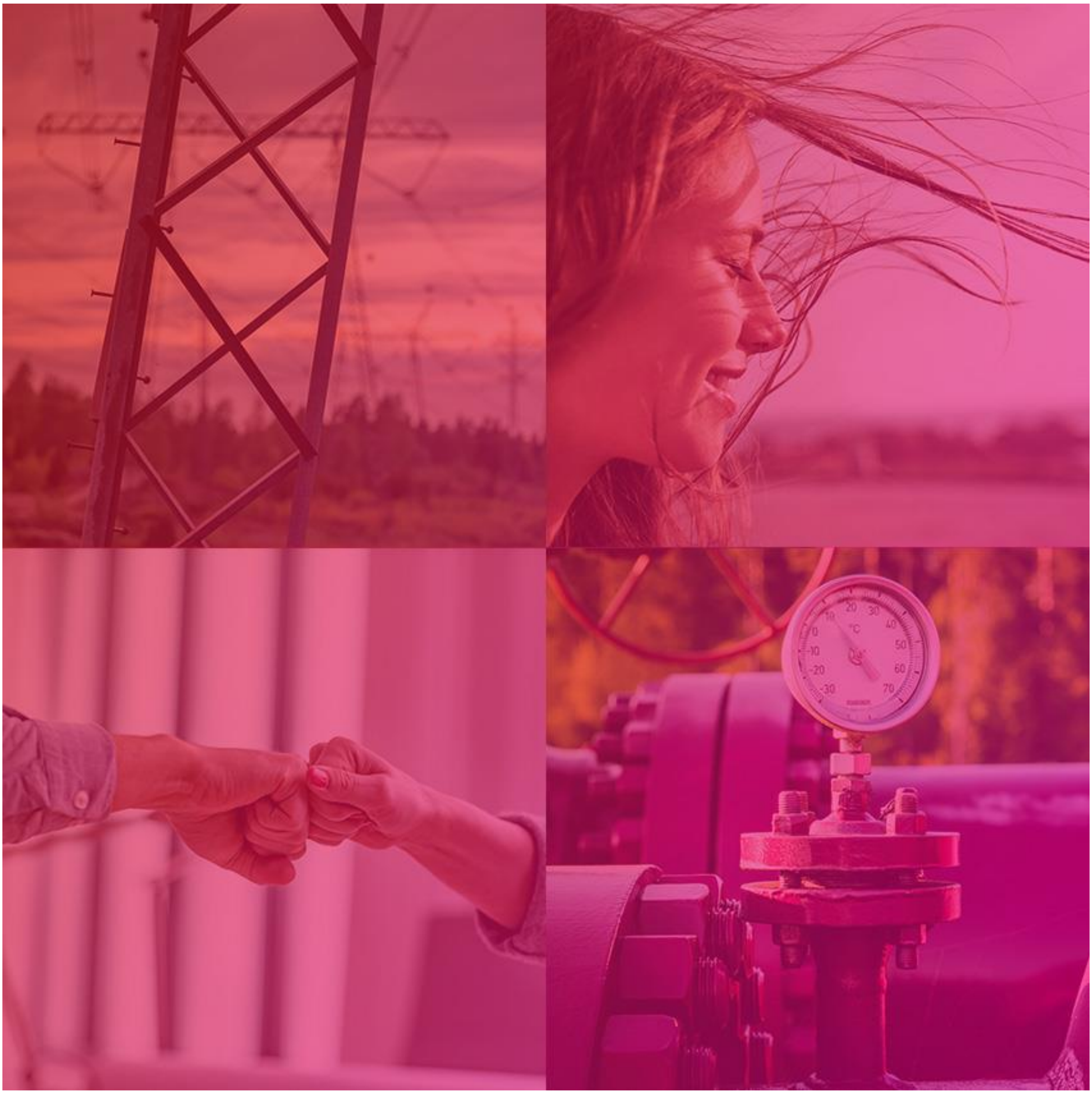

Energy transmission infrastructures as enablers of hydrogen economy and clean energy system - Scenarios

Scenarios of the joint project between Fingrid and Gasgrid Finland

FINGRID

GASGRID

Foreword

Fingrid and Gasgrid Finland are running a joint project that studies the potential trends in the hydrogen economy and their impact on the energy system. The joint project is part of a project portfolio titled HYCGEL (Hydrogen and Carbon Value Chains in Green Electrification) funded by Business Finland. HYCGEL brings together universities and companies in order to jointly study the systemic impacts of the energy revolution, the energy system and the hydrogen economy.

This scenario report is a continuation of the interim report and the scenario consultation carried out last year. We want to thank our customers and stakeholders for the valuable feedback, which we received during the consultation. This report presents the scenarios, which have been finalised based on the customer and stakeholder feedback and joint project research. The scenarios describe on a general level how a hydrogen economy could develop from the perspective of the energy system. Based on these scenarios, preliminary energy system models were created, which were then used to evaluate the importance of different infrastructure solutions.

These scenarios will form the basis for our continued work together to explore what the modelling results mean in terms of Finland's energy infrastructure and the entire value chain of hydrogen economy. Our goal is to find the most cost-effective infrastructure development paths for the Finnish energy system in various future scenarios. In addition, the focus is on different options for the development of hydrogen infrastructure and sector integration between energy infrastructures.

The final report of the project will be completed in autumn 2023.

Contents

1 Introduction

Finland is well placed to be a forerunner in the hydrogen economy, since our energy infrastructure is robust and we have competitive renewable energy resources for the cost-effective production of clean hydrogen. Clean hydrogen and its downstream products can replace fossil fuels in industry and transport, contributing to the transition away from a fossil fuel economy. Industrial investments in green economy bring growth to Finland and contribute to achieving of Finland's carbon neutrality.

In autumn 2021 and spring 2022, Gasgrid and Fingrid outlined scenarios for the development of hydrogen economy. For the scenario work, we interviewed several Finnish companies in autumn 2021 to hear their views on the hydrogen economy. The companies' views highlighted the need to develop the electricity and hydrogen infrastructure in parallel and taking into account the whole energy system. Finnish companies saw several possible roles that the hydrogen network could play in Finnish industry. The companies highlighted the importance of broad cooperation both in the development of the infrastructure and in the creation of industrial value chains.

In June 2022, we presented the draft scenarios of the project to customers and stakeholders and collected feedback on them in a consultation that continued until August. We received very good feedback during the consultation, which was used in the development of the scenarios. In this report, we present the finalised scenarios and the key results of the system modelling. Based on the finalised scenarios, we will continue our work together to explore what the modelling results mean in terms of Finland's energy infrastructure and the entire value chain of the hydrogen economy. We will publish the final report of the joint project in autumn 2023.

The operating environment is undergoing a significant change

The goal of the joint project scenarios is to determine the most cost-effective infrastructure development paths for the Finnish energy system in various future scenarios. The scenarios focus on different options for the development of hydrogen infrastructure and the sector integration between hydrogen, gas and electricity transmission infrastructures. A comprehensive analysis of infrastructure development needs is important to make the future energy system cost-effective, thus supporting national competitiveness in the best possible way.

Since the start of the project, hydrogen's role in the energy system of the future has become increasingly strong, and hydrogen has become a widely accepted basic assumption in energy sector scenarios. The growth potential of the hydrogen industry is based on the fact that hydrogen, produced using renewable electricity, can replace fossil raw materials and fuels in many industries and transport sector. This is also the basis of the European Commission’s REPowerEU plan[1], published in May 2022, which aims to reduce the imports of Russian fossil-based energy and significantly increase the production of renewable energy and accelerate the adoption of renewable hydrogen in the EU.

[1] REPowerEU (europa.eu)

The REPowerEU plan sets a target that the EU countries produce 10 Mt (333 TWh) of clean hydrogen and additionally import 10 Mt of hydrogen from outside the Union by 2030. In total, this would create a European hydrogen market of approximately 670 TWh. The change is about improving energy self-sufficiency, responding to changes in trade flows, and achieving the goal of ending Europe's dependence on Russian fossil fuels. The transition from fossil to renewable energy requires in-depth sector integration, which sets requirements for the development of both the hydrogen and electricity transmission infrastructure.

Gasgrid has participated actively in the initiative of the European Hydrogen Backbone (EHB), a group of 31 European energy infrastructure companies. The EHB group promotes the vision of an integrated hydrogen transmission infrastructure and market development. Analyses by EHB have discovered that the Nordic and Baltic countries not only have excellent conditions for establishing a hydrogen-powered industry, but also a huge potential for commissioning additional wind power. In the future, the region could produce a significant amount of hydrogen for the domestic industry while also exporting significant quantities of hydrogen, e-fuels and other downstream hydrogen products to European and world markets.

In May 2022, the EHB Group has published a vision of five major hydrogen supply corridors that meet the objectives of the RePowerEU plan. The analysis states that the hydrogen production potential in the Nordic and Baltic countries will be up to 127 TWh per year already in 2030. This represents approximately 20% of the total target of REPowerEU for 2030 and approximately 38% of the target for hydrogen produced in the EU.[2] On the other hand, Finland's renewable energy resources and the ongoing renewable energy projects could produce more than 300 TWh[3] of clean hydrogen in Finland, which corresponds to approximately 45% of the estimated European market in 2030.

It is estimated in the Finnish Government's resolution on hydrogen that if market conditions develop favourably, Finland has the conditions to produce at least ten percent of the EU's emission-free hydrogen in 2030.[4] Finland's advantage in the production of renewable hydrogen is the competitiveness of solar and wind power, as shown by Bloomberg’s price comparison of long-term power purchase agreements (PPAs). The comparison indicates that Finnish prices are among the three most affordable in Europe (Figure 1). PPA contract prices have probably increased in all countries after spring 2022, but presumably Finland’s relative position compared to other countries has remained similar.

