feedback and make adjustments based on insights.
- Establish procedures and responsibilities for updating and curating data. Train content editors and adjust the backend user interface to facilitate administration.
- Further develop the country-specific perspective, with each country represented by a country-specific page (may also be at the region level).
- Implement aspects of the application that were not implemented in the prototype due to time constraints. Such as country-specific pages, advanced visualisations and an enhanced mobile experience.

In addition, it will be necessary to update and maintain both the database and the tool on a regular basis to stay relevant over time. Development and investment plans are constantly evolving, and without regular updates from stakeholders, the data will quickly become outdated.

Photo: iStock

5. Hydrogen in Arctic maritime transport

5.1 Scope and method

Drawing on available literature and insights from relevant projects, this section discusses the potential role of hydrogen and hydrogen-based fuels in the foreseeable future (2030+) for maritime transport in the Arctic regions of the Nordic countries.

In this project, based on the input from Nordic Energy Research, the definition of Arctic is as follows: Greenland, Iceland, the Faroe Islands and Northern Norway. This definition may differ from other definitions of Arctic, such as the employed by the Polar Code.[95] As a result, the literature reviewed below may refer to a different geographic region when defining the Arctic.

5.2 Shipping in the Arctic

Arctic marine operations and shipping have gradually increased due to e.g. technological advancements and receding sea ice. Trans-Arctic routes have become a reality, and the Northern Sea Route, which connects Europe to Asia, is now frequently used during the open water season. Additionally, the Northwest Passage through the Canadian Arctic Archipelago has become increasingly open. As a result, Trans-Polar routes connecting Europe to Asia are projected to become viable shipping corridors in the coming decades. These routes are shorter than conventional routes through major canals. For instance, Arctic shipping routes could shorten the distance between Rotterdam and Yokohama from 11 200 nautical miles via the Suez Canal to 6 500 nautical miles. Receding sea ice will also increase accessibility to resources, such as hydrocarbon deposits and precious minerals, in both terrestrial and marine areas of the Arctic.[96]

The number of vessels navigating the Arctic increased by 37% between 2013 and 2023. In 2023, 41% of vessels entering the Arctic Polar Code area were fishing vessels. The sailed

95. International Maritime Organization (2016) Polar Code – International Code for ships operating in polar waters
96. Lin Y., Babb D. G. And NG A.K.Y. (2021) International Encyclopedia of Transportation, https://doi.org/10.1016/B978-0-08-102671-7.10268-4

distance in the Arctic Polar Code area increased by 111% in the same period. Fishing vessels were not only dominant in terms of unique ships but also when focusing on sailed distance, representing 34% of the total sailed distance in 2023. The distance sailed by bulk carriers in this area rose by 205% between 2013 and 2019 due to e.g. mining activities. Additionally, all other vessel types have also seen a rise in activity.[97] The number of shipping days per month through the Arctic Ocean increased by 7% per year between 2013 and 2022.[98]

Rodríguez et. al (2024)[99] analysed shipping traffic in the Arctic Ocean from January 2020 to April 2022 using the Automatic Identification System (AIS). Fishing vessels experienced the highest shipping traffic followed by passenger, cargo and tanker vessels. Fishing vessels showed high activity in the Barents Sea (off the northern coasts of Norway and Russia) and around Iceland. Cargo and tanker vessels operated in the Norther Sea Route and the Northwest Passage. Cargo vessels used a wider area in Baffin Bay (between Baffin Island and the west coast of Greenland), while tankers occupied less area. Passenger ships occupied smaller areas since the most frequently travelled routes were shorter, such as those along the Norwegian and Icelandic coasts.[100]

Based on AIS modelling,[101] fishing vessels, oil tankers, general cargo vessels and other service vessels accounted for approximately 80% of fuel consumption in the Arctic Polar Code area in 2017. Vessels above 10 000 gross tonnage accounted for nearly 50% of total fuel consumption. Heavy fuel oil (HFO) and distillate fuels accounted for 58% and 36% of consumption, respectively. Nuclear ships contributed to 6% of fuel consumption in oil equivalents and liquefied natural gas (LNG) represented less than 0.1%. The analysis showed a 45% increase in fuel consumption during 2014–2017.

While receding ice cover has raised interest in Arctic Sea routes, sea ice remains a threat and an obstacle to operating in the area. Vessels can either avoid ice by operating exclusively during the seasonal open water periods in specific regions, or they must be appropriately ice-strengthened. Open water periods may be too short, and variability in the ice cover may not consistently guarantee ice-free conditions along certain routes. As a result, vessels operating in this area typically have ice-strengthening or ice-breaking features.[102] While the Arctic routes may cut travel time and save on canal fees, fuel costs and freight fees, their lack of accessibility and reliability may increase insurance costs. High ice-breaking fees, restrictive speed limits and investments in specialised vessels with ice-strengthening or ice-breaking features may also impose additional costs.[103]

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97. PAME (2024) The increase in Arctic shipping 2013-2023. Arctic shipping status report (ASSR) #1 March 2020 updated in January 2024.
98. Müller M., Knol-Kauffman M., Jeuring J. and Palerme C. (2023). Arctic shipping trends during hazardous weather and sea-ice conditions and the Polar Code's effectiveness. npj Ocean Sustain. 2, 12. 10.1038/s44183-023-00016-3.
99. Rodríguez J. P, Klemm K., Duarte C. M. and Eguíluz V. M. (2024) Shipping traffic through the Arctic Ocean: spatial distribution, seasonal variation and its dependence on the sea ice extent, ISCIENCE, doi: https://doi.org/10.1016/j.isci.2024.110236
100. Rodríguez J. P, Klemm K., Duarte C. M. and Eguíluz V. M. (2024) Shipping traffic through the Arctic Ocean: spatial distribution, seasonal variation and its dependence on the sea ice extent, ISCIENCE, doi: https://doi.org/10.1016/j.isci.2024.110236
101. DNV (2019) Alternative fuels in the Arctic, report No. 2019-0226, Rev. 0
102. Lin Y., Babb D. G. And NG A.K.Y. (2021) International Encyclopedia of Transportation, https://doi.org/10.1016/B978-0-08-102671-7.10268-4
103. Lin Y., Babb D. G. And NG A.K.Y. (2021) International Encyclopedia of Transportation, https://doi.org/10.1016/B978-0-08-102671-7.10268-4

Another concern is the weather along the shipping routes. In a changing climate, the Arctic is expected to experience an increase in storms, particularly during the summer months when most vessels are active. This could make shipping operations more hazardous. Wavier conditions can significantly impact and erode coastal infrastructure, which is often limited in presence and capacity.[104]

5.3 Environmental and socioeconomic aspects of shipping in the Arctic

In 2023, the Marine Environment Protection Committee (MEPC) adopted the revised International maritime organisation (IMO) Greenhouse Gas (GHG) Strategy. The IMO GHG Strategy has an ambition to reach net-zero GHG emissions from international shipping close to 2050, a commitment to an uptake of alternative zero and near-zero GHG fuels by 2030, as well as checkpoints for reaching the net-zero GHG ambition.[105]

Following submissions by Norway and Canada, MEPC has recently approved proposals for two new emission control areas (ECAs) in the countries' Arctic waters. The new regulation will likely be adopted in October 2024 and could enter into force as early as 2026. The aim is to reduce sulphur oxide emissions, particulate matter and nitrogen oxides from shipping by imposing stricter regulations in these areas. The proposed Norwegian ECA comprises the waters of Norway's Exclusive Economic Zone to the north of 62 degrees, extending all around the country's coastline to the maritime border with Russia in the Barents Sea. In Norway, waters south of 62 degrees North are already part of an ECA.[106]

Potential spills of HFO and black carbon emissions are of concern in the Arctic. If spilled, HFO would be challenging to recover, potentially causing significant harm to the marine environment. In addition, the combustion of HFO leads to emissions of black carbon, which is a short-lived climate pollutant that contributes to global warming, with amplified effect when emitted in the Arctic.[107]

Since 1 July 2024, there has been a ban on the use and carriage of HFO in Arctic waters as defined in the International Convention for the Prevention of Pollution from Ships (MARPOL). Full implementation of this ban is limited due to waivers and exemptions that allow continued use and carriage of HFO until 1 July 2029. MEPC adopted a resolution urging voluntary adoption of cleaner alternative fuels when navigating in or near the Arctic, largely due to the effects of black carbon.[108]

While the negative local environmental impacts of shipping in the Arctic are acknowledged, it is important to emphasise the potential advantages for local communities. Northern communities could benefit from shipping activities, which facilitate the movement of cargo and residents. Shipping could also expand employment

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104. Lin Y., Babb D. G. And NG A.K.Y. (2021) International Encyclopedia of Transportation, https://doi.org/10.1016/B978-0-08-102671-7.10268-4
105. IMO's work to cut GHG emissions from ships; https://www.imo.org/en/OurWork/Environment/Pages/2023-IMO-Strategy-on-Reduction-of-GHG-Emissions-from-Ships.aspx
106. Humpert M. (2024) https://www.highnorthnews.com/en/imo-approves-proposal-new-emission-control-areas-norwegian-and-canadian-arctic-waters High North News
107. Comer B., Olmer N., Mao X., Roy B. and Rutherford D. (2017) Prevalence of heavy fuel oil and black carbon in Arctic shipping, 2015 to 2025; The International Council of Clean Transportation (ICCT)
108. Carr E. W., Winebrake J. J., Elling, M (2024) LNG and shipping in the Arctic; Energy and environment research associates

opportunities and encourage settlement. Additionally, increased access for cruise ships could improve tourism.[109]

