A study of the factors affecting the profitability of Åland's offshore wind power projects

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Content

1. Introduction

Complete version of the work was submitted on 29.1.2024. The analysis of this report and its conclusions are based on the data available at that time.

Objective

- The aim of this study is to assess the factors affecting the value of offshore wind power projects located in the sea areas of Åland, and to identify ways in which Åland can increase the added value from the projects.

Background

- The amount of wind power production has increased significantly in Finland in recent years. While the majority of finished projects have involved onshore wind power, there is a notable surge in the planning of offshore wind power projects.
- The total capacity of offshore wind power projects being planned in Finland is over 33 GW. A significant part of the offshore wind power potential is located in the sea areas of Åland, which offers remarkable opportunities for the region.
- Åland's geographic location presents lucrative possibilities to connect offshore wind power projects to the wholesale market zones of both Finland and Sweden. In addition to the wholesale markets, offshore wind power production could be utilized in the production of hydrogen or synthetic fuels. In the future, the region's hydrogen production may also possibly be connected to the European Hydrogen Backbone network*.
- Due to the factors mentioned above, it is important that when the sea areas are tendered, all the opportunities offered by the projects are known as well as the risks that may have an impact on the profitability of offshore wind power projects and thus the value of the sea areas.

Structure of the report

- The first part of the report 1) describes general principles of how the value of the sea areas is formed, 2) provides an overview of the renewable energy directive that drives the demand for hydrogen and impacts electricity markets and 3) describes the estimated development of electricity and hydrogen markets.
- The second part of the report centers its attention on 1) identifying factors that affect the earning potential of the offshore wind power projects in Åland, 2) analysing the significance of the earning potential and potential business cases of the offshore wind projects and 3) describing how the value of the sea areas could be maximised while highlighting the key uncertainties related to their future value.

*The EHB network is a Europe-wide initiative to establish a common hydrogen market via a network connecting the continent: The European Hydrogen Backbone (EHB) initiative | EHB European Hydrogen Backbone

2. The value of the sea areas in Åland

General principles

The value of the sea areas depends on the relative competitiveness of offshore wind power in Åland

1. **Relative competitiveness of offshore wind as an energy source for the production of hydrogen or its derivatives for global hydrogen economy.**

2. **Relative competitiveness of offshore wind compared with locally produced other renewables (e.g. onshore wind and solar power) and other offshore wind power projects in the Nordic countries.**

- The main drivers for growing electricity demand are electrification of the industry sector, energy usage of data centers and hydrogen production, while electric cars and heating of buildings with electricity play a minor role. Fingrid has forecasted that hydrogen production represents 43 % of the growth in electricity demand by 2030 and the electrification of the industry sector and data centers will represent 42 % of the growth.
- Supply of renewable energy and industrial electricity demand will develop hand in hand. If competitively priced renewable electricity can be made available, it will attract green investments and therefore, demand. In a case of low competitiveness of energy production, investments will end up elsewhere.

Sources: Fingrid (2023): The electric future of Finland, presented in “Sähköverkkoliiketoiminnan ajankohtaispäivä” –seminar 21.9.2023.

The value of offshore wind - breakdown

- The options for electricity sales are sales in wholesale market or individual power purchase agreements (PPA)[1] with major electricity consumers. The value of offshore wind power depends on the future difference between sales price and cost of production.
- The sales price achieved in the wholesale market depends on the market development and capture rate of offshore wind power production. This will be analysed in more detail in the following sections[2].
- The PPA agreements are typically long-term agreements and has followed the wholesale market price in a long run. However, this might change in the future as the EU legislation for RFNBO[3] production requires[4] PPAs, likely having an effect on the future PPA market. In the case of RFNBO production, price of PPAs is linked to global hydrogen markets as hydrogen can be produced and transferred worldwide through pipelines and shipping. The development of hydrogen prices is analysed in more detail in the following sections[2].
- By utilizing PPA agreements, both parties (producer and buyer) can lower market risk and improve visibility of future costs. Offshore wind developers have an incentive to favour PPAs as they have positive effects on their funding and production revenues have less exposure to cannibalization.

Value of offshore wind production

Value in wholesale market

Depends on the relation between market price affected by capture rate and levelized cost of energy production

- Affected by market development scenarios

Value with PPAs

Depends on the relation between long-term PPA prices, levelized cost of energy production and profile costs

- Affected by global hydrogen price levels and its energy cost share.
- Has connection with local energy market development scenarios.

1) PPAs are contracts between producer and a customer for purchasing electricity (at a fixed price).
2) See "European energy markets 2030 – 2050" -section
3) Renewable fuels of non-biological origin are fuels such as hydrogen or synthetic fuels generated from renewable energy. More e.g., here
4) See "Market drivers and regulation" –section

Relative competitiveness of offshore wind power can be improved

- Offshore wind competitiveness in Åland consists of:
  - **Conditions of the sea areas:** wind conditions, water depth, seabed features etc.
  - **General technology development:** foundations, turbines, nacelle, etc.
  - **Grid connectivity and possible business cases** related to offshore wind: interconnectors, hydrogen/e-fuel production and shipping
  - **Area specific costs:** Property taxes, lease agreement for waters

- The government of Åland can only affect the latter two. Promoting possible business cases will improve the relative competitiveness of offshore wind power and thus increase its value in the markets.

- Area specific costs (for power producers) generate income in Åland but decrease competitiveness of offshore wind. These costs should be set to a level which maintains the overall competitiveness of offshore wind projects.

3. Overview of the Renewable Energy Directive

RED III promotes renewable energy and RFNBO production

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The overall target for the **share of energy from renewable energy sources is increased to 42,5 % by 2030** in the REPowerEU Plan. Beyond this mandatory level, Member States should endeavour to collectively achieve an overall Union renewable energy target of 45 %.

Industry sector

- **Annual 1,6 % RES increase to 2030.**
- Member States shall ensure that the contribution of **RFNBO used for final energy and non-energy purposes shall be at least:**
    - **42 % of the hydrogen used for final energy and non-energy purposes in industry by 2030 and**
    - **60 % by 2035.**
- The presented shares are not mandatory in specific cases:
    - First, the country has to be on track to meet their national contribution to the EU's overall target for 42,5% renewables in final energy consumption by 2030.
    - Second, the share of hydrogen or derivatives made using fossil fuels has to be 23% or below in 2030 and no more than 20% in 2035.