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[2] Five hydrogen supply corridors for Europe in 2030. (EHB, 2022).
[3] Intermediate report: Energy transmission infrastructure as an enabler of the hydrogen economy and clean energy system. (Fingrid, Gasgrid, 2022)
[4] Government adopts resolution on hydrogen – Finland could produce 10% of EU’s green hydrogen in 2030. Press release. (Ministry of Economic Affairs and Employment, 9.2.2023)

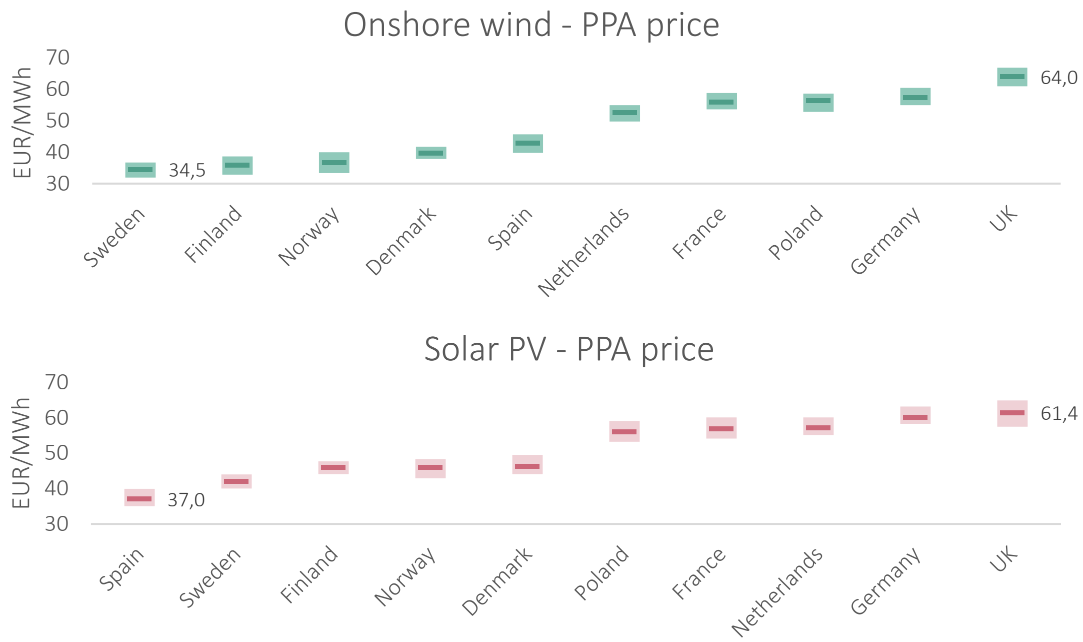

Figure 1 In the first half of 2022, the PPA price of Finnish onshore wind power was the second lowest in Europe; for solar photovoltaic power, the third lowest[5]

Clean hydrogen produced with renewable electricity and downstream products derived from it, which are referred to as Power-to-X or P2X products in this report, may grow into an important export industry for Finland. Finland has plenty of resources for the production of renewable electricity, a robust main electricity grid, a skilled labour force and several companies that can operate in the hydrogen economy value chain. As a result, Finland can punch above its weight in the hydrogen economy. However, in order to maintain Finland's competitiveness, it is important that the energy infrastructure is developed comprehensively, taking into account future energy transmission needs. By promoting the placement of investments related to the hydrogen economy to Finland, Finland can achieve a significant market share of the European hydrogen industry.

[5] Wind and Solar Corporate PPA prices Rise Up To 16.7% Across Europe (BloombergNEF, 28.4.2022)

2 Emergence of a significant new export industry drives the scenarios

This chapter presents the scenarios of Fingrid's and Gasgrid's joint project. Ambitious growth assumptions for the development of the hydrogen economy have been chosen for the scenarios, because they challenge the development of the energy system strongly. Challenging scenarios help ensure that the development needs of the transmission infrastructure are assessed comprehensively and in time. The actual investments in infrastructure are realized through identified needs and concrete projects. The scenarios also create a picture of Finland's great potential and role as a part of the European hydrogen economy, thus also highlighting the hydrogen economy's broader social effects.

Already in connection with this scenario work, it has been observed that the rate of connection inquiries received by Fingrid has significantly accelerated over the past year[6], and several dozens of hydrogen-focused projects have been launched in Finland[7]. The accelerated pace of development means that significant changes affecting the energy system that can be difficult to predict can occur even in the short term.

In comparison to previously published scenario drafts[8], the biggest changes are the higher demand for hydrogen in Finland and Central Europe. The demand development is accelerated by the goal to break free from fossil energy imported from third countries even faster. For this reason, the construction of a hydrogen pipeline connection from Finland to Central Europe was considered possible already by 2030 in two of the three scenarios.

2.1 Development trends in Finland's hydrogen economy – three scenarios

Table 1 describes the guidelines of Gasgrid's and Fingrid's three scenarios for the development of Finland's hydrogen economy. The scenarios explore different development options for future energy transmission infrastructure from the perspective of the Finnish energy system. In the scenarios, the key variable is the assumption of Finland's role in the value chain of the hydrogen market: Will Finland develop into a significant exporter of P2X products, hydrogen gas or both to meet the growing needs of the European market? Based on this variable, a hydrogen infrastructure focusing on foreign export and import has been formed in the scenarios. The formation of a national and international hydrogen infrastructure will also have a substantial impact on other parts of the energy system (see Chapter 3.3).

The basic assumption in all scenarios is that Finland achieves its carbon neutrality targets and the production of clean hydrogen in Finland will grow strongly. In addition to the increase in demand for electricity used for hydrogen production and P2X products, demand for electricity on other sectors is also expected to increase. The demand will increase in transport, heating and the existing industry as fossil fuels are replaced by clean electricity. In addition, Finland is expected to become home to new electricity-intensive industries, such as battery manufacturing and data centres. The electricity demand of these sectors are expected to develop in the same way in all scenarios.

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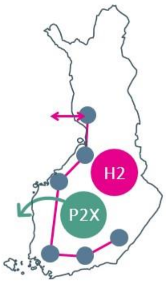
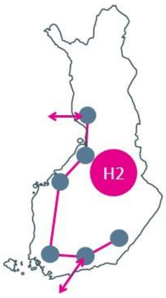
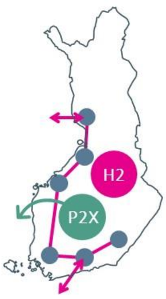
[6] Fingrid's electricity system vision 2023 (Fingrid, 2023)
[7] Green investments in Finland (in Finnish) (Confederation of Finnish Industries, 8.5.2023)
[8] Draft scenarios: Energy transmission infrastructures as enablers of hydrogen economy and clean energy system (Fingrid, Gasgrid; 2022)

Table 1. Description of the hydrogen economy scenarios of Gasgrid and Fingrid and illustrative regional hydrogen transmission connections in the scenarios

SCENARIO	DESCRIPTION
Strong Regional Hydrogen Economy  	Generation and transmission of electricity • A lot of new renewable electricity production will be built in Finland, focusing on onshore wind power • The planned cross-border connections will be built to Northern Sweden and Estonia Production and use of hydrogen • Finland's current hydrogen-using industry switches to clean hydrogen • Finland becomes a major exporter of P2X products Hydrogen transmission infrastructure • Cross-border hydrogen transmission connections will be built in Northern Sweden Storage of hydrogen • Several hydrogen storage facilities will be built in Finland • Finland cannot utilize the large hydrogen storages of Central Europe due to the necessary hydrogen transfer infrastructure not built in the scenario
European Hydrogen Market  	Generation and transmission of electricity • A lot of new renewable electricity production will be built in Finland, focusing on onshore wind power • The planned cross-border connections will be built to Northern Sweden and Estonia Production and use of hydrogen • Finland's current hydrogen-using industry switches to clean hydrogen • Finland becomes a major exporter of hydrogen Hydrogen transmission infrastructure • Hydrogen transmission pipelines will be built in both Northern Sweden and Central Europe for large-scale exports of hydrogen. Storage of hydrogen • Hydrogen storage facilities will be built in Finland • Finland can utilize the large hydrogen storages of Central Europe as the hydrogen transfer infrastructure exists
Leading Hydrogen Ecosystem  	Generation and transmission of electricity • A very large amount of new renewable electricity production will be built in Finland, focusing on onshore wind power • The planned cross-border connections will be built to Northern Sweden and Estonia Production and use of hydrogen • Finland's current hydrogen-using industry switches to clean hydrogen • Finland becomes a very significant exporter of hydrogen **and** P2X products Hydrogen transmission infrastructure • Hydrogen transmission pipelines will be built in both Northern Sweden and Central Europe for large-scale exports of hydrogen Storage of hydrogen • Hydrogen storage facilities will be built in Finland • Finland can utilize the large hydrogen storages of Central Europe as the hydrogen transfer infrastructure exists

It is assumed in the scenarios that clean hydrogen will replace the grey hydrogen that is currently used by domestic industry, and will also be used, for example, to produce fossil-free steel and electric fuels. In addition to covering domestic demand, Finland will develop into a significant player in the European hydrogen market with the majority of demand eventually driven by exports of downstream products and/or hydrogen gas to meet the needs of the European market.

The electrification of industry alone, along with the emergence of a new electricity-intensive industry, requires extensive strengthening of electricity transmission connections both within Finland and in terms of cross-border capacity. In all scenarios, the Aurora Line currently under construction will be in use, and Aurora Line 2 and Estlink 3 cross-border connections will be built in the 2030s.

All scenarios assume that a hydrogen pipeline connection will be in use in Finland and between Finland and Sweden from 2030 onwards. The capacity of the pipeline is set to 13 GW of hydrogen, which corresponds to a pipe with a diameter of 1.2 meters. The capacity of the pipeline was 7.2 GW in the draft scenarios based on the pipe sizes used in the Bothnian Bay Hydrogen Valley research report[9], but with the increase in demand for hydrogen, a larger pipeline is needed especially in 2040. In addition, the *European Hydrogen Market* and *Leading Hydrogen Ecosystem* scenarios contain a pipeline connection built from Finland to Central Europe by 2030, with a transmission capacity of 13 GW of hydrogen based on the European Hydrogen Backbone study[10].

The following chapters describe each scenario and their underlying assumptions in more detail.

2.1.1 The 'Strong Regional Hydrogen Economy' scenario

In the *Strong Regional Hydrogen Economy* scenario, the demand for hydrogen is driven in particular by Finland's development into a major exporter of P2X products, such as e-fuels. A lot of new industry will emerge in Finland, in local hydrogen clusters centred around the production and further processing of hydrogen. Clean hydrogen is produced for the needs of domestic industry, especially by utilising Finnish onshore wind power, which also reduces emissions from Finland's existing industry.

In this scenario, Finland has an internal energy transmission infrastructure and a hydrogen transmission pipeline to Northern Sweden in the Bothnian Bay, but not to Central Europe. In Northern Sweden, the demand for hydrogen will also grow significantly, since hydrogen is used for direct reduction of iron ore for the steel industry, among other things. The need for a transmission connection has been explored, for example, in a study by LUT university where the transmission capacity of the cross-border pipeline was envisioned as 7.2 GW hydrogen[11]. Gasgrid Finland and Nordion Energi have a joint Nordic Hydrogen Route project in the Bay of Bothnia region that is currently analysing the cross-border hydrogen infrastructure of the region[12] and the transmission capacity needs.