5.4 The potential role of hydrogen in Arctic maritime transport

5.4.1 Potential for adopting hydrogen as a marine fuel

In 2023, the European Maritime Safety Agency (EMSA)[110] examined the potential for adopting hydrogen as a marine fuel by studying hydrogen production capacity, the status of regulations, fuel storage options, supply and power generation technologies, techno-economic analyses and risk-based case studies. Although this study does not solely focus on the Arctic region, its approach and concluding remarks are relevant for vessels operating in the Arctic. Some of the findings are highlighted below:

- The global production of green hydrogen is less than 0.1 million tonnes annually. The global energy demand of international shipping is estimated to be equivalent to approximately 95 million tonnes of hydrogen per year. In 2017, 581 000 tonnes of oil equivalents were consumed in the Arctic Polar Code area,[111] which is equivalent to 193 667 tonnes of hydrogen.[112] Therefore, assuming there is no demand for green hydrogen from shipping elsewhere or from other sectors (e.g. road transport), global green hydrogen production would still fall short of the energy needs of vessels operating in the Arctic.
- While there are few costal vessels that currently use hydrogen, it is regarded as a promising fuel option for future short-sea shipping. Despite this, hydrogen storage is seen as an obstacle because compressed hydrogen has low storage density and liquid hydrogen requires specialised tanks. Liquid organic hydrogen carriers and ammonia appear to be more suitable for deep-sea shipping. However, further development is required for onboard installation for marine applications.
- For long-distance shipping, the total cost of ownership (TCO) for hydrogen-fuelled vessels remains a barrier. Case studies estimate that the TCO for green hydrogen will be approximately three times and 20–50% higher than conventional fuels in 2030 and 2050, respectively.[113] For blue hydrogen, the TCO in 2030 is approximately twice as high, though it may reach cost parity in 2050.[114]
- There is experience from other industries regarding the production, use and handling of hydrogen. However, regulations governing hydrogen as a marine fuel are still under development. In the meantime, established methods for approving H2-fuelled ship designs utilise a risk-based 'alternative design' approval process.
- Regarding risk and safety, the EMSA refers to major concerns about hydrogen as a marine fuel with respect to hydrogen flammability range, leakage and flame speed,

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109. Lin Y., Babb D. G. And NG A.K.Y. (2021) International Encyclopedia of Transportation, https://doi.org/10.1016/B978-0-08-102671-7.10268-4
110. European Maritime Safety Agency (2023), Potential of Hydrogen as Fuel for Shipping, EMSA, Lisbon
111. DNV (2019), Alternative fuels in the Arctic, report No. 2019-0226, Rev. 0
112. Own calculation using lower heating values of 120 and 42.8 MJ/kg for hydrogen and marine gas oil, respectively.
113. European Maritime Safety Agency (2023), *Potential of Hydrogen as Fuel for Shipping*, EMSA, Lisbon
114. European Maritime Safety Agency (2023), *Potential of Hydrogen as Fuel for Shipping*, EMSA, Lisbon

as well as detonation and deflagration issues. These require further detailed studies to better understand the risks and implement additional safeguards.

5.4.2 Sustainable zero-carbon fuels for shipping

In 2022 and as part of the Nordic Roadmap – Future Fuels for Shipping project,[115] sustainable zero-carbon fuels for shipping were screened.[116] The focus of the study was on Nordic shipping, which could cover parts of the Arctic. The study showed that hydrogen, ammonia and methanol stand out among other fuels on the pathway to the decarbonisation of Nordic shipping:

- Hydrogen has the potential for use in vessels operating on shorter, regular routes. In the short term, green hydrogen offers a highly scalable production opportunity, which has the potential to match the growing demand, even in smaller ports. Onshore production technology is relatively mature, with costs projected to be competitive compared with other low-carbon alternatives. However, the limited maturity of onboard technology and safety measures remains a barrier, affecting risk assessments and capital costs for shipowners.
- Ammonia has a higher volumetric energy than hydrogen, which makes it favourable for covering a large part of energy demand for Nordic shipping. However, converters have insufficient technical maturity. New ammonia engines are not particularly compatible with existing vessels, which necessitates major retrofits and/or new-builds, adding to capital costs. In addition, regulations on the use of ammonia as a marine fuel require further development. Since ammonia production is dependent on a supply of hydrogen, there is a need for coordination on the supply and demand of both fuels.
- Methanol is used as fuel for methanol tankers, which has so far limited the demand for bunkering facilities. Methanol has the potential to meet a significant portion of the energy demand for Nordic shipping. It is highly compatible with existing vessels, which reduces the cost of retrofits and new-builds. The development of commercially scalable renewable CO_2 production is essential to enable the production of green e-methanol.
- Although hydrogen, ammonia and methanol are considered the most promising options, methane, hydrotreated vegetable oil (HVO) and battery-electric systems will also play an important role in Nordic shipping.

5.4.3 Alternative fuels and technologies for potential use in Arctic vessels

In 2019, on behalf of Protection of the Arctic Marine Environment (PAME), DNV assessed alternative fuels and technologies for potential use in Arctic vessels.[117] The analysis covered hydrogen and hydrogen-based fuels, such as methanol and ammonia. To compare the alternatives, three criteria were considered: environmental, economic and scalability.

115. Nordic roadmap future fuels for shipping https://futurefuelsnordic.com/screening-and-selection-of-sustainable-zero-carbon-fuel/ (Accessed 28.06.2023)
116. Nygård Basso M., Abrahamoglu S., Foseid H., Spiewanowski P., Winje E. and Jakobsen E. (2022) Nordic roadmap for the introduction of sustainable zero-carbon fuels in shipping: Task 1A- Screening of sustainable zero-carbon fuels, Menon-publication No. 116/2022. Menon Economics.
117. DNV (2019), Alternative fuels in the Arctic, report No. 2019-0226, Rev. 0.

The environmental criterion covers air emissions and the risk of bunker spills. The economic criterion covers capital and operating costs. The scalability criterion covers (i) technical scalability (e.g. safety and maturity); (ii) applicability scalability (e.g. power and energy limits; compatibility with existing infrastructure); and (iii) availability scalability (e.g. available infrastructure and security of supply). The main results are as follows:

- While alternative fuels showed better environmental performance compared with traditional fuels, they generally scored worse on economic and scalability criteria.
- LNG with a battery-electric hybrid solution gave the best results for short- and deep-sea shipping. For short-sea shipping, biogas and battery-electric propulsion were the leading alternatives. For deep-sea shipping, biodiesel (HVO) and methanol were the top contenders. Applicability and scalability were the factors that mainly differentiated the scores for short-sea and deep-sea shipping.
- The adoption of all alternative fuels had some barriers. In the Arctic, these barriers are likely to be exacerbated due to the remoteness, as well as challenging ice and weather conditions. The main barriers are the costs associated with machinery, fuel prices, availability of bunkering infrastructure, long-term fuel availability, onboard fuel storage space and safety concerns.
- Finding volume-efficient ways for storing hydrogen onboard is a challenge. Regulations on the use of hydrogen and fuel cells onboard are under development. Fuel availability and the lack of bunkering facilities impose additional challenges.
- Methanol can be produced from various feedstocks, such as hydrogen, and it is available in certain ports, such as in Sweden. The life cycle emissions of methanol from renewable sources are considerably lower than methanol from natural gas. The environmental impacts of a potential methanol spill are expected to be much lower than an oil spill of the same magnitude. On the other hand, methanol is more expensive than distillate marine fuels and the fuel tanks are typically twice the volume of oil tanks for the equivalent energy content.
- Safety and regulatory challenges coupled with space/weight considerations related to storing large quantities of hydrogen have generated interest in ammonia as a hydrogen-based fuel. The volumetric energy density of ammonia is more than 50% greater than that of liquid hydrogen. This makes ammonia a viable option for transporting large amounts of energy over long distances from remote renewable sources. There are significant cost saving projections associated with storing hydrogen as ammonia. There is an existing infrastructure for the transport and handling of ammonia, since it is already utilised as fertiliser. However, the development of an infrastructure for its use as a fuel is a barrier. In addition, ammonia is highly toxic, which imposes a disadvantage.

5.4.4 Environmental impacts

In 2023, as part of the Nordic Roadmap Future Fuels for Shipping project,[118] the impact on the climate and environment of potential zero-carbon marine fuels was assessed using a life cycle assessment method.[119] The project studied potential fuels, such as hydrogen,

118. Nordic roadmap future fuels for shipping https://futurefuelsnordic.com/screening-and-selection-of-sustainable-zero-carbon-fuel/
119. Brynolf S., Hansson J., Kanchiralla F. M., Malmgren E., Fridell E., Stripple H., Nojpanya P. (2023) Life cycle assessment of marine fuels in the Nordic region- Task 1C (version 1.1), Nordic Roadmap Publication No.1-C/1.1/2023. Chalmers University of Technology.

ammonia and methanol, along with propulsion systems (e.g. engines and fuel cells). The study primarily examined greenhouse gas emissions, while also addressing other environmental impacts. Some of the findings are as follows (see report for more details and findings):

- Biomass-based methanol and battery electric options exhibit the lowest climate impact, followed closely by various green hydrogen alternatives and green ammonia in fuel cells.
- Battery electric systems have the lowest acidification potential, followed by biomass-based methanol in solid oxide fuel cells (SOFC), hydrogen in proton-exchange membrane fuel cells (PEMFC) and ammonia in SOFC.
- Biomass-based methanol in SOFC, compressed natural gas, battery electric systems and liquefied hydrogen in PEMFC produce the lowest levels of particulate matter, followed by natural gas-based ammonia in SOFC.
- Further studies are needed to better understand the climate impact of ammonia and hydrogen pathways in marine operations.