Transport sector

- Each Member State shall set an obligation on fuel suppliers to ensure that:
    - **share of renewable energy** within the final consumption of energy in the **transport sector of at least 29 % by 2030; or**
    - **greenhouse gas intensity reduction of at least 14,5 % by 2030**, compared to the baseline set out in Article 27(1), point (b).
    - the combined share of advanced biofuels and biogas produced and of RFNBO in the energy supplied to the transport sector is at least 1 % in 2025 and 5,5 % in 2030, of which **a share of at least 1 percentage point is from RFNBOs in 2030.**
- To kick start the fuel shift in maritime transport, Member States with maritime ports should **endeavour to ensure that from 2030 the share of RFNBO** in the total amount of energy supplied to the **maritime transport sector is at least 1,2 %.**
- The presented shares are not absolute as there are multiplier factors to be used for the calculation energy content of renewable fuels and RFNBO's.

Sources: Directive (EU) 2023/2413 of The European Parliament And of The Council of 18 October 2023 amending Directive (EU) 2018/2001, Regulation (EU) 2018/1999 and Directive 98/70/EC as regards the promotion of energy from renewable sources, and repealing Council Directive (EU) 2015/652

RFNBO production is highly reliant on PPAs

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- **RED II, Delegated Acts* under Article 27(3) define when hydrogen, hydrogen-based fuels or other energy carriers can be considered as RFNBO.** The rules are to ensure that these fuels can only be produced from additional renewable electricity generated at the same time and in the same area as their own production.

- **There are five different options to acquire renewable energy of which three require a PPA or a direct connection to renewable source.** The two methods not requiring PPA or direct contact with the production require over 90 % average share of renewable energy in grid (in a bidding zone) or down regulation in power balancing market.

- **The methods requiring PPAs or direct contact will presumably dominate the market** as the share of 90 % of renewable energy is difficult to be achieved as nuclear power is not considered a renewable energy source and RFNBO production is unlikely to be built relying solely on down regulation of energy systems.

*The so-called hydrogen delegated acts: Commission delegated regulation (eu) 2023/1184 & Commission delegated regulation (eu) 2023/1185

4. Energy markets 2030 - 2050

Hydrogen and electricity markets

Global hydrogen demand increases significantly

- To achieve carbon neutrality, hydrogen is needed in several sectors. McKinsey & Company estimate that global demand for hydrogen is 660 million tons (MT) in 2050.[(1)] PwC estimates that global hydrogen demand could vary from 150 MT to 500MT per year by 2050.[(2)] Current global hydrogen demand is about 140 MT.
- 65% of global hydrogen demand is concentrated in North America, Europe and East Asia. Currently, hydrogen demand is almost 100% industry usage. In the coming decades, the transportation sector is estimated to be biggest consumer. The growth of hydrogen-based transportation is estimated to grow significantly after the year 2030.
- Transportation of hydrogen and hydrogen derivatives is anticipated to be handled via pipelines and maritime shipping. Transmitting large amounts of energy as hydrogen is significantly more efficient compared the transmitting as electricity.
- Currently, China, India, Japan, South Korea, Europe, and North America account for 75 percent of global hydrogen demand. China is likely to be the largest single market for clean hydrogen by 2050 with a demand for 200 MT of clean hydrogen, followed by Europe and North America, each generating demand for 100 MT of clean hydrogen; India with 55 MT; and Japan and South Korea with 35 MT. The rest of the world, including Latin America, the Middle East, Oceania, and Southeast Asia, would account for about 175 MT of hydrogen demand.

Hydrogen supply chain and estimated global hydrogen demand development

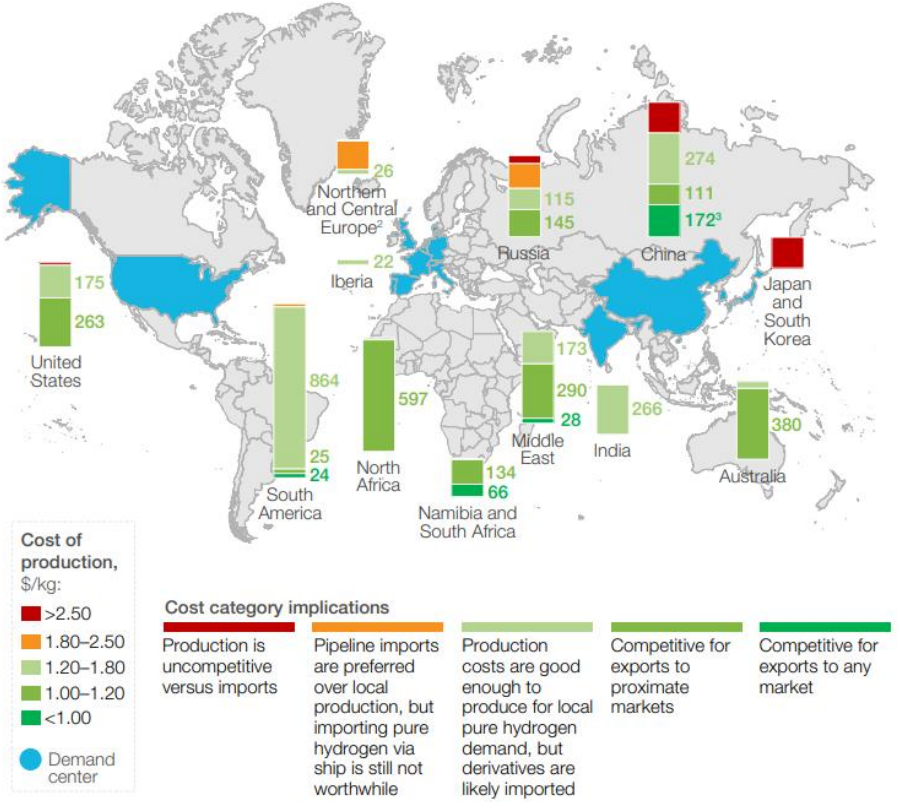
Source: Hydrogen Council and McKinsey & Company[1]:

Sources: 1) Global Hydrogen Flows: Hydrogen trade as a key enabler for efficient decarbonization, Hydrogen Council and McKinsey & Company, October 2022, Available: https://hydrogencouncil.com/wp-content/uploads/2022/10/Global-Hydrogen-Flows.pdf 2) The green hydrogen economy, PwC, 2023, Available: https://www.pwc.com/gx/en/industries/energy-utilities-resources/future-energy/green-hydrogen-cost.html

There is a mismatch between best hydrogen production locations and demand hotspots

- It is estimated that the best locations for hydrogen production are not in locations of high hydrogen demand, and hence hydrogen needs to be transported long distances.
- The most promising locations for production are in China, Namibia, South Africa and Middle East, while locations of high demand are seen to be China, India, Europe, North America, Japan and South Korea.
- The three main factors affecting production costs and commercial potential of hydrogen are:
  - The levelized cost of hydrogen production, driven by local renewable resources, electrolyzer costs, availability or the local cost of methane and carbon capture and storage (CCS).
  - The availability and costs to access other critical feedstocks – for example, biogenic CO2 for synthetic fuels or high-quality iron ore for direct reduced iron (DRI) used in green steel.
  - Country-specific factors, including the region's investment attractiveness (market efficiency, workforce availability, or country risk factor) and local public acceptance of building new infrastructure.
- In Northern Europe, the cost of production is estimated to be 1,8-2,5 US$/kg (2050) with pipeline imports as preferred means of accessing the continental European market. It is important to notice that even if hydrogen production in Europe would not be inexpensive, high local demand and easier transportation options can contribute to its significance in the region. Europe and North America are expected to be first to create a clean hydrogen market.