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[9] Bothnian Bay Hydrogen Valley – Research Report (Karjunen et al., 2021)
[10] Extending the European Hydrogen Backbone (EHB, 2021)
[11] Bothnian Bay Hydrogen Valley – Research report. LUT Scientific and Expertise Publications 134. (Karjunen, et al., 2021)
[12] https://nordichydrogenroute.com/fi/hanke/

The need for hydrogen storages in the Nordic region is the largest in the *Strong Regional Hydrogen Economy* scenario, because in this scenario Finland's hydrogen system has not been connected to the salt rock caves in Central Europe that enable seasonal storage. Hydrogen storage is necessary so that the production of hydrogen using electrolyser can be controlled in a flexible manner according to fluctuating renewable production and price levels, allowing the use of hydrogen to remain constant throughout the year. To enable this, a large number of domestic hydrogen storage facilities are built in the scenario.

2.1.2 The 'European Hydrogen Market' scenario

In the *European Hydrogen Market* scenario, clean hydrogen replaces grey hydrogen and meets the needs of the domestic steel industry, but the P2X industry does not develop in line with the growth of hydrogen production. Instead, the growth of hydrogen production is driven by the potential of exporting hydrogen gas along a pipeline to the rest of Europe, especially by 2040.

Finland builds a hydrogen pipeline to Northern Sweden similar to that in the *Strong Regional Hydrogen Economy* scenario. In Sweden, the demand for hydrogen will grow faster than in Finland, and exports to Sweden via the northern cross-border connection speed up the growth of Finland's hydrogen economy. Also, a large pipeline connection to Central Europe will be built through the Baltic Sea region by 2030. As a result, export volumes will increase considerably especially in the long term. Therefore, Finland's hydrogen economy will be driven by the high demand for clean hydrogen in the Baltic Sea region and Central Europe. Finland's affordable onshore wind power can meet this demand more cost-effectively than Central Europe's renewable energy resources.

The hydrogen transmission infrastructure through the Baltic Sea region to Central Europe enables the utilisation of the gas storage facilities in the region. Some regions of Europe already have large natural gas storage facilities, such as salt caverns. Large salt caverns are also expected to be able to store hydrogen at a very low cost, and the Baltic Sea pipeline connection will also enable their flexibility to be leveraged in Finland. This reduces the need and profitability of domestic hydrogen storages.

2.1.3 The 'Leading Hydrogen Ecosystem' scenario

The *Leading Hydrogen Ecosystem* scenario combines the demand drivers of the other scenarios. Finland is home to strong domestic demand, as in the *Strong Regional Hydrogen Economy* scenario, and Finland also exports clean hydrogen in response to the Central European demand, as in the *European Hydrogen Market* scenario.

In this scenario, pipeline connections are built to Northern Sweden and Central Europe, which also contribute to the flexibility of the energy system and reduce the need for domestic hydrogen storage capacity.

In this scenario, Finland produces a very large amount of clean hydrogen, which requires a lot of clean electricity generation. The increase in production is limited by the assumption that no more than 4 GW of onshore wind power can be built in Finland per year, which is approximately twice the expected rate of construction in the next few years. This would mean that Finland's wind power capacity could increase to approximately 60 gigawatts by 2040. In this scenario, all onshore wind power that can be built within the limits set is used, along with building of additional offshore wind and solar power.

2.2 Scenario modelling and background assumptions

The purpose of the modelling of the scenarios is to forecast market-driven investments in electricity generation and hydrogen production if the operating environment were to develop as described in that particular scenario. The modelling of the scenarios was carried out by applying an electricity market model, AFRY's BID3[13], which is also used for other purposes at Fingrid. The model analyses the functioning of the market both at an hourly level and at the level of the investment horizons of various production and consumption facilities. The modelling covers the Baltic Sea region and the majority of Central and Western Europe. For example, to export hydrogen from Finland, hydrogen produced in Finland must be cheaper at the time of export than hydrogen produced in the destination country.

Domestic demand for hydrogen was determined separately for each scenario according to the development paths described in Chapter 2.1 above. Sweden's demand for hydrogen was assessed on the basis of reports by Energiforsk[14] and Fossilfritt Sverige[15] among others, but these were modified to make the demand drivers of hydrogen exports and downstream hydrogen products similar in Finland and Sweden. The demand for hydrogen in other European countries was determined on the basis of a scenario by ENTSO-E[16]. The ENTSO-E scenario does not take into account some recent changes in the operating environment, which is why the scenarios have been updated in terms of the effects of the RePowerEU program on clean hydrogen and the renewable volumes, for example.

The electricity generation capacity trends in the scenarios take into account the national minimum requirements for the production of renewable energy in the different European countries. The scenarios assume that if the investments needed to achieve the national targets do not appear to be profitable on market terms, they will be granted support as necessary. On the other hand, the scenarios also set maximum levels for the capacity and commissioning of renewable electricity by country. These maximum levels will be reached by market-driven investments, particularly in Central Europe, reflecting the challenges of commissioning enough renewable electricity generation to meet to the high demand in the region.

Market-term investments in wind and solar power, electrolysis and hydrogen storage were determined by applying a method in which the operating margin obtained by the investments on the wholesale market covers the levelised investment costs and the required return on capital investments[17]. The calculation model optimises the production, consumption and storage of electricity and hydrogen on a region-wide common market, the simulations of which assume perfect competition and complete information over a 10-day time horizon.

The assumptions about the investment costs, operation costs and maintenance costs of electricity generation are primarily based on the ENTSO-E scenario mentioned above. The investment costs of renewable onshore and offshore wind and solar power will decrease, but onshore wind will remain the most competitive one. The investments take into account the connection costs, which are higher for offshore wind power than for onshore wind power, for example.

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[13] https://afry.com/en/service/bid3-power-market-modelling
[14] The role of gas and gas infrastructure in Swedish decarbonisation pathways 2020-2045. (Energiforsk, 2021)
[15] Strategy for fossil free competitiveness – Hydrogen. (Fossil Free Sweden, 2021)
[16] Ten Year Network Development Plan 2022 – Scenario report (ENTSO-E, 2022)
[17] The default required return on capital investments is 5% in real terms

The main categories of electrolysis technologies are alkaline (ALK), polymer membrane (PEM) and solid oxide electrolyser cell (SOEC). The model assumes a 70% efficiency and cost trend for electrolysis, which is in line with alkaline electrolysis. Sources for the estimate of cost trends are the IEA study[18], which was also used for Finland's Hydrogen Roadmap, and other sources[19,20].

Hydrogen can be stored in salt rock caves, rock caves, steel tanks and hydrogen pipes. Of these, especially larger cave solutions can be a cost-effective and suitable solution for longer-term energy storage compared to, for example, electricity storages, which usually have a limited capacity to meet the longer-term need for flexibility due to cost reasons[21]. Rock cave storages have been assumed to be the most cost-effective, large-scale hydrogen storage form in Finland. The cost estimates were refined from the preliminary figures based on the study ordered from LUT university[22] and the studies carried out in the HYBRIT project[23], but they still contain substantial uncertainties due to the novelty of the storage technologies. As a whole, it is most cost-effective to store hydrogen in transmission pipelines. Hydrogen storage solutions and their role in the scenarios are discussed in more detail in Chapter 3.3.

[18] Business Finland, National Hydrogen Roadmap for Finland: (Laurikko, et al., 2020)
[19] https://ens.dk/sites/ens.dk/files/Analyser/technology_data_for_renewable_fuels.pdf
[20] https://ec.europa.eu/energy/sites/ener/files/documents/2018_06_27_technology_pathways_-_finalreportmain2.pdf
[21] https://gasgrid.fi/wp-content/uploads/Gasgrid_Study-on-the-Potential-of-Hydrogen-Economy-in-Finland_ENG-FINAL.pdf
[22] The study will be released separately
[23] https://www.hybritdevelopment.se/en/research-project-1/researchlibrary/

3 Key modelling results of the scenarios

This chapter presents the main modelling results of the scenarios. Chapter 3.1 discusses the production of clean hydrogen in Finland for each scenario, including domestic demand and exports. A summary of the need for electricity and production capacity is given in Chapter 3.2. Chapter 3.3 then discusses the role of hydrogen storages in balancing the energy system.

3.1 Hydrogen production volumes, electrolyser capacities and their use in different scenarios – Clean hydrogen for domestic use and export

In the scenarios, the hydrogen production capacity increases significantly to enable the export of P2X products and hydrogen from Finland. Figure 2 summarises Finland's current consumption of grey hydrogen and the consumption of clean hydrogen for domestic use and exports in each scenario, and the electrolysis capacity used to produce the clean hydrogen in the scenarios.

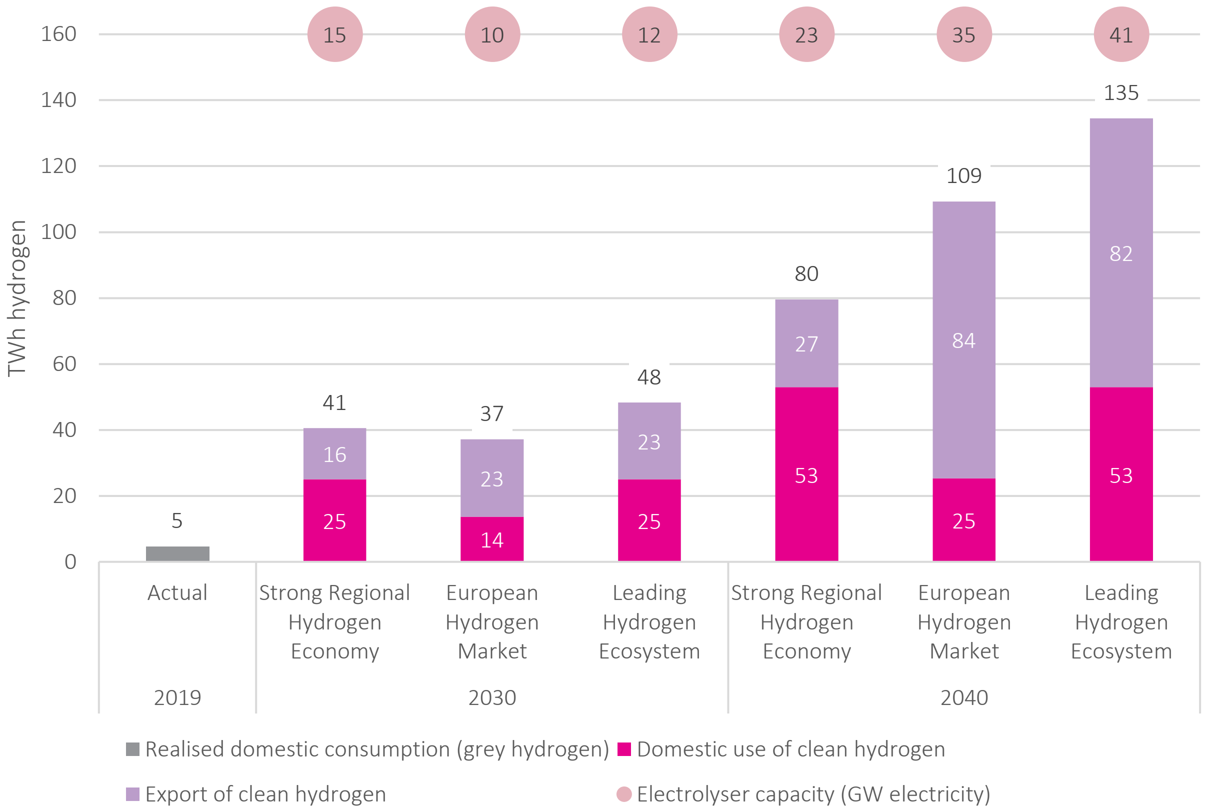

Figure 2 Finland's actual consumption of grey hydrogen and the domestic use and exports of clean hydrogen, and electrolyser capacity, in the scenarios

In the scenarios, approximately 35–50 TWh of clean hydrogen will be produced in Finland in 2030 and 80–135 TWh in 2040. In order to produce these amounts, 10–15 GW of electrolyser capacity has already been installed in Finland by 2030, and the capacity will multiply to approximately 25–40 GW by 2040.