5.4.5 Infrastructure

Shipping in the Arctic requires reliable and resilient infrastructure for bunkering, navigational aids and rescue systems etc. Although some port construction projects are underway, ports and infrastructure along Arctic shipping routes are scarce and of low quality. In addition, there is a lack of professional know-how in building, maintaining and operating these facilities. Ports require major investments, which could further increase the costs of Arctic shipping. As mentioned, with a changing climate and increasingly wavier conditions expected, coastal infrastructure may also face heightened risks from coastal erosion.[120]

Energy security is a critical challenge in the Arctic. Low population density has led to scattered settlements, which are often remote and not connected by roads. This remoteness, combined with long distances between settlements, increases the complexity and cost of infrastructure projects from planning through to the maintenance stage. In temperate areas, electricity lines follow the roadways. In the absence of roads, many settlements use isolated islanded electricity grids, which makes them more vulnerable to disruptions. Most settlements use diesel as their primary energy source, and the transport of diesel using barges, ice roads or planes comes with considerable risk, uncertainty and cost.[121]

Wind and photovoltaic (PV) power offer huge potential in the region. Wind is a widespread energy source with a high potential in coastal areas. Wind energy projects are scalable to the required output, which is an advantage. There are numerous wind turbines installed in the Arctic, such as the Raggovidda wind farm in Finnmark, Norway.[122] Solar power contributes to less than 1% of the total electricity generated in the Arctic. The summer daylight in the Arctic makes PV an interesting energy source for some remote

120. Lin Y., Babb D. G. And NG A.K.Y. (2021) International Encyclopedia of Transportation, https://doi.org/10.1016/B978-0-08-102671-7.10268-4
121. de Witt M., Stefánsson H., Valfells Á, Larsen J. N. (2021) Energy resources and electricity generation in Arctic areas, Renewable Energy, Volume 169. 2021.01.025.
122. Varanger Kraft, https://www.varanger-kraft.no/lokal-kraft/vindkraft/raggovidda-vindkraftverk/

applications.[123] Both sources of energy are untapped in the Arctic and can be used to produce hydrogen, ammonia and methanol to fuel shipping and other local users. Section 3.3 provides an overview of relevant projects focusing on the use of hydrogen and hydrogen-based fuels for Arctic shipping.

123. de Witt M., Stefánsson H., Valfells Á, Larsen J. N. (2021) Energy resources and electricity generation in Arctic areas, Renewable Energy, Volume 169. 2021.01.025.

Photo: iStock

6. Drivers, barriers and policy for hydrogen valleys in the Nordics

The initial phase of this part of the study involved creating an overview of a wide range of drivers, barriers and policy suggestions for advancing hydrogen production and the development of hydrogen valleys in the Nordics. This work was based on a broad literature review, referencing sources such as von Dalwigk et al.,[124] Lara et al.,[125] Perner & Bothe,[126] the World Business Council for Sustainable Development,[127] the European Hydrogen Observatory[128] and the Fuel Cells and Hydrogen Observatory.[129] It also incorporated information from previous and ongoing hydrogen projects, as well as interviews conducted as part of this project.

These initial lists of drivers, barriers and policy suggestions were then used as a basis for discussions and inputs from workshop participants, in the stakeholder interviews and within the project team.

6.1 Drivers for the development of Nordic hydrogen valleys

6.1.1 Characterisation of potential drivers

The initial list of drivers was characterised and divided into eight areas, which are explained and elaborated on in more depth below. The areas are presented in order of overall perceived importance for the development of Nordic hydrogen valleys (see also next section).

124. on Dalwigk, I., Söderbom, J., Ghaem, S., Vätgas för flexibelt och robust energisystem: En vätgasöversikt för Sverige i ett internationellt perspektiv. 2021.
125. Lara A., Peters D., Fichter T. Guidehouse. The role of gas and gas infrastructure in Swedish decarbonisation pathways 2020-2045. REPORT 2021:788. ISBN 978-91-7673-788-0.
126. Penrer, J., Bothe, D. International aspects of Power-to-X roadmap: A report prepared for the World Energy Council Germany. October 2018.
127. World Business Council for Sustainable Development. Policy recommendations to accelerate hydrogen deployment for a 1.5°C scenario. 2021.
128. The European hydrogen market landscape. November 2023.
129. Fuel Cells and Hydrogen Observatory. Chapter 3. 2022 EU and National Policies Report.

Access to renewable energy production

While a key aspect for developing large-scale production and use of hydrogen is the access to large amounts of renewable electricity, access to other renewable energy value chains would favour development.

The Nordic countries already have vast renewable energy resources, particularly wind and hydroelectric power, which can be used to produce green hydrogen. Further, there is significant potential for expanding renewable electricity production, particularly with regard to onshore and offshore wind power. Several wind power projects are being planned in the Nordic countries, capitalising on the region's favourable wind conditions, especially along the coasts and offshore. Another factor is the absence of feed-in tariffs (e.g. in Sweden and Finland), and this is advantageous for power-to-X applications where hydrogen plays a significant role. At the same time, there is strong competition for renewable energy from various industrial sectors, which are expected to increase their electricity demand. This increasing demand could compete with the electricity required for hydrogen production.

In relation to electricity prices on a European level (or even global scale), Nordic spot prices are generally low, which is favourable for the conversion of electricity into hydrogen. Finally, the Nordic countries, especially Sweden and Finland, have many industrial and district heating sites where biomass residues are used for large-scale combustion and where the generated CO_2 (if captured) could be used as raw material to produce electrofuels.

Policy support

Since the transition to include hydrogen in the future energy system will result in added costs compared with "business as usual", policy support for the funding of these projects will be an important driver.

In the Nordics, there are several national and Nordic support programmes for hydrogen/decarbonisation technologies. National initiatives include a Danish support programme for green industry, as well as the Climate Leap (Klimatklivet)[130] and the Industry Leap (Industriklivet)[131] in Sweden. Sweden also has a specific programme directed at the role of hydrogen in the energy transition. As an example from Finland, renewable hydrogen projects are eligible to receive national energy aid from the Ministry of Economic Affairs and Employment.[132] In Norway, several funding entities have programmes that favour hydrogen technology development and implementation. For instance, Enova has funding programmes specifically focused on hydrogen for various part of the transport sector, as well as for industry.[133] In addition, support for investments in hydrogen production can also be facilitated by creating a market or off-take demand for hydrogen/hydrogen-derived fuels. One example of such a policy measure is the distribution obligation for renewable fuels in the transport sector in Finland.[134] Other support schemes include CO_2 compensation and the use of public procurement for decarbonisation. At the Nordic level, Nordic Energy Research and the Joint Nordic Hydrogen Research Programme provide funding for research and development projects.

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130. https://www.naturvardsverket.se/amnesomraden/klimatomstallningen/klimatklivet/
131. https://www.energimyndigheten.se/forskning-och-innovation/forskning/industri/industriklivet/
132. https://tem.fi/en/-/ministry-of-economic-affairs-and-employment-sets-energy-aid-priorities-for-2024
133. https://www.enova.no/bedrift/hydrogen/
134. https://tem.fi/sv/-/lagutkast-om-andringar-i-distributionsskyldigheten-pa-remiss

One prominent example being, of course, the "Nordic Hydrogen Valleys as Energy Hubs" programme.[135] At the EU level, there are also several funding schemes that could support the development of hydrogen projects, also in the Nordics. When the Fit-for-55 package was presented in July 2021, a number of legislative proposals were presented, with a view to translating the European hydrogen strategy into a concrete European hydrogen policy framework.[136] This funding scheme can be seen as a key enabler for supporting long-term ambitions in this area. The framework includes:

- Proposals to set targets for the uptake of renewable hydrogen in industry and transport by 2030
- The Recovery and Resilience Facility for clean energy (to end dependence on Russian fossil fuels)[137]
- Important Projects of Common European Interest (IPCEI) on hydrogen[138]
- The Clean Hydrogen Partnership
- The Renewable Energy Directive

In addition to funding specifically aimed at hydrogen, the availability of more general funding and policy measures for the energy transition may also contribute to driving development. These include:

- EU ETS (Emission Trading System)
- CBAM (Carbon Border Adjustment Mechanism for CO_2), which adds carbon taxes on e.g. imported good such as steel, fertilisers and cement
- The European Hydrogen Bank
- Clean Energy Transition Partnership
- Connecting Europe Facility (CEF)
- EU Innovation Funds
- Funding through European partnerships that focus on transport, such as Clean Aviation and Zero Emission Waterborne Transport

Industry presence and ambitions

To realise a large-scale transition towards increased use of hydrogen, there is a need for industrial stakeholders in relevant sectors with high ambitions related to the transition.