Hydrogen production potential, 2050, million tons per annum



Sources: Global Hydrogen Flows: Hydrogen trade as a key enabler for efficient decarbonization, Hydrogen Council and McKinsey & Company, October 2022, Available: https://hydrogencouncil.com/wp-content/uploads/2022/10/Global-Hydrogen-Flows.pdf

Global trade of hydrogen and hydrogen derivatives* will be covered via pipelines and maritime shipping

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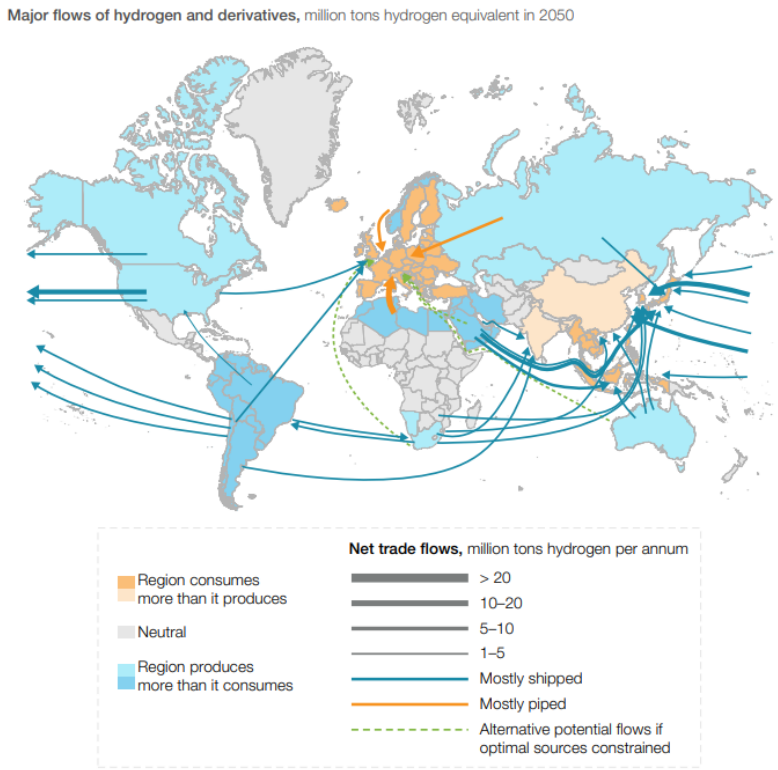
- Based on IRENA estimations for 1,5°C scenario, **a quarter of global hydrogen demand will be covered by international trade** of which **55 %** is expected to be traded **through pipelines** as hydrogen and **45 % shipped as ammonia** by 2050. [1]
- The cost difference between domestic production and import is one of the key drivers in global trade.[1]
- Importing pure hydrogen via ships to European market is estimated not to be economically viable.[2] Instead of transporting pure hydrogen, it is estimated that transporting green ammonia via maritime shipping could be viable in the future.
- Major hydrogen flows to Europe are expected to be from North Africa and Asia via pipeline and Latin America and North America via ships.[2] It is expected that North Africa will be a key player for hydrogen export to Europe if the pipeline investments will happen.[1]
- According to H2 Cluster Finland, in the coming decades it could be possible to produce hydrogen and hydrogen derivatives at a competitive price (pure hydrogen about 1,8-2,5 €/kg), and to export the production to the European market.[3]

Estimated global hydrogen trade, 2050



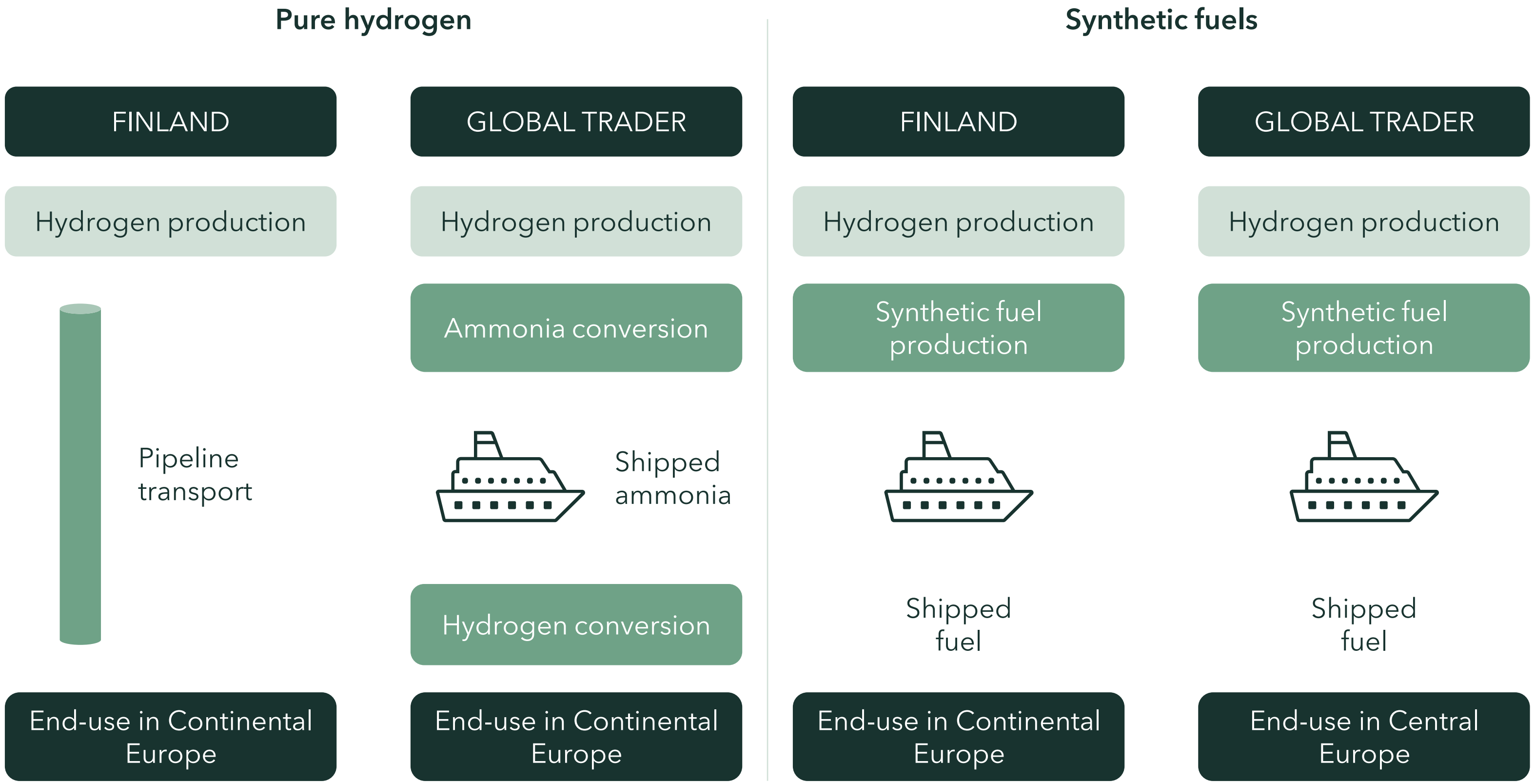
Picture: Hydrogen Council and McKinsey & Company[1]:

*Hydrogen derivatives include fuels and energy carriers derived from hydrogen, such as e-fuels and ammonia.
Sources: 1) Global hydrogen trade to meet the 1,5°C climate goal – Part 1, IRENA, 2022, Available: https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2022/Jul/IRENA_Global_hydrogen_trade_part_1_2022_.pdf
2) Global Hydrogen Flows: Hydrogen trade as a key enabler for efficient decarbonization, Hydrogen Council and McKinsey & Company, October 2022, Available: https://hydrogencouncil.com/wp-content/uploads/2022/10/Global-Hydrogen-Flows.pdf 3) Clean hydrogen economy strategy for Finland, H2 Cluster Finland, June 2023, Available : https://h2cluster.fi/wp-content/uploads/2023/06/H2C-H2-Strategy-for-Finland.pdf

Perspectives on the competitiveness of RFNBO production in Finland compared to global alternatives

- **The European Hydrogen Backbone is a key factor effecting the competitiveness of hydrogen production in Finland** compared to global alternatives as conversion between energy carriers could be avoided.
- **In case of synthetic fuel production** (such as e-ammonia, e-methane, e-methanol) **competitive advantage is more difficult to achieve** as the pathway to end-users in continental Europe is the same.
  - The costs of maritime shipping is marginal in the value chain and is not greatly dependent of the distance.
- Advantage in Finnish synthetic fuel supply could be achieved through access to biogenic CO2 sources (if hydrogen production is more cost-efficient elsewhere as predicted in the literature). However, this apply to carbon-based fuels and thus does not extend to ammonia.

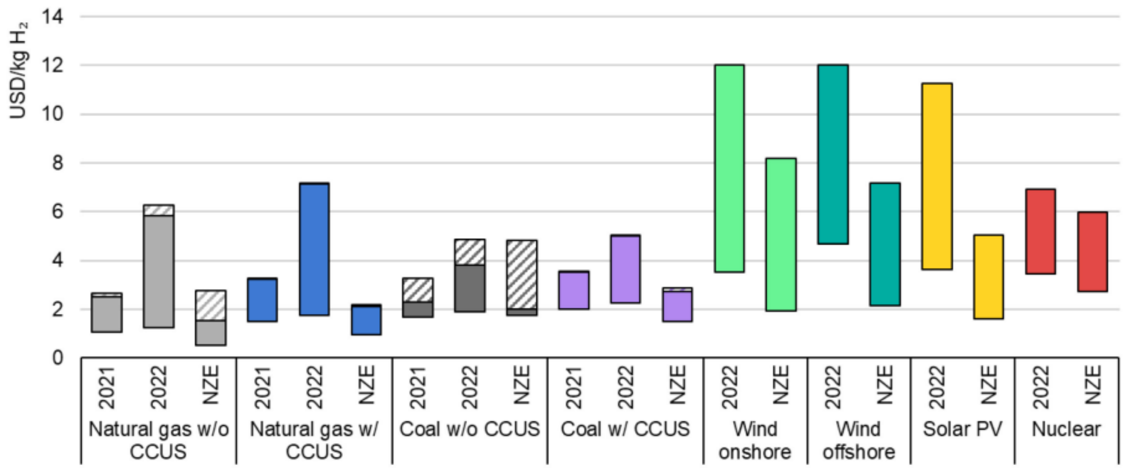
Total cost difference of production, conversions and transport between the suppliers determines the competitiveness of hydrogen / synthetic fuels



There are uncertainties related to hydrogen production costs

- The production costs of green hydrogen are estimated to decrease by half compared to the current level by 2030 and then more moderate pace until 2050.
- PwC[1] estimates that the cost of green hydrogen in 2050 will be around €1/kg in the Middle East, Africa, Russia, China, USA and Australia, but in Europe the cost is believed to be around €2/kg.
  - Analysis from CRU[2] estimates that several optimistic cost estimates have ignored costs related to storage, compression and distribution. Accordingly, capital expenditure costs of both renewable electricity and electrolyzer investments are estimated to decrease significantly. Taking these facts into account, according to CRU, it is more realistic that the actual cost of green hydrogen will settle at the level between 3 – 7 €/kg of hydrogen still in 2050.
- In the Global Hydrogen Review published by the IEA[3] at the end of September, the Net Zero Emissions by 2050 scenario (see adjacent picture) production cost of green hydrogen in 2030 is between 2 and 8 USD/kgH2 (€1,9-7,6/kgH2), depending on the technology. In previous year's review [3], the costs for 2030 were between 2 and 6 USD/kgH2 (1,9-5,7€/kgH2) in 2030 and between 1,0 and 5,5 USD/kgH2 (0,95-5,23 €/kgH2) in 2050.

Levelized Cost of Energy (LCOE) for different hydrogen production technologies in 2030



IEA Global Hydrogen Review 2023

*Used exchange rate is 1 USD = 0,95 €.