3.1.1 Clean hydrogen for the domestic industry and P2X exports

The domestic demand for hydrogen in the scenarios is based on the existing industry's shift to clean hydrogen and the emerging P2X industry's demand for clean hydrogen, but the volumes vary depending on the scenario (Figure 3). In all scenarios, the level of domestic demand in 2030 is based on the replacement of grey hydrogen with clean hydrogen and on targets released by many companies[24,25,26] in which clean hydrogen is used in new applications such as the steel industry and fuel refining. Most of the consumption would take place in new P2X industry, and hydrogen would be produced especially for the production of e-fuels.

In the *Strong Regional Hydrogen Economy* and *Leading Hydrogen Ecosystem* scenarios, 19 TWh of hydrogen would be used for producing e-fuels in 2030, increasing to 43 TWh in 2040. In the *European Hydrogen Market* scenario, the domestic e-fuel production would be lower, requiring 8 TWh hydrogen in 2030 and 15 TWh in 2040. In all scenarios, the annual demand for hydrogen used in the production of non-e fuels remains the same at 6 TWh in 2030 and increases moderately to 10 TWh by 2040.

Based on the scenarios, the total demand for hydrogen will increase at least threefold and even fourfold from the current level by 2030. This means an annual increase of approximately 3–5 TWh in hydrogen demand if most of the increase takes place between 2025 and 2030.

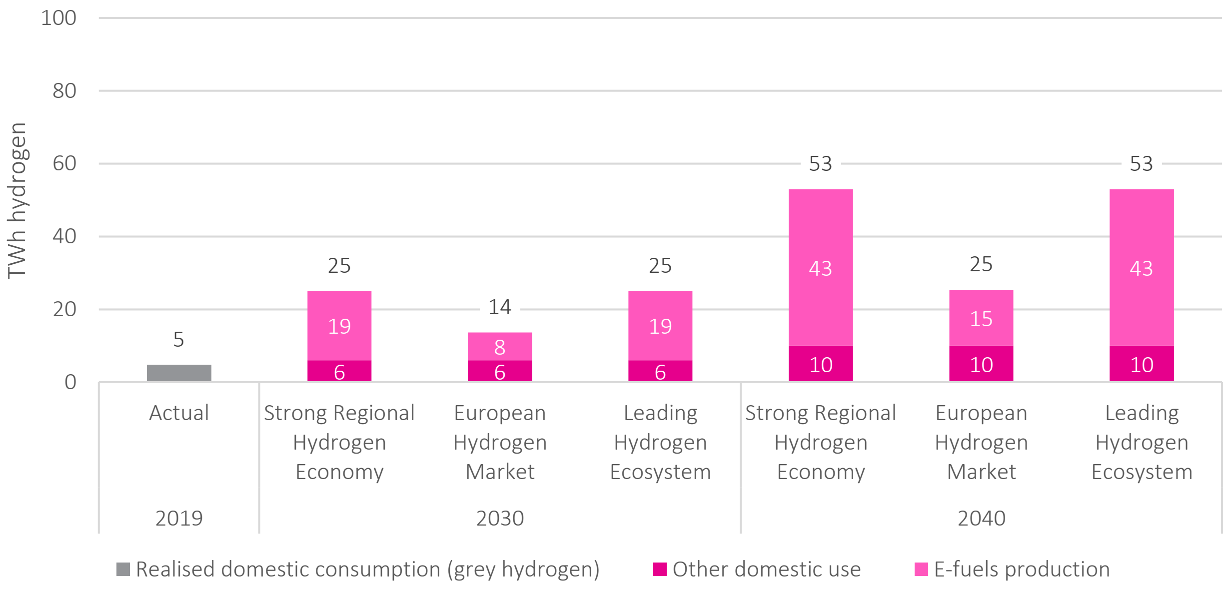

Figure 3 Finland's actual consumption of hydrogen in 2019 and the domestic demand for clean hydrogen in the scenarios

The 2040 estimate for domestic consumption of clean hydrogen in the *Strong Regional Hydrogen Economy* and *Leading Hydrogen Ecosystem* scenarios is close to 60 TWh. This estimate is based on the highest demand level in the scenarios outlined in the study of the hydrogen economy commissioned by

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[24] Ren-Gas: 2.5 TWh of renewable gas fuels for heavy transport. (Company website, accessed on 27 May 2022)
[25] P2X Solutions: 1,000 MW of electrolysis power over the next 10 years. (P2X Solutions, 2022)
[26] Business Finland, National Hydrogen Roadmap for Finland: the consumption of hydrogen will grow by 170 kt (~6 TWh) per year, especially in the oil refining and steel industry (Laurikko, et al., 2020)

the Finnish government[27], which was utilised in the modelling of the scenarios above. This level of demand would mean roughly 3 TWh annual demand increase in the 2030s. *In the European Hydrogen Market* scenario, domestic demand reaches 25 TWh of hydrogen by 2040 and the growth of Finland's hydrogen economy is mainly based on the export of hydrogen gas.

3.1.2 Hydrogen export volumes as hydrogen gas in different scenarios

In the scenarios, the transfer of hydrogen has been modelled based on the assumed pipeline connections and the supply-demand balance of hydrogen in Finland and other countries in the Baltic Sea region. In all scenarios, a pipeline connection to Northern Sweden will be built. In addition, a pipeline connection to Central Europe is built in the *European Hydrogen Market* and the *Leading Hydrogen Ecosystem* scenarios. Figure 4 shows the quantities of clean hydrogen exported as gas to the countries of the Baltic Sea region. Based on the calculations, Finland will become a competitive hydrogen producer, and in addition to covering domestic demand, hydrogen will be exported to both Northern Sweden and Central Europe.

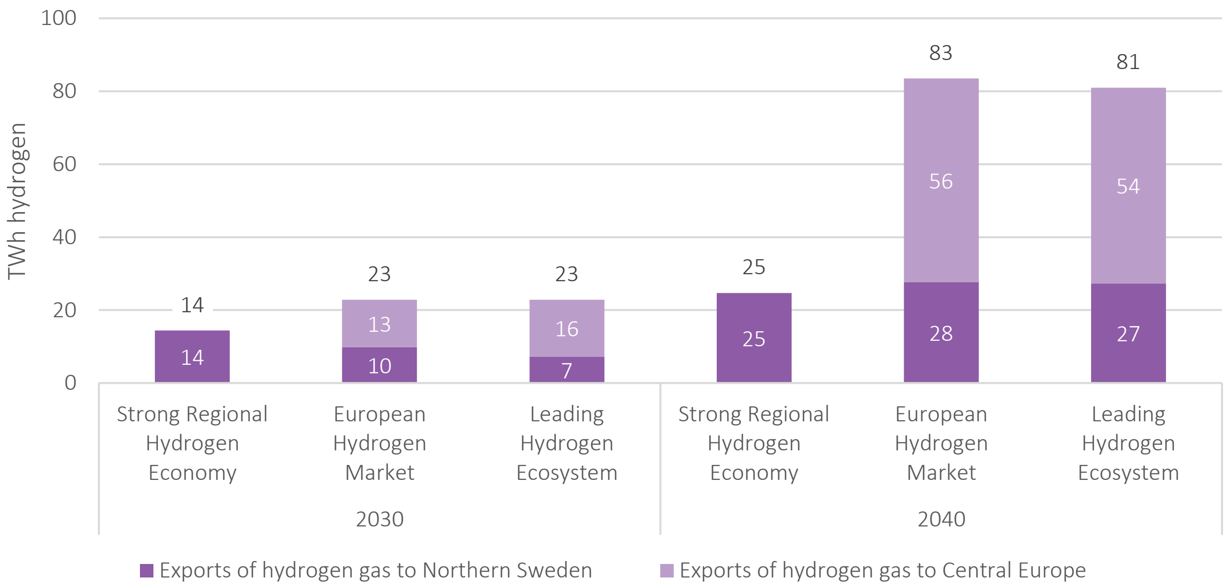

Figure 4 Finland's net exports of hydrogen gas via pipeline connections to Northern Sweden and Central Europe

In 2030, approximately 7–14 TWh of hydrogen (net quantity) will be exported for the industrial needs of Northern Sweden and in the two scenarios with the pipeline to Central Europe, an additional 13–16 TWh is exported to other European countries. By 2040, the amount of exports to Northern Sweden will increase to approximately 25–27 TWh. Most notably, the amount of hydrogen exports will increase to Central Europe, especially in the *European Hydrogen Market* scenario, where exports rise to approximately 80 TWh. In the *Leading Hydrogen Ecosystem* scenario, exports of hydrogen as gas are slightly lower, since a large proportion of the available resources and especially renewable electricity are tied to meeting the domestic demand, which is already very high.

[27] Prime Minister's Office, Hydrogen economy – Opportunities and limitations, p. 162 (Sivill, et al., 2022)

3.2 Growth in electricity generation in the scenarios – Finland's affordable wind power as a driver of competitiveness

In the scenarios, Finland's electricity consumption will almost double from the current level by 2030 and triple-quadruple by 2040. This trend is mainly driven by electricity needed for hydrogen production (Figure 5). In the scenarios, most of the electricity in Finland will be used for clean hydrogen production. In 2030, 50–70 TWh of electricity will be used for hydrogen production, and by 2040, the figure will be 110–190 TWh, depending on the scenario. In 2040, hydrogen production uses more electricity than all other sectors combined, despite the fact that the consumption of electricity will also increase in other sectors due to the electrification of industry, transport and heating, as well as the emergence of new industry and data centres.