In the Nordics, several industries have a clear need to decarbonise and limited availability to other options. Examples include steel production, refineries and petrochemical industries with defined ambitions to implement hydrogen in their future value chains. In addition, it is expected that there will be a significant demand for hydrogen-based fuels, such as methanol and ammonia, in the shipping sector. Further, a broad range of industrial stakeholders and customers have ambitions to decarbonise their value chains, creating opportunities to pay a certain premium for carbon-free products further up or down the value chain. This willingness to invest could facilitate investments in new hydrogen projects. More recently, it has become clear that some stakeholders are

135. https://www.nordicenergy.org/programme/nordic-hydrogen-valleys-as-energy-hubs/
136. https://energy.ec.europa.eu/topics/energy-systems-integration/hydrogen_en
137. Recovery and Resilience Facility for clean energy - European Commission (europa.eu)
138. IPCEI Hydrogen (ipcei-hydrogen.eu)

demanding their entire value chain to be CO_2 neutral. The Nordic countries also have several industries with experience producing and using hydrogen (e.g. refineries and the petrochemical industry). Increasing demand would be a driver for the development of infrastructure (production/storage/distribution) for hydrogen, which would in turn support the general establishment of hydrogen valleys.

Finally, collaborations and strategic partnerships between industrial actors could drive co-innovation and enable the sharing of expertise and risks (e.g. between supplier and producer). Such collaboration would also involve work to harmonise regulations, sharing best practices and collaborating on cross-border infrastructure projects between the Nordic countries.

Access to potential off-takers of excess heat and oxygen

Transitioning to hydrogen production would also increase access to excess heat and oxygen as by-products. Consequently, access to users of these by-products is a significant driver for development.

The Nordic countries have extensive district heating networks, which could be a key enabler for finding uses for excess heat from hydrogen production processes, as well as industries that use large volumes of oxygen (e.g. for bleaching at pulp and paper plants and for steel production processes).

Several other initiatives are also being investigated in the Nordics, including aquaculture (fish/shrimp) and vegetable production in greenhouses, which could have an increasing role as potential off-takers for the by-products of hydrogen production.

Support from local communities and local energy systems

Support at the local level can also be an important driver for development. Here, distributed generation of hydrogen and electrofuels would have the potential to support local hydrogen value chains and the local and regional electricity grid. Further, local support tends to increase for projects that can provide job opportunities, possible tax revenues for municipalities and overall strengthening of local economies and investments.

Technological innovation

Increasing performance and reducing cost would be key enablers for global and Nordic hydrogen projects. The Nordic countries have many companies involved in R&D efforts that aim to reduce costs and improve the efficiency of hydrogen production, storage and utilisation technologies (fuel cells, gas turbines etc.). Cost reductions can also be expected as a result of increased use of key hydrogen technologies, such as electrolysers.

Limitations of the electricity grid

Difficulties in co-locating electricity production sites with consumers could drive the production of hydrogen as an energy carrier (Power-to-X-concepts) in the vicinity of production sites, e.g. offshore wind farms. Hydrogen production could also offer flexibility in electricity utilisation by e.g. operating electrolysers based on the electricity spot price or grid limitations, thereby supporting local, regional or national power systems.

Energy security

Given that power used for hydrogen production is produced from regionally or nationally available renewable sources, hydrogen could increase self-sufficiency in terms of energy supply, increase energy security and contribute to a more robust energy system. In addition, hydrogen is storable and can thus serve as a backup energy supply. Conversion from electricity to hydrogen does, however, imply substantial energy losses, and hydrogen is not always the best alternative to provide this backup energy. Evaluations, determining the system level impact from using hydrogen, must be made on a case-by-case basis.

There are also opportunities for developing production capacity to export hydrogen to other parts of Europe, especially since the Nordic countries are generally regarded as uncomplicated trade partners. For areas such as Greenland/Iceland, where it is challenging to transfer electricity to neighbouring countries, hydrogen export could be particularly interesting.

6.1.2 Primary drivers according to stakeholders

At the workshop, the eight areas above were presented to and ranked by the participants (apart from support from local communities, which was added after the workshop). The results are presented below. It should be noted that several of the factors are linked to each other and several of these are dependent on each other, which makes ranking difficult in general.

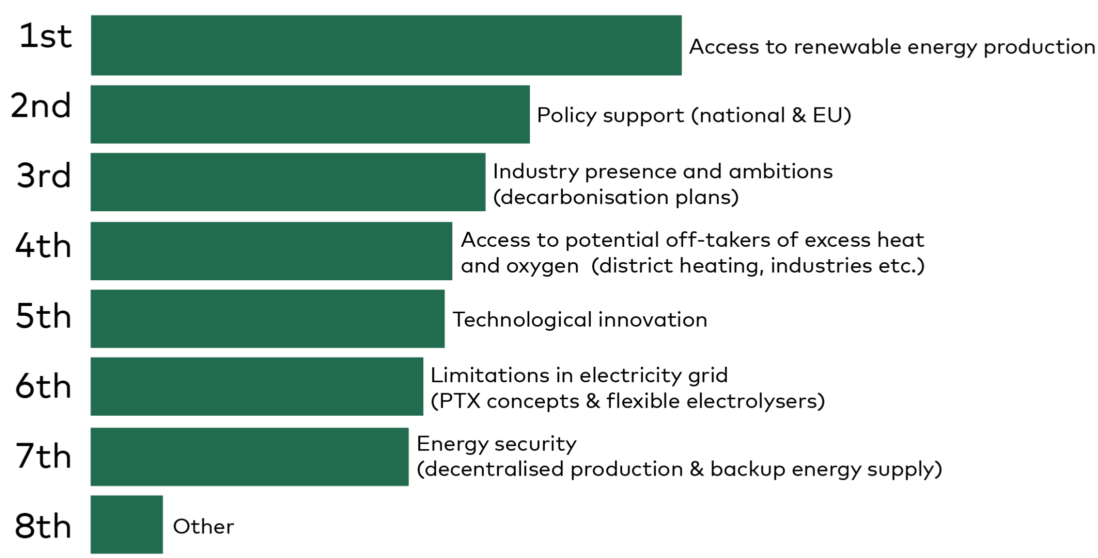


Figure 17. Results from the ranking based on the question "How do you rank the following list of drivers for the Nordic hydrogen valleys?" at the workshop on 18 April 2024 (12 votes).

The workshop participants considered access to renewable energy the most important factor for establishing Nordic hydrogen valleys. This factor is considered important both at the Nordic level and in more localised contexts, where proximity to energy production plays a crucial role in facilitating access energy and driving down costs. This also pertains to the proximity of hydrogen off-taker, which is essential for creating a sustainable value chain. Additionally, the consensus from both the workshop and the interviews was that the key driver is either policy support (especially at the EU level) or the industries' ambitions to decarbonise their activities. Apart from industry, which is explicitly included in the ranking above, the need and interest to decarbonise the transport sector was mentioned by several interviewees as a key driver for many of the hydrogen projects in the Nordic countries. This includes a push towards fuels such as e-SAF and e-methanol for aviation and shipping, respectively.

Both the workshop participants and the interviewees regarded access to potential off-takers of excess heat and oxygen as moderately important. Several interviewees pointed out that the business case did not currently seem to be significantly influenced by this factor. However, one interviewee mentioned that this factor could be significantly underestimated, since overall system efficiency could be an essential aspect of creating local synergies with other stakeholders in the area. This could facilitate industrial symbiosis initiatives, which are not just linked to hydrogen, and thus broader public support for hydrogen valleys. Some interviewees also mentioned the potential for using electrolysers for additional services (e.g. ancillary services for the grid, heat and oxygen) as an added value and potential driver.

One example of the interdependence between factors can be taken from the first three ranked factors in the workshop. Support from national governments and the EU has a major influence on both the short-term and long-term market conditions for stakeholders involved in developing renewable energy production and decarbonising their own activities. Examples of this include handling conflicts between local and national interests and creating support schemes to enable this transition (which in many areas require additional support to enable first movers). Better policy support in general lowers the risks for stakeholders involved in developing renewable energy production and industry stakeholders involved in the transition to hydrogen as a means of decarbonisation. The interviewees had slightly different opinions on the importance of policy support to lower this risk, which naturally influenced their individual rankings.

Several interviewees noted that while the Nordic countries share many similarities, there are also distinct differences in the overall drivers influencing each country's development of hydrogen projects. One opinion is that Denmark and Norway are more export-oriented in general. Denmark has a special focus on converting electricity from wind power assets to hydrogen and electrofuels for export. Norway is highly motivated to facilitate the export of mainly blue hydrogen. For countries with a strong focus on export, bilateral agreements and cross-border standardisation of hydrogen and electrofuels are especially important. Sweden, Finland and Iceland are more focused on supplying hydrogen to their own industries and other sectors with potential to utilise hydrogen. Another interviewee saw similarities between Norway, Iceland and Finland in terms of their focus on the direct use of hydrogen, whereas Sweden and Denmark tend to have a greater tendency towards the production of electrofuels. This sentiment was not confirmed by the project mapping (Chapter 3), which identified several projects targeting hydrogen derivatives (electrofuels and chemicals).