1) Analysing the future cost of green hydrogen (pwc)

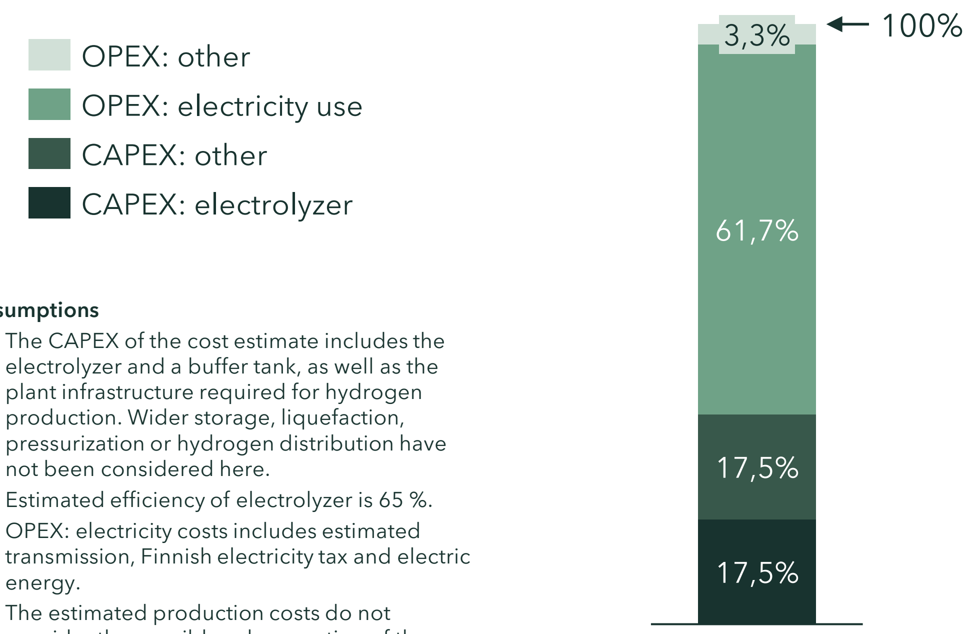
2) Energy from green hydrogen will be expensive, even in 2050 (cru)

3) IEA: Global Hydrogen Review 2023, IEA: Global Hydrogen Review 2022

Price of electricity is a significant factor in hydrogen production as it accounts for over 60% of production costs

- The share of the investment capital expenditure (CAPEX) is about 35% in hydrogen production costs, while the remaining share of 65% is accounted by operation expenditure (OPEX)
- About half of the CAPEX are caused by the production infrastructure (other than electrolyzer), project planning and project management. The OPEX are dominated by electricity use costs (62% of total costs)
- When hydrogen is used to produce e-fuels, such as methane, methanol or ammonia, the investment costs are expected to increase significantly. In e-fuel production electricity consumption increases and the overall efficiency decreases as energy is converted between carriers. Overall, the share of the investment in the price of the product increases compared to pure hydrogen.
- The CAPEX estimate includes electrolyzer and a buffer tank, as well as the plant infrastructure required for hydrogen production. Wider storage, liquefaction, pressurization or hydrogen distribution have not been considered here. The efficiency of the electrolyzer used in the evaluation is about 65%.
- The estimated production cost do not consider the possible revenues from waste heat or oxygen sales.

Production cost of hydrogen* €/kg (8 %, 20 a)



Assumptions

- The CAPEX of the cost estimate includes the electrolyzer and a buffer tank, as well as the plant infrastructure required for hydrogen production. Wider storage, liquefaction, pressurization or hydrogen distribution have not been considered here.
- Estimated efficiency of electrolyzer is 65 %.
- OPEX: electricity costs includes estimated transmission, Finnish electricity tax and electric energy.
- The estimated production costs do not consider the possible value creation of the waste heat or oxygen sales.

Electricity demand increases. Onshore wind power is expected to play a significant role in Finland and Sweden

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Overview of the Electricity market development modelling results until 2050

- Electricity demand is expected to increase by around 150 % in Finland and by 140 % in Sweden by 2050. Current electricity demand in Finland is about 80 TWh[1] and in Sweden about 134 TWh[2].
- In Finland between 2035 and 2050, onshore wind power is expected to play the most important role covering 50–55 % of the electricity demand. The second biggest source of electricity in Finland will be nuclear power. Offshore wind power, hydro power and combined heat and power each account for an approximate share of 6–11 %.*
- In Sweden between 2035 and 2050, onshore wind power is expected to have a significant role with about 35–38 % market share, with the share of hydro power following at 23–28 % market share. The third largest electricity production source in Sweden is expected to be offshore wind power.*
- In the base scenario, it is expected that significantly more offshore wind power is developed in Sweden than Finland. Between 2035 and 2050, the installed offshore wind capacity ranges between 2,6 GW and 3,9 GW in Finland, while installed capacity in Sweden is from 6,5 GW to 11,3 GW.

1) In 2023, Finnish Energy
2) In 2023, Statistics Sweden

* All assumptions are based on a combination of TYNDP, scenarios in the TSOs system development plan, NECP and the latest trends

Hydrogen demand is a key factor in determining how the Nordic energy market develops in the coming decades

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Hydrogen demand is the main driver of the increase in electricity demand. The average wholesale electricity price is estimated to be around 50 €/MWh in Finland and Sweden in 2040 and gradually increase towards 2050. However, there are major uncertainties related to price development, and depending on the scenario, the price level range could vary between 30 – 70 €/MWh.

Highlighted assumptions behind the reference case

Demand and Supply

- An ever-increasing demand for power and hydrogen in the Nordics
- Nuclear *not* pushed into the market in Sweden by 2035

Costs

- Increasing CO_2 prices steer power prices
- Despite recent material price and capital expenditure cost increases, LCOE and capture price for onshore wind below market price and can be invested in on its own merits

Market development

- Continued physical market integration within the continental Europe and UK
- No/limited experimentation with Nordic market design in the near- and mid-term, maintaining energy-only market as the main tool

Highlighted potential factors affecting the market prices

+ Higher prices could be driven by

+ A tighter supply and demand balance
  + Which in turn could be driven by market reasoning for new build power production or political decisions to halt certain developments, e.g. offshore wind in Sweden
+ Higher fuel and CO_2 prices than assumed in the reference case
+ A stronger interconnection to continental Europe

- Lower prices could be driven by

- A loose/generous supply and demand balance
  - Which in turn could be driven by low electricity and hydrogen demand from e.g. too high electrolysis/e-fuel costs and a massive buildout of onshore wind in the near-term plus political decisions to introduce non-market power production capacity, such as nuclear in Sweden by 2035
- Lower fuel and CO_2 prices than assumed in the reference case
- A halt in interconnection to continental Europe

5. Earning potential of offshore wind power projects in Åland

Based on the interviews*, business cases for offshore wind development in Åland rely on hydrogen production and strong grid connections

Key takeaways from the interviews form the basis of earning potential analysis

- **Hydrogen production** plans are a common factor for all interviewees
- Development of **hydrogen backbone** is a key enabler in large-scale hydrogen production
- Access to mainland electricity market via **grid connection** is seen as important benefit in all of the business cases. In an ideal case**, interconnector would be built** between SE3 price area and Finland

Hydrogen production

- Hydrogen was seen as one of the key mediums to access energy markets with large-scale offshore wind production.
- Not all interviewees have planned hydrogen and or derivative production in Åland. Some players have focus on hydrogen production on mainland. Excess heat utilisation opportunities and access to CO2 feedstock** might have effect on locating P2X projects elsewhere.