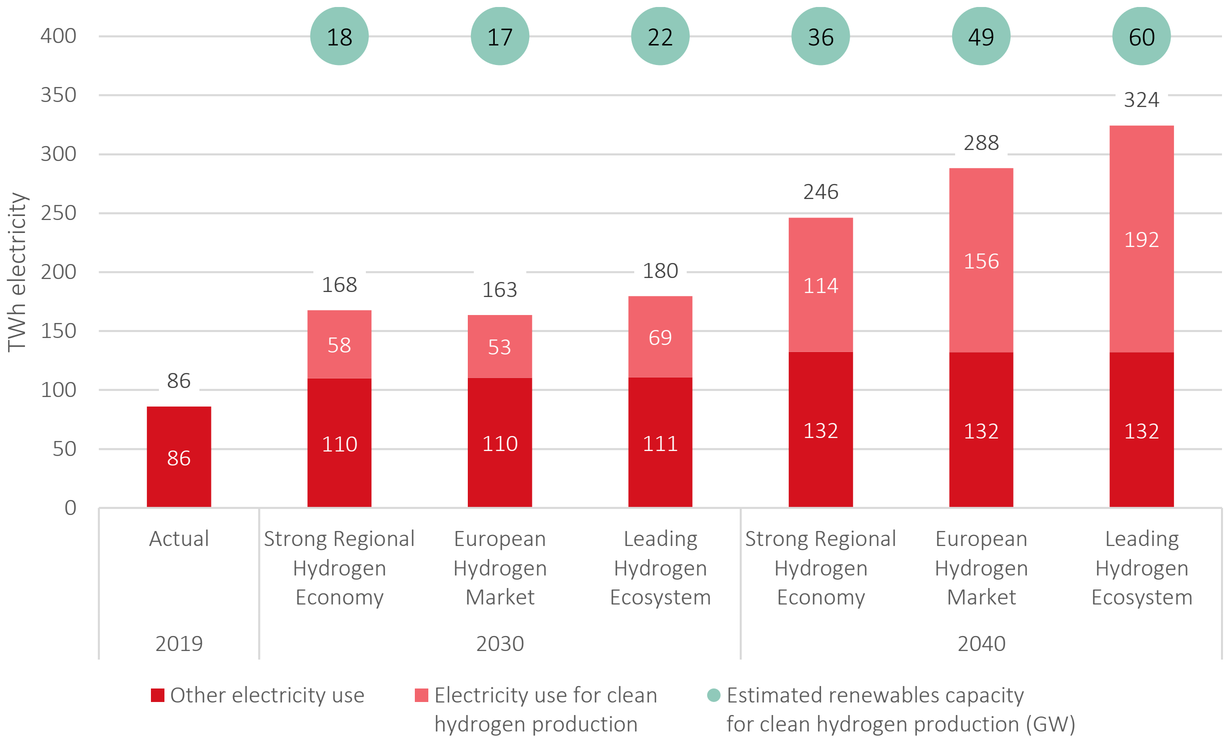

Figure 5 Finland's consumption of electricity split between electricity use for clean hydrogen production and for other use, and the estimated renewable capacity required for producing the clean hydrogen[28,29]

Very significant investments are required in renewable electricity generation to match the increasing demand with clean electricity. The volume of onshore and offshore wind and solar power will increase considerably in order to meet the demand. Figure 5 shows an estimate of the renewable electricity generation capacity needed for clean hydrogen production. In addition, renewable sources of electricity are used to meet other increased demand. Most of this is onshore wind power, which is the most competitive new electricity generation in Finland with a very large number of projects under development.

[28] Source for electricity consumption in Finland in 2019: Official Statistics of Finland (OSF, 2019): Energy supply and consumption
[29] In this context, 'renewable electricity generation capacity' refers to onshore and offshore wind power and solar power. The capacity is estimated at an average utilisation period of maximum load of 3200 hours.

In the scenarios, onshore wind capacity will increase to more than 20 gigawatts by 2030 and to 50–60 gigawatts by 2040. This requires the capacity of onshore wind power to increase by approximately 3–4 GW per year in the 2030s, while the annual growth rate in the next few years is projected to be around 2 GW at most. As a result, the growth rate of renewables, especially onshore wind power, is one of the key uncertainties in the scenarios.

In one hand, if the additional construction of onshore wind power progressed faster, the production volumes of clean hydrogen in Finland could be even higher than those presented here. On the other hand, if additional onshore wind power were constructed at a slower rate, this would also limit the production of clean hydrogen. Therefore, increasing speed of permitting for wind power and the energy transmission infrastructure it requires, as well as the utilisation of the wind power potential of Eastern Finland, would contribute to the actualisation of investments in hydrogen. In addition to onshore wind power, 4–9 GW of offshore wind power and 7–15 GW of solar power will be built in Finland by 2040 in all scenarios.

In the scenarios, the generation of onshore and offshore wind and solar power will reach 100–115 TWh by 2030 and will increase further to 215–290 TWh by 2040. This means that most of Finland's power generation would be weather-dependent. This creates an enormous need for demand flexibility to keep the electricity system in balance.

3.3 The role of hydrogen storage in different scenarios – Hydrogen storage brings flexibility to the energy system

Hydrogen storages can bring flexibility and cost-effectiveness to the energy system. By integrating the electricity and hydrogen system, enormous amounts of renewable electricity can be generated for hydrogen production with onshore and offshore wind power and solar power, although their output varies depending on weather conditions. For example, an extensive hydrogen network can itself act as an energy buffer in the energy system.

The strong increase in hydrogen production and consumption outlined in the scenarios requires significant hydrogen storage capacity to balance weather-dependent wind power and consumption of hydrogen in the industry, which is assumed to be flat around the year. Therefore, the scenarios model the role of hydrogen storage in the balancing of the energy system and smoothing out the differences between production and consumption. Figure 6 presents the capacities of these hydrogen storage facilities as energy quantity and as injection capacity.

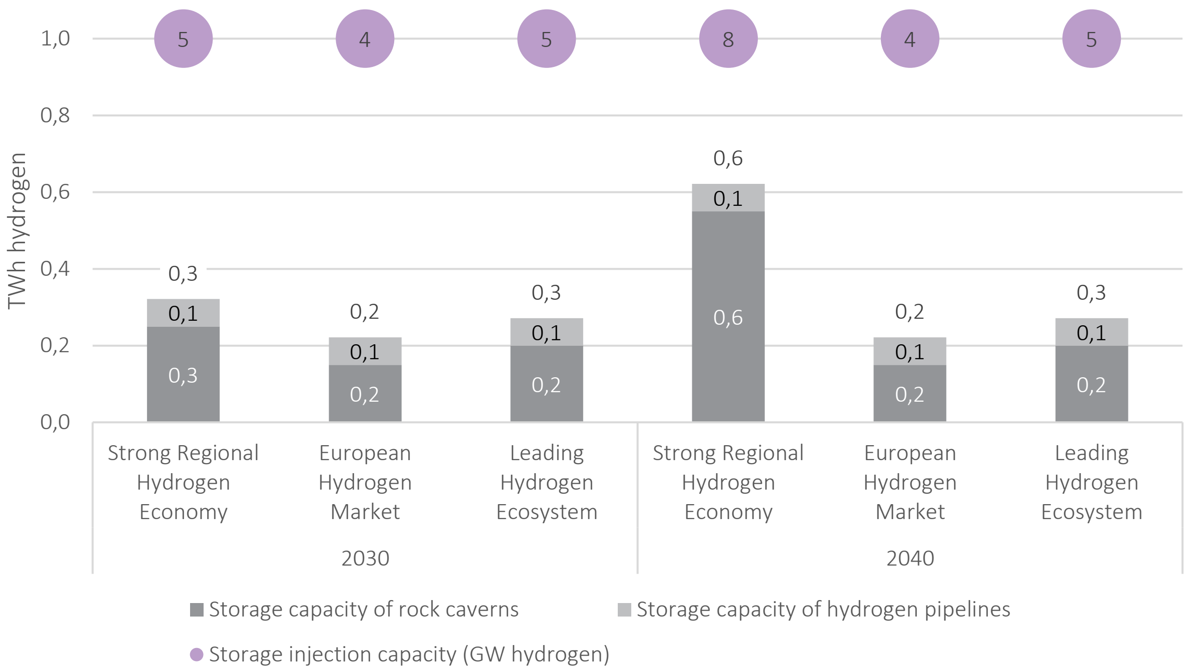

Figure 6 Energy and injection capacity of hydrogen storages in the scenarios

The storage volumes take into account both storage in rock caverns and the storage capacity of the hydrogen transmission infrastructure, meaning the so-called buffer capacity of the pipelines. In all scenarios, the need for flexibility in the system and consequently for hydrogen storage will increase significantly by 2040, but the scenarios diverge in this respect. Domestic rock cavern storage plays an important role in the *Strong Regional Hydrogen Economy* scenario, whereas in the other scenarios, the domestic storage capacity is primarily based on the storage capacity of the pipeline network. In these scenarios, the need for domestic storage capacity is lower, since the salt cavern storage facilities in Central Europe can be used, due to the hydrogen pipeline connecting to the region.

In the *Strong Regional Hydrogen Economy* scenario, the combined storage capacity of domestic hydrogen storage facilities corresponds to approximately 4–5 days of domestic hydrogen consumption. The injection capacity of the storages in the scenario corresponds to approximately half of the electrolyser hydrogen production capacity. In the other scenarios, the capacity of domestic hydrogen storages is in comparison much lower because the large and more cost-effective salt rock cave storages in Central Europe can be utilized through the export and import of hydrogen.

The hydrogen transmission infrastructure enables a wider hydrogen market to emerge when connections to other countries are built. Because of this, the reliability of hydrogen supply will improve as consumption and production are balanced by more actors (production, consumption and storage) and the direction of hydrogen flow can be determined according to the market balance. From the point of view of security of supply, domestic hydrogen storages are also needed in addition to foreign salt rock cave storages to balance production fluctuations at all times. Part of the domestic storage need is met through the storage capacity of the hydrogen pipelines, but in addition to this, there is a need for rock cave storages in the scenarios.

4 Investments and markets in the hydrogen economy

4.1 Massive investments pave the way to a clean energy system

Producing clean hydrogen on the scale presented requires massive investments in renewables capacity, electrolysers, and hydrogen storages. Investments are also needed in energy transmission and to further processing of hydrogen to P2X products, such as e-fuels. Large-scale investments are expected to be carried out on market terms. Finland's advantage compared to the rest of Europe is especially very high potential in affordable renewable electricity generation.