Other aspects mentioned as drivers for Nordic hydrogen valleys by at least one of the interviewees were:

- Access to logistical hubs and proximity to other stakeholders with a potential demand for hydrogen. Here, ports were considered especially important, based on connections to different modes of transportation.
- Local access to clean water (which is especially relevant for electrolysers), which limits the need for desalination of salt water.

One interviewee considered limitations in the local power grid to be a barrier for the development of hydrogen valleys, since investments in hydrogen should not be seen as a tool to get around limitations in the power grid.

Further, the importance of energy security as a potential driver for hydrogen valleys was considered especially relevant for more isolated areas such as islands with limited connections to other areas (such as Iceland).

6.2 Barriers for the formation of Nordic hydrogen valleys

6.2.1 Characterisation of potential barriers

The initial list of barriers was characterised and divided into five areas, which are explained and elaborated on in more depth below. The areas are presented in order of overall perceived importance for the development of Nordic hydrogen valleys (see also next section).

Project business case

A key barrier for the development of hydrogen valleys and hydrogen projects in general is the project's overall business case. Challenges with the business case include the hydrogen price and technical maturity, as well as overall risk and uncertainty.

Current production technologies, which are based on electricity as input (mainly with electrolysers), are at present more expensive than the state-of-the-art production technologies based on natural gas. This is the case even though electricity prices are generally lower in the Nordics than in the rest of Europe. Further, the spot price is pushed upwards by high European gas prices, due to the geopolitical situation, for example. One possible consequence of hydrogen prices (or the prices of products derived from hydrogen) being excessively high is that fossil-based production processes may remain competitive in the longer term, which would be devastating for development.

The technical maturity of key technologies is limited, resulting in high initial costs and a high risk of first-mover disadvantage, thus complicating the value chain. This includes electrolysers as well as the storage and distribution of hydrogen. To develop hydrogen valleys, achieving scale is a key condition. However, the scale-up period presents numerous challenges.

Key areas of uncertainty include the political strategies, priorities and ambition levels, as well as the development of EU ETS and natural gas prices, making the investment environment difficult to navigate. There is a general lack of national hydrogen strategies to support development on a local/regional level, which may be due to insufficient top-down national policies. In addition, current support schemes may be misaligned. For instance, while there is considerable support for developing hydrogen refuelling stations, there is less support for hydrogen production for these stations or for the adoption of hydrogen-fuelled vehicles.

As a result, risk-sharing mechanisms are likely necessary. There are many stakeholders involved, which indicates a need for formalised commitments from various counterparts (producer/user/distributor). Since multiple stakeholders must make investment decisions, there is also a natural time delay. This can be seen as the chicken-and-egg problem, where demand is needed to incentivise production.

One factor linking several of the examples above is timing.[139] As an example, while Finland is experiencing significant growth in wind power, the demand for green hydrogen is not increasing at the same pace. In Sweden, it can be difficult to obtain a permit for electricity use, particularly when it comes to timely approvals. One example is Febertia, which relocated their planned electrolyser site from Boden to Jokkmokk due to challenges in securing the necessary electricity allocation. Now, the hydrogen produced will be distributed by pipeline to Luleå for fertiliser production.[140]

Regulatory environment

The regulatory environment impacts the overall business case but can also be a barrier (or driver) for development.

In general, the Nordic countries have limited regulatory and institutional knowledge related to hydrogen, compared with e.g. more gas-heavy EU countries. Authorities lack permitting experience on the municipal or regional level, which could create new challenges when use is scaled up and projects may include hydrogen storage above or below ground.

Lengthy and unpredictable regulatory review processes for building production and distribution infrastructure, such as the process for obtaining permits to transmit electricity offshore, are an additional barrier. Based on current legislation, there are often limited opportunities to proactively plan and build infrastructure for electricity and gas. Further, the regulatory environment is not adapted to facilitate sector coupling and related business models, especially for decentralised systems.

Another regulatory area, that may become a barrier is safety regulations related to hydrogen production, storage and pipelines, which may be either inadequate and overly strict.

Finally, there may be limitations in the funding schemes that impact development. One example can be found in Sweden, where, since February 2023, the Climate Leap (Klimatklivet) funding scheme has required the electricity to be produced from renewable sources (zero carbon footprint) for the entire lifetime of the plant. This can be difficult to achieve in some electricity areas in Sweden, such as SE3 and SE4, where some fossil resources are used to support the grid.

139. https://www.energi.se/artiklar/2024/april-2024/vatgasprojekten-tuffar-pa--men-tajmingen-ar-komplicerad/
140. https://northswedenbusiness.com/news/2024/februari/power2earth-to-produce-fossil-free-mineral-fertilizer/

Lack of local energy supply and infrastructure

A significant barrier is the lack of available electricity grid capacity, which in many cases limits the possibility to add local production. There can also be significant competition for grid capacity (e.g. Fertiberia in Luleå, as mentioned above). The intermittency of renewable energy may add to these grid challenges. Although the Nordics host significant renewable energy production, it is intermittent in nature, and managing variations is a key challenge.

The barrier of infrastructure development in the Nordics is also related to current gas grid coverage, the lack of operating hydrogen refuelling stations and the lack of available natural geological formations for large-scale hydrogen storage in most of the Nordic countries (with Denmark being an exception, where hydrogen storage in salt caverns is being developed in e.g. the Green Hydrogen Hub project[141]). It should be mentioned, however, that it may be possible to establish lined rock caverns in other countries with suitable geological conditions.

Access to skills, material and workforce

A general barrier to a large-scale societal transition is the availability of competence and material resources. For hydrogen valleys, knowledge gaps in parts of the value chain (e.g. for purchasers of services or on a local level), may become an obstacle to development. Another aspect is that, while safety procedures and standards are well known within industry, they are otherwise lacking in the workforce.

Certain materials required to produce hydrogen, e.g. in electrolysers, can be difficult to obtain in sufficiently large quantities. This can include rare earth metals, which are needed in many transition technologies and for which demand is increasing rapidly. In a rapidly growing market, the Nordics could face challenges in sourcing technology suppliers.

Local support

The development of hydrogen valleys must consider not-in-my-backyard (NIMBY) sentiments, especially related to the construction of large-scale energy generation and transmission projects. This is a challenge, especially at the local and regional level.

6.2.2 Primary barriers according to stakeholders

At the workshop, the following list of five factors was presented to and ranked by the participants. The results are presented below.

141. https://greenhydrogenhub.dk/about-ghh/

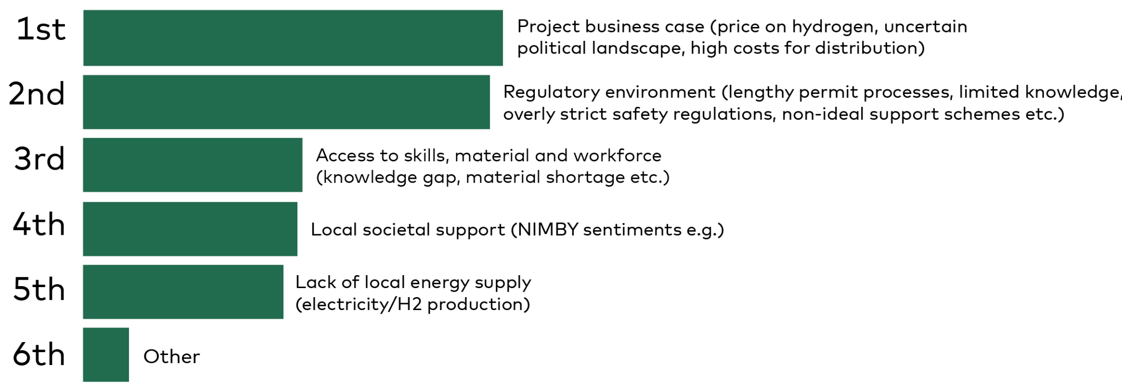


Figure 18. Results from the ranking based on the question "How do you rank the following list of barriers for the Nordic hydrogen valleys?" at the workshop on 18 April 2024 (12 votes).

The overall project business case and the regulatory environment were regarded as the primary barriers for the development of Nordic hydrogen valleys by the workshop participants. Just as for the presented list of drivers, the barriers are interdependent, which makes the ranking difficult. In discussions with the interviewees, it was clear that the likelihood of some of the factors was small but with potentially devastating consequences for hydrogen projects. An example of this can be NIMBY sentiments related to wind power projects or regulatory aspects that could potentially completely disrupt the energy supply to a hydrogen project (high consequence); assessing the likelihood of this happening is therefore especially important. A related aspect discussed with several of the interviewees was which stakeholders should assume the risks related to developing Nordic hydrogen valleys. One of the key conclusions from these discussions was that, to create clear market conditions, it is crucial to have risk sharing mechanisms in place and remove as much uncertainty as possible (e.g. through political action).

It is also relevant to point out the competition between establishing a hydrogen value chain within the Nordics and outside the region (or the EU), as this may pose a potential barrier. One interviewee noted that the hydrogen required for decarbonisation in the Nordic countries could potentially be sourced from Australia, where ammonia could be shipped to the region, converted back to hydrogen through cracking and then transported to the user. The value chain and thus the origin of the hydrogen will be driven by the cost of production and distribution to the user, and it is not certain that the cost-optimal solution is local hydrogen production in the Nordic countries even though (as pointed out earlier) there is good access to renewable energy production.