Hydrogen backbone

- A key part of the business case for offshore wind is the development of the hydrogen backbone which connects Åland to continental Europe.
- All interviewees had assessed hydrogen derivative production as an alternative plan to hydrogen backbone and as a possibility to cover local fuel demand in maritime sector.
- Many of the interviewees targeted both local and global hydrogen / hydrogen derivative markets. However, some developers have their main target on local hydrogen markets.

Grid connection to mainland

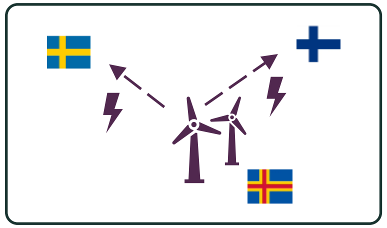
- Grid connection to mainland is seen as an important factor, as it guarantees route to the Nordic electricity markets.
- Grid connection to mainland enables other locations for P2X plants and more demand opportunities for PPA contracts.

*Several offshore wind and hydrogen developers were interviewed during the project.
**required by carbon-based hydrogen derivatives such as methanol or methane

Three different business cases were chosen for evaluation based on the interviews*

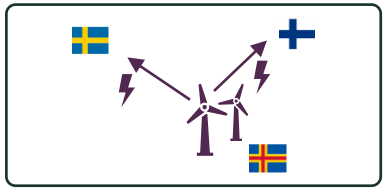
1. Offshore wind power site is connected to mainland Finland (or Sweden)

In this business case offshore wind site is connected to mainland Finland or Sweden via an interconnector and energy is transmitted as electricity. Electricity can be sold to the wholesale market to FI or SE3 price area or by a PPA agreement to industry customers (for example hydrogen production plant). The value of the offshore wind production is based on the captured electricity price from the wholesale market or the PPA market. The cost of sea-cable has an influence on the LCOE of offshore wind production. The possibility of utilizing excess heat (of hydrogen production) and surplus electricity (when production exceeds demand) on mainland can affect to willingness to pay for electricity in the PPA market.



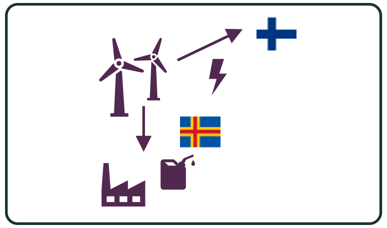
2. Offshore wind power site is connected to mainland Finland and Sweden

This business case differs from case 1, as the offshore wind power unit is connected to both mainland Finland and Sweden via interconnectors. The value of the offshore wind power production is determined in the same way as in business case 1. In this case, the PPA market size is larger, and the capture price is higher (in the wholesale market) as the production can be sold to the bidding zone with higher price. On the other hand, the cost of interconnecting sea-cable is higher.



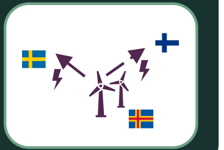
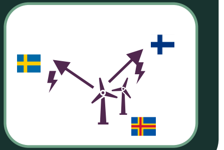
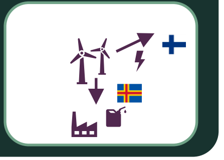
3. Offshore wind power site is connected to hydrogen site in Åland and to mainland Finland

In this business case the offshore wind site is connected to hydrogen/hydrogen derivative production in Åland. In addition, the site has a connection to mainland Finland. The grid connection capacity to mainland is smaller compared to case 1. The hydrogen/derivatives produced in Åland are sold via pipeline or ships. The value of the site is highly determined by the cost of electricity used in hydrogen production. Surplus electricity will be sold to the wholesale market via the grid connection to mainland Finland. Hydrogen developer's willingness to pay for electricity depends on the market price of their product and the competitiveness of the hydrogen production in Åland versus mainland Finland. Excess heat cannot be fully utilized in this business case. On the other hand, the cost of grid connection sea-cable is much lower than in other business cases.

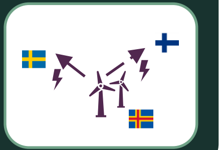
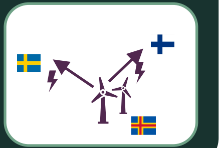
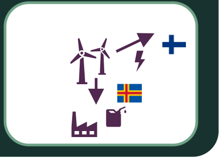


*The business cases are not identical with the business cases discussed in the interviews. They are modified to highlight the differences between different concepts.

Qualitative analysis of the business cases

	Electricity Sales / Production		Hydrogen / Hydrogen derivatives production	
	Advantages	Disadvantages	Advantages	Disadvantages
1. Offshore wind power site is connected to mainland Finland (or Sweden) 	+ Access to electricity markets at full capacity	– Access limited to one price area, saturation of wind resource / lower capture price – Access to grid development / Swedish grid might prioritise local Offshore wind	+ Hydrogen production can be located in different locations + Excess heat utilisation options on mainland + Easier access to CO_2 feedstock	– The regional economic impact benefits are limited in Åland – Cost of electricity transmission (if no direct connection)
2. Offshore wind power site is connected to mainland Finland and Sweden 	+ Access to electricity markets at full capacity + Access to two price areas	– High investment costs due to interconnector unless TSOs will build the connection – Grid development might take some time as they are depended on the schedules of Finnish and Swedish TSOs	+ Hydrogen production can be located in different locations + Excess heat utilisation options on mainland + Easier access to CO_2 feedstock	– The regional economic impact benefits are limited in Åland – Cost of electricity transmission (if no direct connection)
3. Offshore wind power site is connected to hydrogen site in Åland and to mainland Finland 	+ Lower grid connection costs due lower capacity connected to mainland	– Access to electricity markets limited by grid connection capacity to mainland	+ The full regional economic impact benefits are achieved in Åland + Hydrogen production could be directly connected to wind farm, reducing transmission costs	– Hydrogen sales would be dependent on hydrogen backbone development – Sourcing of biogenic CO_2 – Local excess heat utilisation opportunities are limited

Foreseen potential impacts on maritime activities

	Electricity Sales / Production	Hydrogen / Hydrogen derivatives production
1. Offshore wind power site is connected to mainland Finland (or Sweden) 	**No additional impacts*** on marine traffic control (navigation, radar and radio systems) **No additional impacts** on marine traffic, waterways or marine operations **No additional impacts** on safety, rescue or damage prevention in maritime activities Followed by no major changes in the planning, construction nor in the operations of the three items above.	N/A
2. Offshore wind power site is connected to mainland Finland and Sweden 		
3. Offshore wind power site is connected to hydrogen site in Åland and to mainland Finland 	Locations of hydrogen production plants and their optional refinement plants may change the locations of the offshore wind parks, and – as a result of this – **may create additional impacts** on marine traffic control, marine traffic, waterways and marine operations as well as safety, rescue and damage prevention. **This may create changes** in the planning, stationing, constructing, connecting (grid) and in operating the offshore wind parks.	Locations of the hydrogen production plants and hydrogen derivative plants are tightly connected to the locations of the offshore wind parks which result in **intensive concurrent project planning.** In addition, hydrogen production plants and their optional refinement plants require and result in increase in marine traffic and/or bunker & loading stations and/or vessels, and **more intensive planning for integrating the needs** in marine traffic control, marine traffic, waterways and marine operations as well as safety, recue and damage prevention, with the needs in offshore wind parks.