Figure 7 illustrates the scale of investments in the production of clean hydrogen by 2030 and 2040 in the different scenarios. Renewables generation requires most of the investments, which reach approximately EUR 15–20 billion by 2030 and around EUR 30–60 billion by 2040. The investments in electricity generation equal the electricity consumed by electrolysis, which would primarily be produced by Finnish onshore wind power (see 3.2, Figure 5). Investments in domestic energy transmission are a fraction of the presented costs. In addition to the figures presented, investments are required to utilise hydrogen and produce P2X products. According to VTT's report[30], the value of current hydrogen economy projects related in Finland is around 10 billion euros, and especially investments in the direct reduction of iron ore using hydrogen to produce fossil-free steel and to methanation and ammonium plants to produce e-fuels stand out.

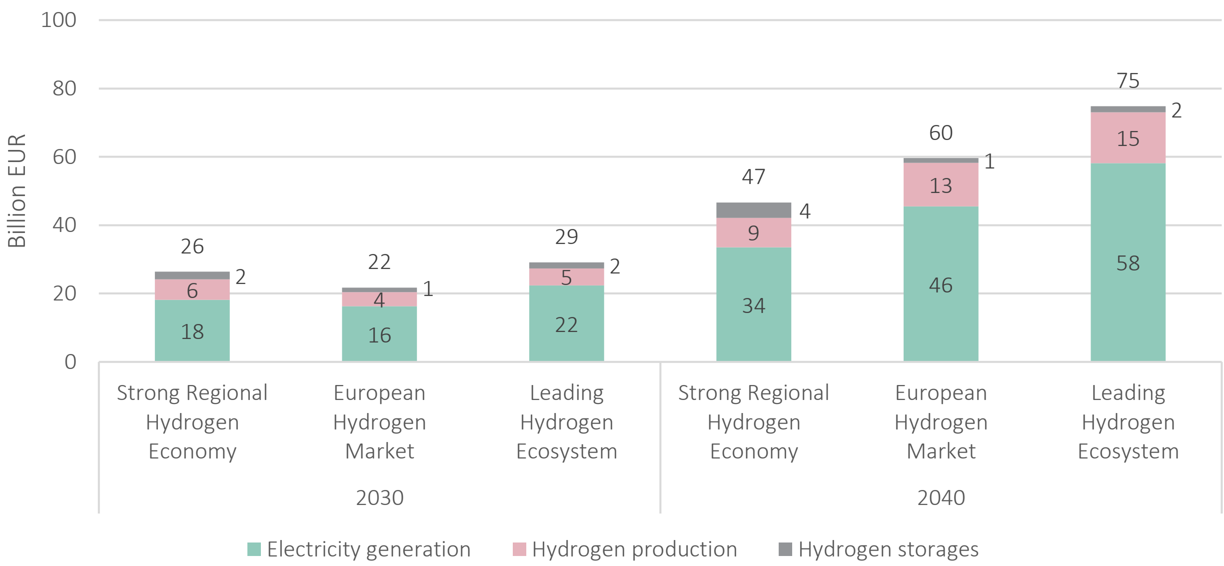

Figure 7 An estimate of cumulative investments in the production of clean hydrogen in Finland by 2030 and 2040 – does not include investments in energy transmission and hydrogen use or downstream processes

By 2030, investments in hydrogen production and storage will be 5-8 billion euros and will reach a total of 13–17 billion by 2040. The majority of these investments take place in electrolysis (see capacities, Figure 2), but the magnitude of investments required for rock caverns is also significant (see capacities, Figure 6). This is particularly evident in the *Strong Regional Hydrogen Economy* scenario, in which significant

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[30] Pre-study on transition to hydrogen economy, specifically in Northern Ostrobothnia (Kiviranta et al., 2023)

investments of almost EUR 4 billion are made in domestic storage and EUR 9 billion in electrolysers. The magnitude of the investments does not take into account any additional investments in the hydrogen economy value chains (e.g. P2X downstream chain), which further highlights how investments in transmission infrastructure have a multiplier effect on the emergence of new industries. The benefits of the value chains will be assessed in the future phases of the joint project.

It has to be noted that investments on hydrogen storages are subject to significant uncertainties, for example in the construction costs of hydrogen storage facilities and technical solutions. A range of storage solutions already exists for natural gas, but large-scale storage facilities for hydrogen are still in the pilot phase. In Sweden, for example, a rock cavern is being piloted for hydrogen storage in the HYBRIT project[31].

4.2 Investments open the door to a multibillion-euro hydrogen market

Large investments in the production of clean hydrogen will enable Finland to participate in the multibillion-euro market for clean hydrogen in the EU (Figure 8). The price of competitive clean hydrogen is estimated to be EUR 2.5/kg in 2030, falling to around EUR 2/kg by 2040[32]. At these prices, the value of Finland's clean hydrogen production is EUR 3–4 billion annually in 2030, rising to EUR 5–8 billion by 2040. In addition to this, added value is generated in Finland by further refining hydrogen into P2X products such as e-fuels, the value of which is clearly higher than the value of hydrogen production alone. This added value has not been estimated in this report.

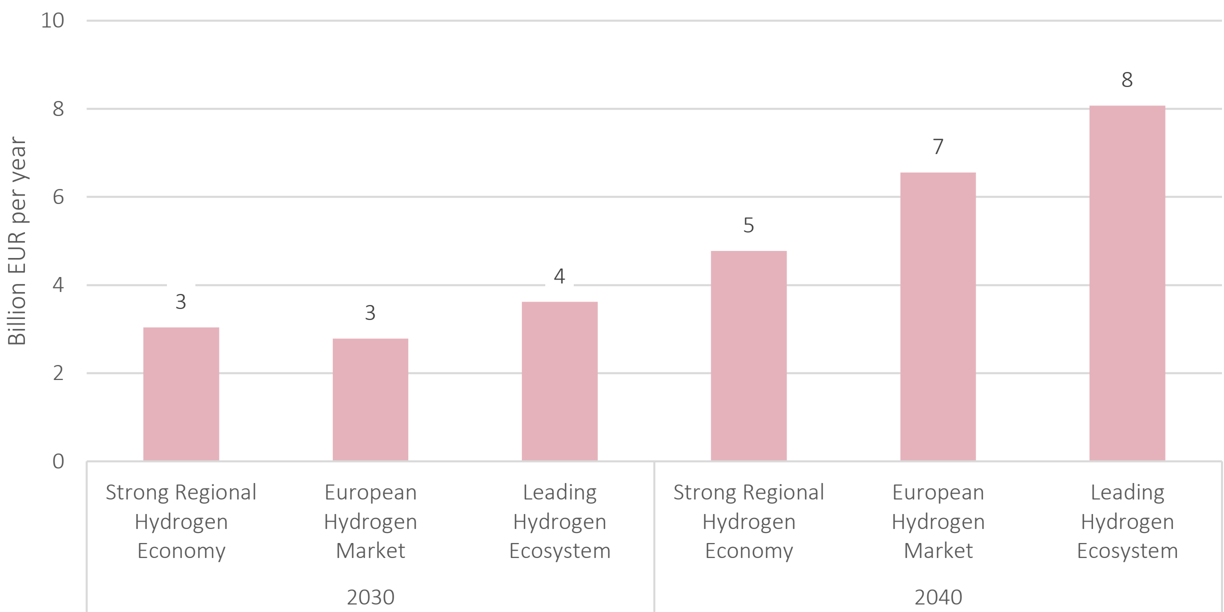

Figure 8 Estimated annual value of Finland's clean hydrogen production – includes only the estimated value of hydrogen gas and excludes the added value of P2X products

[31] https://fuelcellsworks.com/news/ssab-lkab-and-vattenfall-started-building-a-rock-cavern-storage-facility-for-storing-hydrogen/
[32] Five Hydrogen supply corridors for Europe in 2030, p. 115 (EHB, 2022)

When assessing Finland's potential as a hydrogen exporter, it is important to take into account the EU's objectives for a clean hydrogen market. The estimated size of the EU hydrogen market in 2030 is approximately 670 TWh[33] and in 2040 approximately 1,300 TWh[34]. In the REPowerEU plan, the goal for 2030 is that half of the EU hydrogen demand would be covered by hydrogen production in the EU and half would be imported from other regions. Considering these targets and clean hydrogen produced in Finland in the scenarios, Finland's share of the hydrogen produced in the EU is 11–14% in 2030 and 12–21% in 2040 (Figure 9). Scenarios show that Finland has what it takes to punch above its weight, to develop into Europe's leading position in the hydrogen economy and produce over 10 % of clean hydrogen produced in the EU.

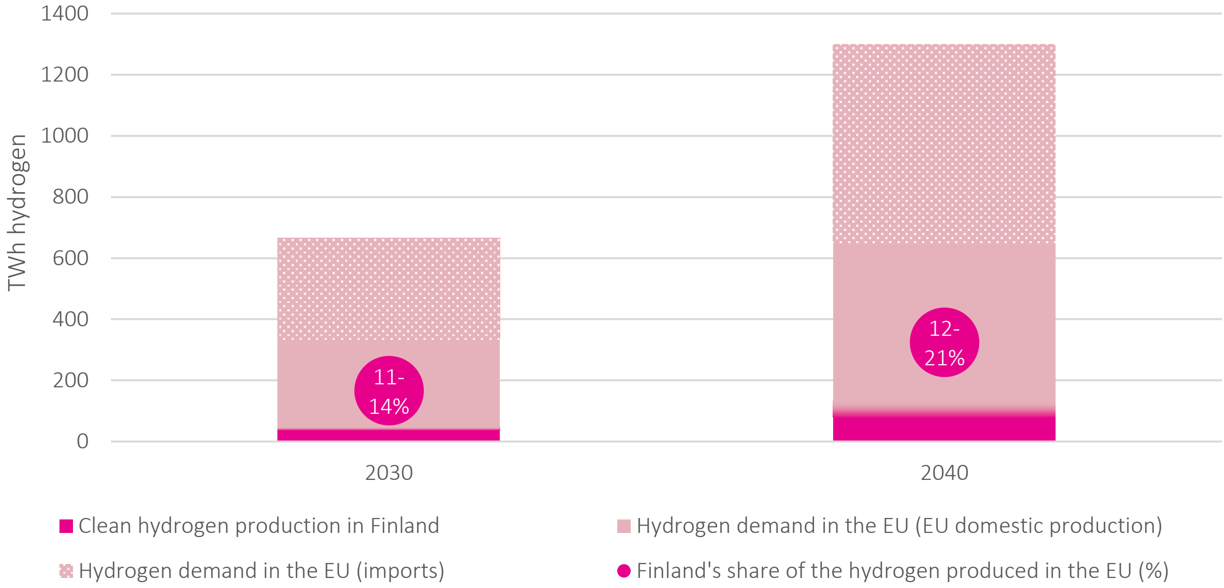

Figure 9 Estimate of Finland's share of the hydrogen produced in the EU based on the scenarios[35]

[33] Based on the EU's REPowerEU plan, taking into account both the EU's 10 Mt production target and the 10 Mt import target by 2030 (European Commission, 2022)
[34] Based on the scenarios in the Development Plan for European Electricity and Gas Network Operators. Note: the scenarios do not take into account the impact of the REPowerEU plan, against which the estimated hydrogen demand appears low. (ENTSO-E, ENTSOG, Ten Year Network Development Plan 2022)
[35] Estimate considers hydrogen demand figures in the EU are estimated from the sources above, and that half of EU's hydrogen demand is covered by imports from other regions based on the EU's REPowerEU plan target for 2030, i.e. half of the demand is produced within the EU. The figure shows the range of Finland's clean hydrogen production in the scenarios of this study.