Technological neutrality is another aspect which was brought up in the interviews as important for creating a long-term, sustainable market for electrification and hydrogen projects. If this is not achieved, there is a risk of lock-in effects associated with certain technologies that may prove too costly in the future. The need to focus on technological neutrality relates to both national level and EU level. One interviewee described the United States as a good example of having a system that prioritises the overall goal of hydrogen production volume, rather than focusing on specific technologies used to achieve it.

There is clearly an important link between the development of both hydrogen and electricity infrastructure to develop the Nordic hydrogen valleys. Interviewees identified specific barriers related to this issue, including access to local power and lengthy permit processes for expanding the electricity grid and industrial projects. One interviewee pointed out that Finland can serve as a good example in terms of its ongoing process to create a "one-stop-shop principle" to streamline and speed up the permitting processes for industrial projects.[142][143]

In general, the interviewees believed that there is enough knowledge on hydrogen and its potential role in the value chain and that the technology required to develop Nordic hydrogen valleys is present. The challenge is rather the business case. This can be improved both through measures that stimulate the use of hydrogen and by impeding the use of other energy sources such as natural gas, coal, diesel or LPG. This can be achieved both by measures that impact the market price and by regulations that restrict the use of carbon-containing fuels. Several interviewees pointed out that the price of fossil fuels in relation to hydrogen is currently too low.

An additional barrier pointed out by one of the interviewees related to organisational structures, where support for hydrogen projects might be good in one area (for example R&D) but at the same time lacking in another (sales). This disparity negatively impacts the development of hydrogen valleys.

Other barriers mentioned included the lack of standards related to the transport of hydrogen gas via offshore pipelines and that the size of the stakeholder (in terms of financial and human capital) has a major influence on handling risks related to developing hydrogen projects, with major stakeholders in a significantly better position to follow through with these projects.

6.3 Policy suggestions to support Nordic hydrogen valleys

6.3.1 Characterisation of potential policy measures

The workshop and the interviews clear indicate that there are multiple ways to support the development of Nordic hydrogen valleys. The various types of measures can be grouped in the following three areas:

Policy – Broad strategic direction: Overarching guidelines or principles established by governments/organisations to guide decision-making and action in a particular area. In the context of hydrogen, energy or environmental policies, this may include goals, targets and strategies for promoting the use of hydrogen as an energy carrier or addressing related issues such as emissions reduction or energy security. These policies often set the direction for legislative and regulatory action.

Legislation Specific legal requirements: Legislation refers to laws enacted by a legislative body, such as a parliament or congress. Legislative measures related to hydrogen may include laws that provide funding or incentives for hydrogen research, development and deployment, establish regulatory frameworks for hydrogen production, distribution and

142. https://www.ymparisto.fi/fi/ymparistollisten-lupamenettelyjen-yhteensovittaminen
143. https://www.both2nia.com/en/news/one-stop-shop-permitting-finland

use, or mandate certain actions or standards related to hydrogen technology or infrastructure. Legislation can vary widely between countries and regions, depending on their legal and political systems and priorities.

Standards – Technical specifications: Standards are technical specifications or guidelines developed by standards-setting organisations or industry bodies to ensure consistency, interoperability, safety and quality in products, processes or services. In the context of hydrogen, standards may cover various aspects such as hydrogen production methods, storage technologies, transport, refuelling stations, safety protocols and environmental performance. Adherence to standards can help facilitate the widespread adoption of hydrogen technologies by providing assurance of reliability and compatibility.

The tables below present lists of potential measures for each group, also indicating the level at which the decision can mainly be influenced (local/national/Nordic/EU/international).

POLICY	
All levels	Co-plan electricity and gas infrastructure to find potential synergies between electricity and gas grids to enable proactive grid development.
EU	Support the implementation of CU Carbon Border Adjustment Mechanism (CBAM) where carbon emission costs should be imposed on the import of goods, including steel, cement and electricity.
National/Nordic/EU	Stimulate alignment at a regional/national level through bilateral or multilateral partnerships to facilitate trade with hydrogen internationally.
National/EU	Define a shadow carbon price or social cost of carbon that helps governments allocate funds to accelerate deployment of clean energy technologies, including hydrogen.
	Create new models for the market to finance investments in new hydrogen infrastructure (not just refuelling stations).
National/Nordic	Incorporate hydrogen into the Nordic countries' decarbonisation strategies to define targets for hydrogen production and utilisation, including e.g. specific use of hydrogen/electrofuels in the transport sector and green electricity production (on/offshore wind power). Further, collaborate to align these strategies at the Nordic level.

National	Provide long-term agreements within the political landscape to remove uncertainties related to future subsidies/taxes on electricity/hydrogen production.
	Develop tests of market designs in regulatory sand pits before common implementation. Areas with bottlenecks in the electricity grid could be seen as especially interesting.
	Improve support schemes for both supply and demand side related to the use of hydrogen use in heavy-duty transport. One example from a Swedish perspective is that there is significant support for establishing hydrogen refuelling stations, while at the same time, there are limited support schemes for the demand side.
	Define a coordinating body to simplify partnerships (public/private), which can be used to close investment and operational gaps and prioritise the biggest impact on GHG emissions.
Local/National	Define an internal carbon price to influence decision making in companies and authorities.
	Support early-stage projects that could kickstart the formation of hydrogen hubs and where it is possible to synchronise and co-locate production and demand through capital expenditure subsidies, loans/financial guarantees, public investments, contracts for difference, facilitate long term off-take contracts etc. Doing so can better secure stability and predictability for future revenue streams.
	Implement a programme to inform and educate the public on hydrogen and its benefits and risks, to achieve public support. This can be used to raise awareness among end-users and relevant stakeholders in the future hydrogen value chain.

LEGISLATION	
National/EU	Define supportive tax regulations to decarbonise energy and avoid the risk of "double" taxation because of energy conversion from one energy carrier to another.
	Set up clear, long-term market rules for hydrogen generation, transport, utilisation and related issues.
National	Define requirements for national agencies to purchase fossil-free transport services in the future to facilitate the right conditions to switch to decarbonised fuels (regardless of whether it is hydrogen or something else).
	Provide support to decision makers involved in national, regional and local permitting processes for adding new decarbonised production and distribution of hydrogen and electricity, with a view to reducing lead times.
	Adjust current legislation that is not adapted to new types of fuels. One example is the Swedish Energy Taxation Act (1994:1776), which is based on the EU's Energy Taxation Directive (ETD) from 2003. This results in the use of hydrogen being taxed when used in a combustion engine in a vehicle or on a ship but not when used in a fuel cell.

LEGISLATION	
EU/international	Adopt a global, verifiable methodology that can define origin, quality and life cycle of GHG emissions from hydrogen. This would improve transparency and enable consumers to make well-informed decisions. Certification schemes for other commodities could be used as inspiration.
	Update and harmonise hydrogen regulations and standards related to the entire hydrogen value chain. This includes adopting international standards and enabling the removal of limitations that could inhibit the repurposing of existing natural gas installations for example and make blending possible. The harmonisation of standards is especially important to facilitate the transport of hydrogen across borders.

6.3.2 Most important policy measures according to stakeholders

The results from the ranking exercise at the workshop related to different policy suggestions are presented in Figure 19. Note that a different grouping of suggestions was used.

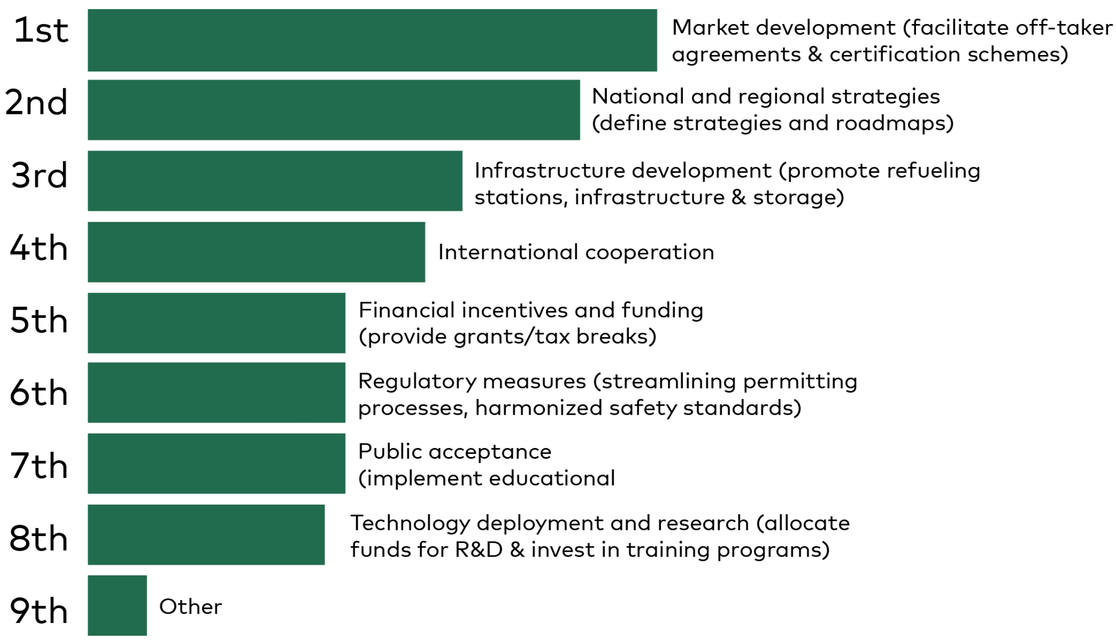


Figure 19. Results from the ranking based on the question "How do you rank the following suggestions for policy changes to support Nordic hydrogen valleys?" at the workshop on 18 April 2024 (4 votes).