* "Additional" means that the business case itself does not create additional impacts compared to the situation that occurs in each offshore wind park planning and execution solely and jointly with other neighbouring offshore wind park locations

Capture prices on the wholesale electricity market do not justify offshore wind investments alone

Electricity modelling results overview for business cases 1-3

- The average wholesale electricity capture price for offshore wind is estimated to remain lower than the indicative LCOE in the next decades in all analyzed cases 1-3.
- A significant increase in utilization of wind resource is expected to saturate the market during windy conditions, which can be seen in lower capture prices in cases 1 and 2, as 6 GW* of additional offshore wind in Åland is connected to the markets in Finland and/or Sweden. The saturation effect on prices occurs at lower connected capacities as well.
- Case 1 seems to offer lowest capture prices, especially when connected to Finland, while the interconnector in case 2 generally offers better capture prices in both Finnish and Swedish price areas.
- To justify the investment from the developers' perspective, the LCOE should roughly be at least equal to discounted capture price over the lifetime of operation, and therefore the analysis suggests that wholesale of electricity is seen as an additional revenue stream to complement the hydrogen route-to-market.

*The realisable range of offshore wind power in Åland is estimated to be around 6 – 10 GW, (Source). 6 GW potential was chosen to be used in this study.

Competitive hydrogen production could be achieved with 30 – 50 €/MWh electricity costs

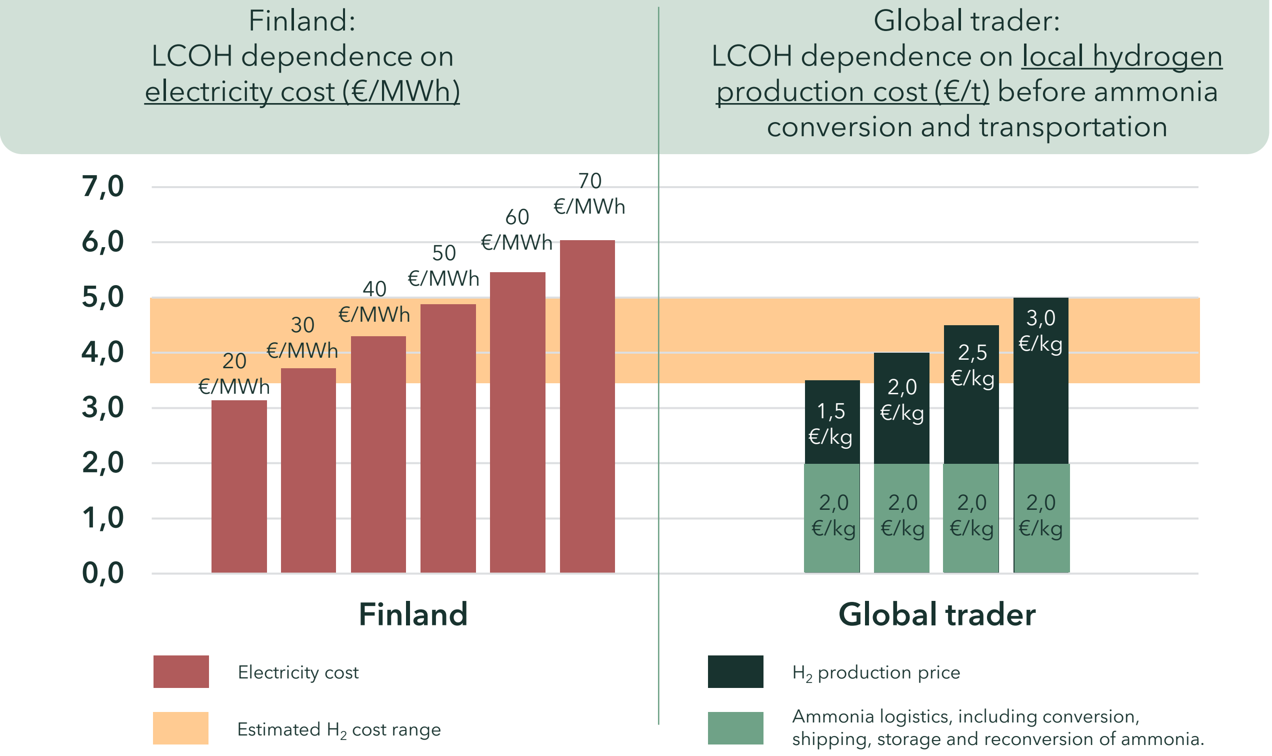
- Competitive hydrogen production cost level of 3,5 – 5,0 €/kgH2 could be achieved with 30 – 50 €/MWh electricity cost in Finland. IEA has estimated that the cost of hydrogen production varies between 2 - 6 €/kgH2 in 2030. Cost level as low as 1,5 €/kgH2 could be achieved in some locations such as Argentina, Chile and Morocco, however global locations require shipping, bringing cost of hydrogen closer to Finnish level.
- Excess heat utilization can further improve competitiveness of production in Finland. Utilization of excess heat is estimated to reduce LCOH (levelized cost of hydrogen) by 3 – 10 % depending on the heat sales price and demand volume. Thus, effective heat utilization and around 8 €/MWh higher electricity costs result in same LCOH compared to a case without heat utilization.

Main assumptions:

- It is estimated that 4600 full load hours could be achieved with offshore wind. Capex and opex estimations are based on current hydrogen investment project cost levels combined with 33 % investment decrease of electrolysis by 2030. Project lifetime is 30 years and WACC (weighted average cost of capital) is 5 %.
- Hydrogen delivery by ammonia shipping is estimated to be 2,0 €/kgH2 including conversion, shipping, storage and reconversion.
- The levelized transportation cost for EHB (European Hydrogen backbone) is estimated to be 0,15 €/kgH2,1000km for onshore piping.