5 Transmission infrastructure enables investments in Finland

Based on the scenarios, the production of clean hydrogen is cost-competitive in Finland, which makes it profitable to produce and also export as gas or P2X products to other parts of Europe, where demand is expected to grow enormously. In all scenarios, hydrogen transmission infrastructure will enable the transmission of hydrogen gas in a pipeline between Finland and Northern Sweden in 2030. In addition, the *European Hydrogen Market* and *Leading Hydrogen Ecosystem* scenarios assume that a hydrogen pipeline is constructed between Finland and Central Europe. The chapters below discuss in more detail what kinds of transmission infrastructure development needs exist in each scenario.

5.1 The need for energy transmission will grow many-fold from the present level

A large part of Finland's electricity consumption is located in the south, while a significant part of the growth potential of renewable electricity production is in the north. It has been identified in Fingrid's electricity system vision[36] scenarios that domestic north-south electricity transmission capacity must be multiplied in the long term. The locations of hydrogen and renewable electricity production have a very large impact on the transmission needs.

Most of Finland's existing wind farms are in Ostrobothnia region, while Southern and Eastern Finland have only a few. In Southern Finland, the potential of wind power is constrained by the higher population density, among other things. In Eastern Finland, the constraint is created as a matter of defence policy as wind turbines can interfere with radar surveillance, which limits the areas in which wind farms can be constructed and their size. This, in turn, reduces the interest of operators in developing wind power. Due to these constraints, most new wind power projects are located in Western and Northern Finland. In the scenarios, however, the constraints in Eastern Finland are assumed to be solved, which is supported by a recent study[37], and wind power can be built in Eastern Finland as well.

In Finland, hydrogen is currently used in the chemical industry, especially in Southern Finland[38], and hydrogen production is largely concentrated in the vicinity of the industrial facilities using hydrogen. In the scenarios the grey hydrogen use is replaced with clean hydrogen in the current industrial facilities, in addition to which the emergence of new industry is a main driver of the increasing hydrogen demand. Most of the domestic hydrogen projects announced so far are in Southern Finland[39] in locations including Vantaa, Porvoo and Inkoo[40]. In addition to this, there are several investments on the coast of the Bay of Bothnia[41] along with growth prospects in Eastern Finland.[42]

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[36] Fingrid's electricity system vision 2023 (Fingrid, 2023)
[37] Itäisen Suomen tuulivoimarakentamisen tehostaminen (in Finnish) (Räty, 2023)
[38] Business Finland, National Hydrogen Roadmap for Finland: (Laurikko, et al., 2020)
[39] Valtioneuvoston kanslia, Vetytalous – mahdollisuudet ja rajoitteet (Sivill, et al., 2022)
[40] Four-billion-euro investment planned into a green steel plant in Inkoo, Finland – Release (Business Finland, 10.1.2023)
[41] Both$_2$nia-network (for more information: https://www.both2nia.com/en)
[42] Suomen Vetylaakso ry perustettu edistämään itäisen Suomen elinvoimaa ja teollisia investointeja (in Finnish) (Lappeenranta.fi, 2.2.2023)

Currently, hydrogen is mainly produced close to the point of use, but in the future energy system, hydrogen production and use can be located in different geographical areas if the hydrogen infrastructure develops to enable the necessary transfer between them. The geographical distribution of hydrogen production and use is one of the most significant questions in the scenarios and affects the necessary energy transmission infrastructure substantially.

The production of clean hydrogen using an electrolyser requires a lot of renewable electricity, as does the industrial processing of hydrogen into downstream products. The locations of hydrogen production facilities and user sites in relation to electricity production therefore determines the need for internal energy transfer in Finland. The need to transfer electricity becomes critical if hydrogen production plants and sites of use are located far from the production of renewable electricity. On the other hand, if hydrogen production facilities are located close to renewable production of electricity but far from the hydrogen users, the need to transport hydrogen becomes a critical factor. The need for energy transmission is the lowest if both the production of renewable electricity and the production and use of hydrogen are located as close to each other as possible. This formation of the need for energy transfer within Finland is described in more detail in Chapter 5.1.2.

In order to achieve the potential shown by the scenarios, it is important that the production of renewable electricity as well as the hydrogen production plants and applications are located in a rational way from the point of view of the system and are flexible if necessary. The market should also give signals to the transfer of electricity and hydrogen in accordance with society's overall optimum. Electricity and hydrogen infrastructure can work well together and support each other, which enables the growth seen in the scenarios as cost-effectively as possible.

5.1.1 Location of hydrogen consumption and renewable electricity generation in Finland

In the scenarios, Finland is divided into Northern and Southern parts across Central Finland. This division is used to describe the domestic energy transfer needs within Finland. The need for energy transmission is greatly influenced by the location of electricity and hydrogen production and consumption.

Figure 10 shows domestic regional and export hydrogen demand in the scenarios in 2030. In the north, the growth will mainly be driven by the steel industry's use of hydrogen and exports to Northern Sweden. In the south the demand grows due to the replacement of grey hydrogen in existing industrial plants and in the production of electrical fuels, as well as due to exports in the two scenarios with a hydrogen pipeline to the Central Europe.

In all scenarios, the domestic demand for hydrogen is higher in the southern part of Finland due to the assumptions made about the locations of the industry, although in the *European Hydrogen Market* scenario, the development between the regions is fairly even by 2030. However, due to the export of hydrogen, the demand will be focused on the north in the *Strong Regional Hydrogen Economy* scenario, because a large hydrogen market will develop in the region of the Gulf of Bothnia with the hydrogen pipeline connection. In the *European Hydrogen Market* scenario, the export demand is slightly higher towards Central Europe and thus the overall demand is higher in the southern part of Finland. In the *Leading Hydrogen Ecosystem* scenario, the focus of hydrogen demand is strongly on the southern part due to both the Finnish industry and Central European export demand.

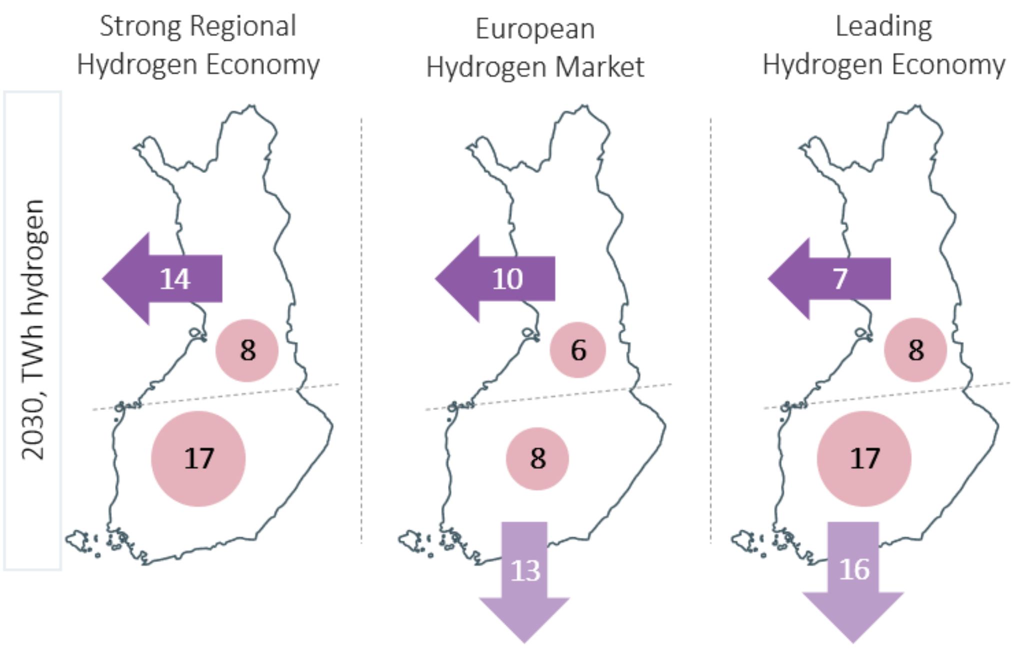

Figure 10 Domestic regional and export hydrogen demand in the scenarios in 2030 (TWh hydrogen)

In all scenarios, the majority of new renewable production is built in the north, even though there are no restrictions on wind power commissioning in the Eastern Finland, which would be part of the southern region. As there is also lower electricity demand in the north, it has surplus production, while the south remains in deficit due to higher electricity demand. Because of this, there is a need to transfer energy from north to south in all scenarios.

By 2040 (see Figure 11), the growing production of electrical fuels in production facilities located in the south evens out the area's hydrogen demand in the *Strong Regional Hydrogen Economy* scenario, when taking into account also the exports to Northern Sweden. In the *European Hydrogen Market* and *Leading Hydrogen Ecosystem* scenarios, in addition to the domestic industry growth in the south, the increasing export of hydrogen gas via a hydrogen pipeline from the south drives the focus of hydrogen demand to southern Finland. In all scenarios, renewable onshore and offshore wind power is built especially in the north, which increases the area's surplus. A large surplus in the north and a deficit in the south leads to a very large need to transfer energy from the north to the south.