The workshop participants who responded to this question generally agreed that the policy suggestions should be particularly focused on developing a hydrogen market and on defining long-term strategies and roadmaps on a national/regional level. They considered the need to support R&D to be less important. It should be noted that the number of respondents was lower for this part of the workshop, which makes it more difficult to draw more general conclusions. However, the result presented in Figure 19 was also confirmed during the expert interviews.

There were some common themes throughout all interviews, including the need for financial support for hydrogen projects, which related to the entire value chain (energy supply, hydrogen production, hydrogen distribution infrastructure and utilisation). There was also consensus that hydrogen projects that are actually realised play an important role in showing that it is possible to develop large-scale Nordic hydrogen value chains for different sectors. It was also highlighted that there is still a significant window of opportunity to develop Nordic hydrogen valleys, but that this development is threatened by several factors. Examples include competition with other regions, the current business case in relation to other options and a lack of sufficient funding schemes and legislation.

There were also several interesting differences in the responses. Some examples are presented below:

- The interviewees had differing views on the importance of national hydrogen strategies. Some considered them to be a crucial overall message, while others placed greater emphasis on the strategies defined by the EU. Interviewees also noted that a key driver is industry ambitions to establish a fossil-free value chain, which is expected to accelerate the shift towards hydrogen and other renewable energy carriers.
- The interviewees placed varying importance on "hydrogen-specific" policies versus general policies based on technological neutrality, with a view to increasing the cost of CO_2 emissions.
- There were also conflicting opinions on the need for hydrogen production support versus the need for support on the demand side. Several interviewees pointed out the importance of not focusing too much on hydrogen refuelling infrastructure, but rather on hydrogen production itself. The idea is that this would facilitate local access to hydrogen and reduce the purchase price for hydrogen. Others believed that the focus should rather be on financially supporting the stakeholders that could use hydrogen in the future.
- One interviewee considered public acceptance as one of the most important factors, in contrast to most other respondents. This was mainly based on the fact that local residents living near potential hydrogen valleys play a crucial role in the success of these projects.

One interviewee also questioned the overall importance of a policy framework. It was pointed out that, for some of the countries that appear to have a strong push towards developing hydrogen projects, this cannot be explained by a successfully developed policy framework but rather other factors. One example mentioned was Spain, which had by far the most bids (around 2.9 GW_e of the total capacity of 8.35 GW_e) in the European Hydrogen Bank pilot auction.

Photo: Freepik

7. Key findings, conclusions and recommendations

7.1 Hydrogen valley mapping and tool development

The project mapped 167 Nordic hydrogen projects, ten of which fulfilled the proposed hydrogen valley definition at the time of the mapping.

The hydrogen valley criterion that most projects fail to meet is the requirement to supply hydrogen to several end-use sectors. Only 25 of the mapped projects supply hydrogen to specific off-takers in multiple sectors, meaning that 142 mapped projects fail to meet this criterion. Of the 25 projects that do supply more than one end-use sector, 16 fail to meet the hydrogen valley definition, mainly because of insufficient project maturity.

The capacity of the mapped projects is significant – about 8 Mt or 270 TWh hydrogen per year – but only about 0.2% of this capacity is operational, with an additional approx. 1% under construction. Most projects – especially those very large in scale (hundreds of MW or more) – are in the early stages of development (pre-feasibility phase).

Projects in Sweden and Finland often aim to use hydrogen on-site for e-fuel/chemicals production or to decarbonise existing industrial processes. While Danish projects also commonly focus on hydrogen for on-site e-fuels/chemicals production, Denmark also hosts several large-scale export-oriented projects aimed at supplying hydrogen to potential future European or global markets. To export hydrogen, Danish projects often plan to use (prospective) hydrogen gas grids. Norwegian projects also cover a variety of end-uses but are distinguished by a focus on utilising hydrogen for ammonia production or as a maritime fuel. These two aspects are sometimes combined, with hydrogen being used to produce ammonia for use as maritime fuel. However there are projects that focus on one aspect, either producing hydrogen for direct use as maritime fuel or producing ammonia for industrial purposes (e.g. to decarbonise fertiliser production). It should be noted that, for the Norwegian projects, the mapping often failed to identify intended end-users, indicating that the planned hydrogen capacity is available "on the market" for interested off-takers. In contrast to Swedish, Finnish and Danish projects, fewer Norwegian projects produce hydrogen for use on-site (instead exporting hydrogen to e.g. the transport sector), meaning that they are not in control of the entire value chain. Consequently, final off-takers are sometimes not identified even in advanced stages of project development.

The number of mapped projects in Iceland, Åland, the Faroe Islands and Greenland is too low to draw general conclusions. Most of the mapped Icelandic projects target e-fuel/chemicals production or direct use in transport. This is in-line with the Hydrogen and E-fuels Roadmap for Iceland which identifies hydrogen and e-fuels as key elements in decarbonising the transport and maritime sectors in Iceland. Identified projects in Åland are export oriented (aiming to export hydrogen via prospective Baltic Sea hydrogen infrastructure).

The most common hydrogen derivatives produced by the mapped projects are methanol, ammonia and methane, with the production of e-SAF being less common. Common direct uses of hydrogen include road transport, industrial heating and decarbonisation of industrial processes by replacing a fossil input (e.g. coal in steel making or fossil hydrogen in refinery processes or ammonia production).

This project has not assessed Nordic strengths and weaknesses in relation to other EU countries. However, the presence of large-scale export projects targeting the European market (especially in Denmark) indicate a position of strength.

The digital tool, as a publicly available interactive web application, allows users to view and analyse data gathered during the mapping process. It is thus essential for the mapping to indicate any true added value for Nordic stakeholders. However, the tool is currently only a prototype and both the database and the tool will require regular updates, maintenance and development to stay relevant.

7.2 The role of hydrogen in Arctic maritime transport

Since 1 July 2024, there has been a ban on the use and carriage of HFO in Arctic waters, which can be expected to incentivise the use of alternative fuels in Arctic maritime transport.

Hydrogen and hydrogen-based fuels are among the promising alternatives to facilitate the decarbonisation of shipping. In addition to their environmental benefits, the isolated power infrastructure in the Arctic makes green hydrogen and hydrogen-based fuels particularly interesting. Wind and PV have huge untapped potential in the region and can be put in use in areas with no grid or low grid capacity. In addition to supplying marine fuel, the scattered communities in the Arctic would benefit from the harnessed power, which would in turn contribute to job and value creation in the region.

The current use of hydrogen in Arctic maritime transport is negligible compared to fossil fuels. Projects producing hydrogen or hydrogen-based e-fuels suitable for maritime applications (such as ammonia and methanol) are under development in the region, especially in Northern Norway where about 600 thousand tonnes of hydrogen capacity (including natural gas reforming with CCS) is under development, mostly for ammonia production and often aimed at maritime off-takers. Several large-scale e-fuel projects are also under development in Iceland (in particular, roughly 300 ktpa of planned ammonia production), where maritime activities are an important part of the economy.

The advancement of regulatory frameworks, bunkering facilities and technical and operational know-how onboard ships could all facilitate the adoption of hydrogen and hydrogen-based fuels in Arctic maritime transport.

7.3 Drivers, barriers and policy measures for Nordic hydrogen valley developments

The three most important drivers for the formation of Nordic hydrogen valleys are current and future access to renewable energy production, adequate policy support on a Nordic and EU level and the ambitions of industries to use hydrogen for the decarbonisation of their own activities.

The three most important barriers that need to be addressed include the overall business case for hydrogen projects, deficiencies in regulatory frameworks, and the lack of local energy supply and infrastructure. The overall business case is affected both by an undeveloped market, inadequate infrastructure and the availability and cost of power supply.

One important finding in this work is the significant variation in priorities between stakeholders regarding which policy measures are considered most important to implement. However, based on the findings in this work, the highest-priority policy measures to support the development of Nordic hydrogen valleys include:

- Defining long-term strategies and targets for the development of hydrogen production and use on the national level, with a view to supporting investments.
- Promoting the development of a cost-effective hydrogen value chain by improving the support schemes for both the demand and supply side.
- Supporting the development of hydrogen infrastructure (pipeline and refuelling infrastructure, hydrogen storage) through the creation of partnerships to reduce risk.
- Supporting the implementation of more general climate policies at the EU level (such as CBAM, EU ETS, RED III etc.), as a general driver for fossil-free alternatives, including hydrogen.
- Providing support to reduce unnecessary lead times in permitting processes for electricity and hydrogen infrastructure, while establishing suitable regulations to streamline these processes.
- Creating standards to define the origin, quality and life cycle of hydrogen GHG emissions.

The respondents of the interviews, who represented national hydrogen associations and project managers involved in the "Nordic Hydrogen Valleys as Energy Hubs" programme, stressed the need for financial support for the entire value chain of early-stage hydrogen projects. This value chain includes energy supply and hydrogen production, as well as hydrogen distribution, infrastructure and utilisation.

Appendix A: Interview guidelines

The interviews included a general introduction to the project, but the scope of the interview was adapted to each interviewee.

The interview guide used for these semi-structured interviews was based on the following questions:

Part 1: Introduction:

- What is your current role?
- What is your background?
- What projects are you involved with in relation to hydrogen?

Part 2: Nordic hydrogen valleys/hotspots

- Presentation of draft definition of Nordic hydrogen valleys and hotspots.
- What is your opinion about this definition? What parts would you change and why? What elements of Nordic hydrogen valleys do you consider to be unique to the Nordic countries in relation to the rest of the EU?
- What tips do you have to identify possible Nordic hydrogen valleys/hotspots?

Part 3: Drivers, barriers & policy for developing Nordic hydrogen valleys

- What do you define as the key drivers for the creation of hydrogen valleys?
- Which three drivers do you see as the most important? *[Show our shortlist if there are fewer than four drivers mentioned so far.]*
- What do you define as the key barriers/challenges for the creation of hydrogen valleys?
- Which three barriers do you see as the most important? *[Show our shortlist if there are fewer than four barriers mentioned so far.]*
- Which policy changes would you suggest on a regional/national/Nordic level to support the development of Nordic hydrogen valleys?
- Of the suggested policy changes mentioned so far, which do you consider as the most important changes?

Appendix B: List of interviewees

Representatives of National hydrogen associations/universities actors:

- Sweden (Vätgas Sverige – Anders Lundell)
- Norway (The Norwegian Hydrogen Forum – Tor Kristian Haldorsen)
- Denmark (Associate professor, Aalborg University – Iva Ridjan Skov)
- Finland (Coordinator of Hydrogen Cluster Finland – Pia Salokoski)
- Iceland (General Manager, Icelandic New Energy Ltd – Jon Björn Skulasson)

Representatives of five NER Hydrogen Hubs projects:

- Nord_H2ub (Anne Neumann & Johannes Giehl)
- H2AMN & H2SIPP (Cecilia Wallmark)
- NordicH2ubs (Sigrid Lædre)
- MatHias (Vigdis Olden)

Appendix C: Workshop

An online workshop has hosted on 18 April, 13:00–15:30, to collect input from hydrogen stakeholders involved in research, industry and policymaking in the Nordic region. The event was marketed through the Nordic Energy Research (NER) LinkedIn page and further spread through the personal communication channels of NER staff and project participants.

The workshop was carried out using the interactive presentation software Mentimeter. Forty-one participants registered responses for the first question, which related to their affiliation (see result presented below).

Figure 1. Actor affiliation of the participants at the NER workshop.

The majority of the participants were affiliated with public authorities or universities/research institutes.

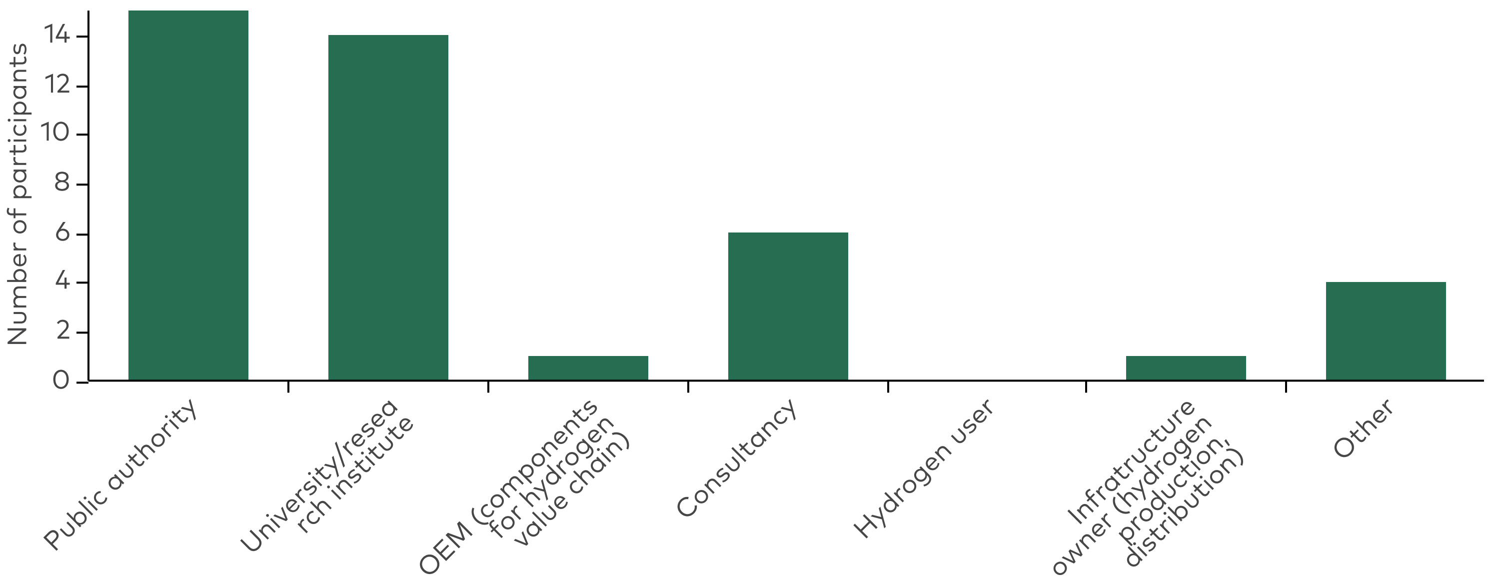
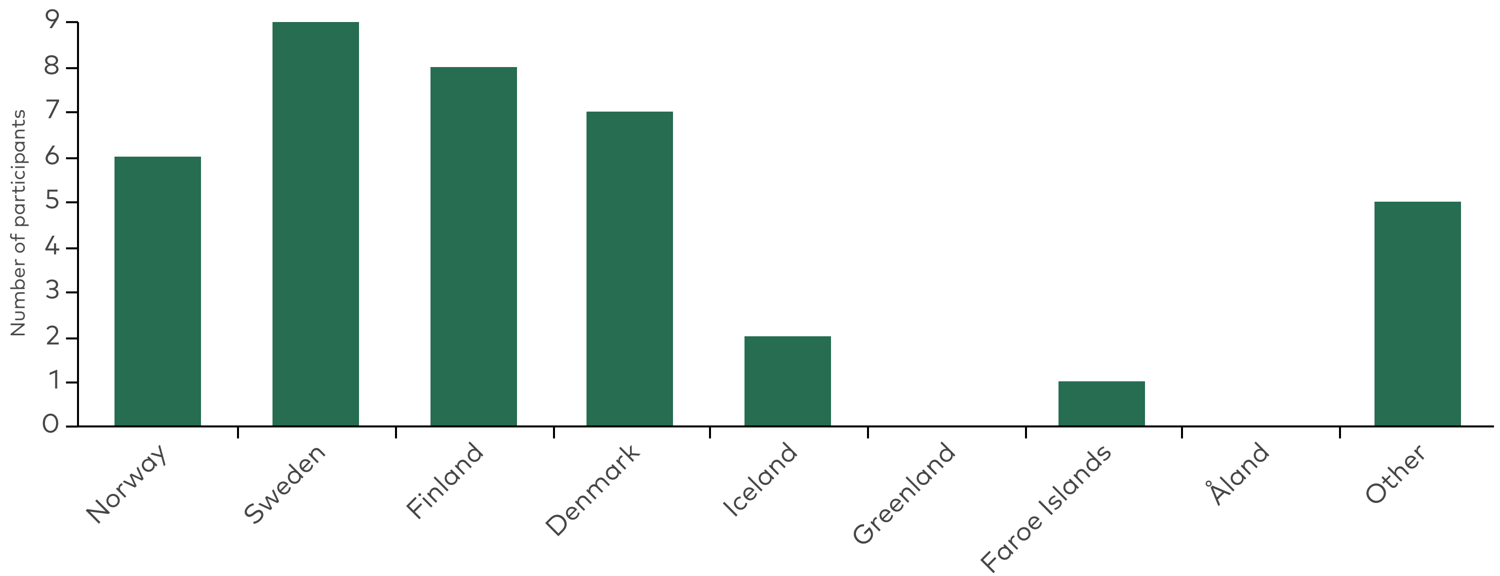


Figure 2. Result showing the countries in which the workshop participants were based.

The next question was about the respondents' country of residence. The responses indicate a well-balanced distribution of respondents across the Nordic countries.



The workshop agenda was divided into the following three parts:

- A general presentation of the project, followed by a presentation of the suggested definition of Nordic hydrogen valleys and hotspots. Based on this presentation, a discussion was held where the participants contributed with feedback on the suggested definitions.
- A description of the development of the online mapping tool, including which existing mapping tools were used as inspiration, suggested design principles for the planned tool and structure of the information. After this presentation, all participants provided feedback on what kind of information should be on the start page and other potentially relevant data to display.
- An introduction to the benefits of Nordic hydrogen valleys, which was followed by a discussion where participants suggested key drivers, barriers and policy measures for the development of Nordic hydrogen valleys. In addition to offering open suggestions on these topics, participants also ranked pre-formulated suggestions within these categories, which were prepared in advance by the project team.

All input gathered during the workshop was incorporated into subsequent work on the tool and included in the project report.

About this publication

Nordic Hydrogen Valleys – value chain mapping across the region

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