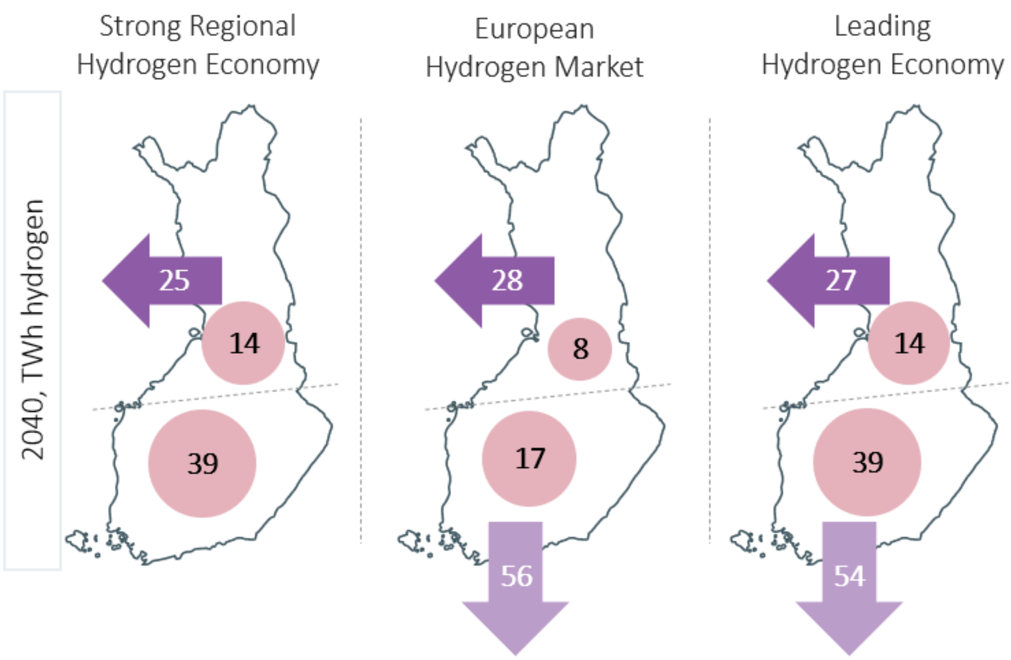

Figure 11 Domestic regional and export hydrogen demand in the scenarios in 2040 (TWh hydrogen)

5.1.2 Assessment of the energy transmission required in Finland in the scenarios

The need for energy transfer between Northern and Southern Finland is currently approximately 10 TWh, and it will more than double by 2030. By 2040, the need for energy transmission will increase by several times: to a minimum of 60 TWh and a maximum of up to 100–115 TWh. The higher transmission need in the two last scenarios stems from the need to export hydrogen in large quantities via the pipeline that runs from Southern Finland to Central Europe.

Energy transfer can be either as electricity or as electricity and hydrogen. The location of the hydrogen production facilities affects whether the energy would be transferred as electricity or hydrogen. For example, an electrolyser connected to a wind farm in the north could produce clean hydrogen, which could then be transferred to industrial facilities in the south. Similarly, the electrolyser may be located near the industrial facility far from electricity generation, in which case the transmission is carried out as electricity. However, when energy is transferred as electricity, a larger amount of energy is needed, since 30% of the electricity is wasted in the losses of the electrolysis process. On the other hand, most of the losses can be utilised as waste heat, which can encourage the placement of electrolysers close to large cities and their district heating networks, for example.

Therefore, the need for energy transmission in Finland is determined through the following locational factors, which are also depicted in Figure 12.

1. The production of renewable electricity, the production of hydrogen, and the use of hydrogen are at location A
   - **No large-scale national energy transfer need**
   - Electricity and hydrogen are utilized in production of P2X products; energy is bound to the products and transferred in the form of P2X products such as chemicals and fuels
2. The production of renewable electricity and the production of hydrogen are at location A, the use of hydrogen is at location B
   - **Energy is transferred to the destination, industrial site, as hydrogen**
3. The production of renewable electricity is at location A, the production and use of hydrogen is at location B
   - **Energy is transferred to the destination, industrial site, as electricity**
   - There is a possibility of utilizing the waste heat generated in hydrogen production in applications such as the production of district heat near to the industrial site
4. The production of renewable electricity at location A, the production of hydrogen at location B, and the use of hydrogen at location C
   - **Energy is transferred as both electricity and hydrogen:** as electricity from renewables production site to hydrogen production site, and as hydrogen from hydrogen production site to the destination, industrial site, using hydrogen

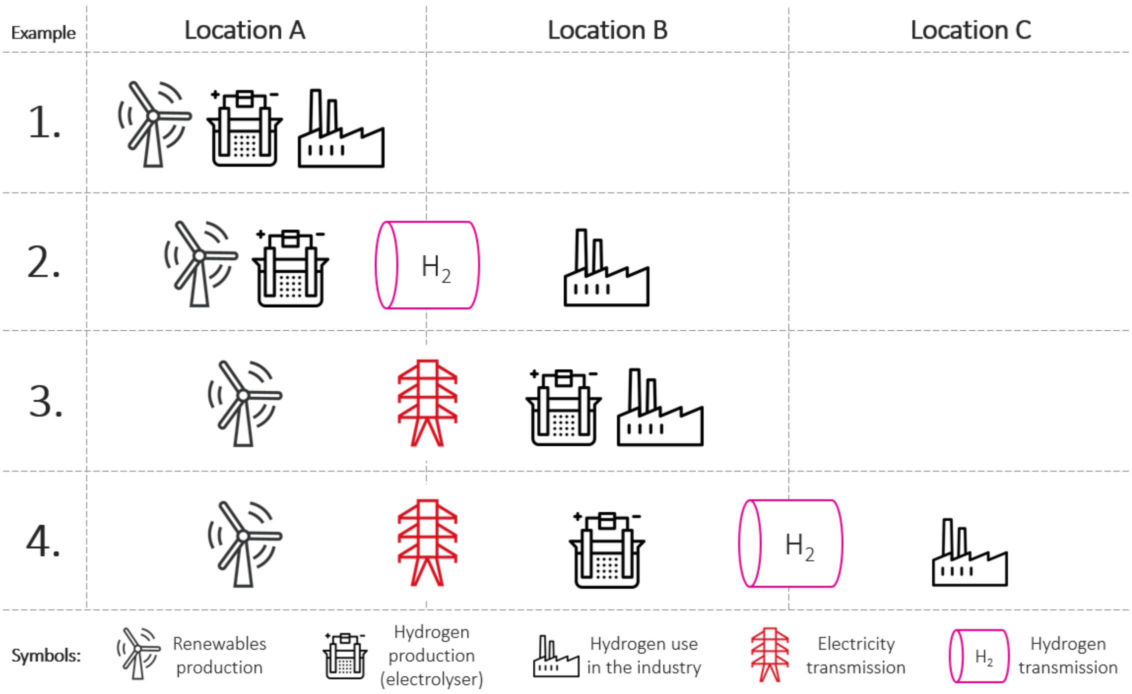

Figure 12 The need for energy transmission is determined by how the production of renewable electricity, the production of hydrogen, and the use of hydrogen are located in relation to each other

If the production of hydrogen is located close to the point of production of renewable electricity, need for electricity transfer is reduced. Correspondingly, the production of hydrogen at the point of use reduces the need for hydrogen transfer. The need to transfer hydrogen is also affected by exports from North Finland to Sweden and from South Finland to Central Europe.

The large-scale energy transfer from Finland to Central Europe outlined in the scenarios (56 TWh of hydrogen corresponds to 80 TWh of electricity) is only possible using hydrogen pipelines or in the form of downstream P2X products. The transfer of an equivalent amount of net energy as electric power with the same peak usage times would require almost 19 GW of electricity transmission capacity, i.e. approximately 19 similar connections to the current ones, which would not be efficient from the point of view of the electricity system.

In terms of developing the system, it is of primary importance for Fingrid and Gasgrid to identify their customers' energy transmission needs in time, and respond to them by planning and building the necessary transmission infrastructure. As the sector integration of electricity and hydrogen continues, the companies must also consider the development of each other's transmission infrastructure in their planning, and strive to create the most cost-effective energy system in Finland through joint planning. From the point of view of the total costs of the system, it is important to encourage both production and user facilities to locate and/or be flexible in an optimal way while also taking the transfer investments into account. This enables the greatest possible growth potential to be realized in a cost-effective manner.

6 Conclusions

Finland has very good preconditions to develop into a pioneer in the hydrogen. The potential of Finland's renewable electricity production is significant and can be utilized both for the electrification of society and for the use of new electricity-intensive industries. In addition to resources of renewable electricity, Finland has a robust power grid, skilled workforce and several companies to operate in value chains of the hydrogen economy. Hydrogen produced using clean electricity along with the downstream P2X products may grow into an important export industry for Finland.

According to the Finnish Government's resolution, Finland is aiming for Europe's leading position in the hydrogen economy throughout the entire value chain. During the scenario work, the considerable growth of renewable production has continued in Finland and several dozen hydrogen-related projects have been launched. The operating environment is constantly changing, and the pace of development has accelerated considerably in the recent times.

The scenarios presented three development paths for Finland's role in the value chain of the European hydrogen market. In the scenarios, Finland develops into a major producer of either P2X products or hydrogen gas, or both, to meet the growing needs of the European market. In all scenarios, Finland's market share will increase to more than 10 percent of the clean hydrogen produced in the EU by 2030. The growth assumptions of the scenarios strongly challenge the development of the energy system and thus help to ensure that the development needs of both electricity and hydrogen transmission infrastructure are assessed comprehensively and in time.

Energy transfer in the scenarios increases significantly when the production and consumption of both electricity and hydrogen are located across Finland. The energy transfer required by the hydrogen industry can take place either as electricity, as is the case today, or in the future, part of the transfer can also be carried out as hydrogen, as in the scenarios. This requires the development of electricity transmission and hydrogen transmission infrastructure to meet customer needs. The scenarios develop both domestic and cross-border electricity transmission and hydrogen transmission infrastructure. The formation of the hydrogen transmission infrastructure also enables the essential export and import of clean hydrogen gas in the scenarios, which has a wide impact on the rest of the energy system as well.

Gasgrid and Fingrid see joint planning as important for the development of the most cost-effective energy system. In order to promote Finland's competitiveness, it is important that the energy infrastructure is developed comprehensively, taking future transmission needs into account. By promoting the hydrogen economy investments in Finland, we can achieve Europe's leading position in the hydrogen economy. In addition, building international hydrogen infrastructure expands the hydrogen market and creates new business opportunities for companies in the hydrogen value chain.

Based on the finalised scenarios, we will continue our work together to study what the modelling results mean in terms of Finland's energy infrastructure and the entire value chain of the hydrogen economy. Our goal is to find the most cost-effective infrastructure development paths for the Finnish energy system in various future scenarios. In addition, the focus is on different options for the development of hydrogen infrastructure and sector integration between energy infrastructures.

The final report of the project will be completed in autumn 2023.

In spring 2021, Finland's gas transmission grid operator, Gasgrid Finland, and its electricity transmission system operator, Fingrid, began work to identify opportunities for the hydrogen economy to thrive in Finland and to clarify the role of energy infrastructure as an enabler of the hydrogen economy. The collaboration was followed up in tangible form by a research and development project jointly run by Gasgrid and Fingrid. The new project is being executed as part of HYGCEL, a wide-ranging research project consortium consisting of several Finnish companies and research institutes. On 28 October 2021, Business Finland awarded a grant for the joint project between Fingrid and Gasgrid, as well as for the larger entity.

Gasgrid Finland Oy is a state-owned company that acts as the gas transmission system operator with system responsibility in Finland. We offer our customers safe, reliable and cost-effective transmission of gas. We develop our transmission platform, services and gas markets actively and in a customer-focused way to promote carbon-neutral energy and the raw materials system of the future. For more information, see: www.gasgrid.fi

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