IEA: Global Hydrogen Review 2023
IEA: Energy Technology Perspectives 2023 (windows.net)
EHB (2023): Estimated Investment & Cost

Levelized cost of hydrogen estimations in Central-Europe depending on electricity price in Finland and global hydrogen production cost in 2030 (€/t)



Finland:
Hydrogen is produced with offshore wind that is directly connected with offshore wind. Hydrogen is transported via hydrogen backbone. Subsidies or excess heat utilization are not taken into account.

Global trader:
Hydrogen is produced locally, converted to ammonia, shipped to Central-Europe and converted back to hydrogen. Subsidies or excess heat utilization are not taken into account.

There is no significant difference in the benefits of hydrogen production in Åland compared to mainland Finland or Sweden if distant grid connections could be avoided*

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Overview of findings from the business case analysis

- The levelized costs of offshore wind energy production are rather close to each other in case 1 with connection to mainland Finland or Sweden, and case 3 with primary connection to Åland and a smaller secondary connection to mainland Finland. The difference in levelized cost depends on whether distant grid connection points are needed when connecting some of the projects to mainland Finland or Sweden. The levelized cost is estimated to be 5 - 7 €/MWh higher on average when distant connection points are required. This means that around 6 % lower cost of hydrogen production could be achieved when distant connections are avoided.

- Improvements in cost effectiveness of hydrogen production could also be achieved with a direct electricity connection to a hydrogen plant (avoiding transmission costs) and efficient utilization of excess heat.
  - In case of hydrogen production in Åland, the direct connection of an offshore wind power plant to a hydrogen plant could be potentially arranged and result in roughly 5 % lower cost of hydrogen production compared to a similar plant connected to a transmission/regional grid. However, as the potential for heat utilization in Åland is rather limited and the cost reduction potential of excess heat utilization is estimated to be around 3 – 10 %, other locations might benefit from heat utilization.

- Interconnector between Finland and Sweden (case 2) improves the revenue potential from electricity sales, but is expected to be viable only as a TSO investment.

*Possible subsidies, difference between local connection fees, fluency of permitting process and storage possibilities are not included in the analysis

6. Synthesis and recommendations for maximizing the potential of offshore wind power in Åland

The value of the sea areas in Åland depends on local, EU-level and global factors

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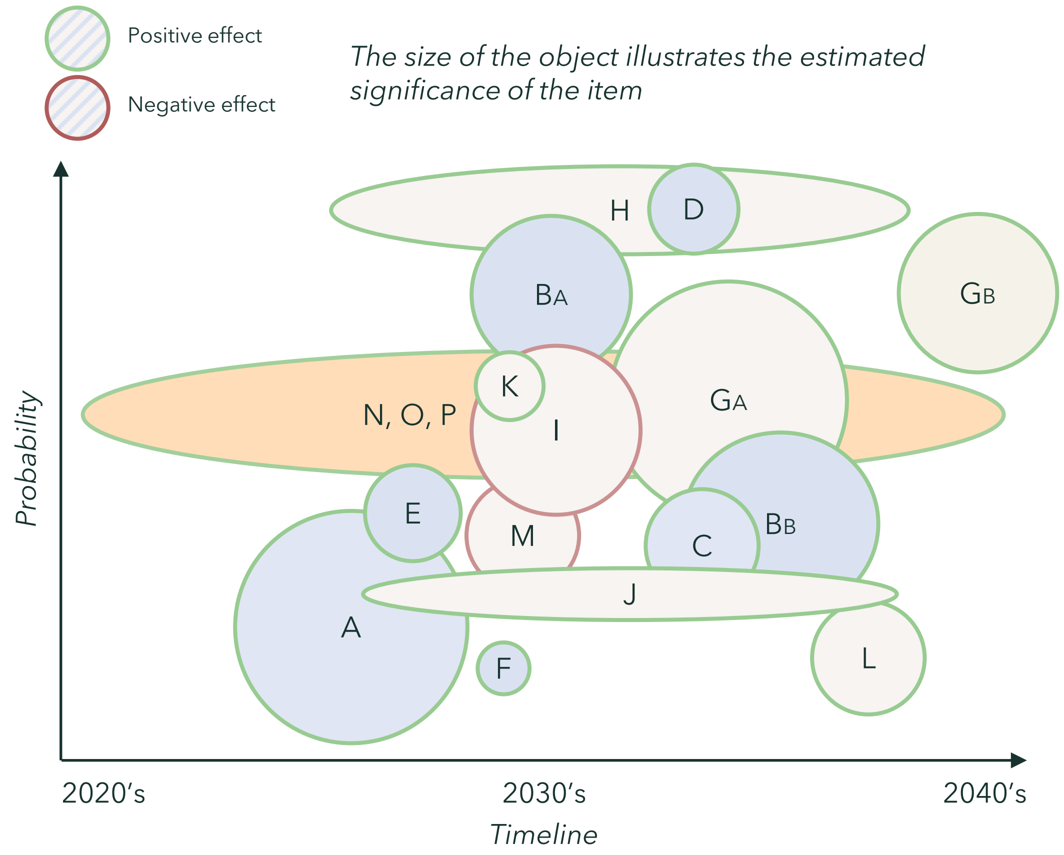
High-level overview of probability and significance of events affecting the value of Åland sea area development



Factors

Technological
Åland offshore wind & P2X projects

- **A. Favourable short-term capex and opex development** (high learning curve, low inflation)
- **B. Grid access from Åland offshore wind projects**
  - A. Access to mainland Finland
  - B. Access to Sweden
- C. Interconnector established through OW projects between Finland and Sweden
- D. Installation vessels will be available for the projects
- E. Cost-efficient CO2 transportation and distribution
- F. Excess heat could be utilized in Åland

Energy Market Development
Nordics & Global

- **G. Hydrogen backbone through Åland**
  - A. Constructed by 2030-2035
  - B. Constructed by 2040-2045
- **H. EU hydrogen targets adopted in the industry and transportation sectors increasing hydrogen demand**
- **I. Global hydrogen production cost below 2 €/kg in 2030-2040**
- J. Electricity demand grows faster than supply in the Nordics
- K. Domestic market price for hydrogen distinctly higher than global level
- L. Electricity interconnector to Continental Europe
- M. Adoption of competing el. production technologies (e.g., nuclear)

Political
European & Global

- N. Geopolitics
- O. Trade policy
- P. European energy security

Positive political environment

The value of the sea areas in Åland depends on local, EU-level and global factors

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	+ Positive Scenario	- Negative Scenario
Technological Åland offshore wind & P2X projects	+ Negative **CAPEX & OPEX cost development** trend due to inflation and supply chain issues turn around and cost development follows a steep learning curve in offshore wind power development reaching low-cost levels in 2030's. + **Available grid connection** options to Finland and Sweden boost viability of offshore wind projects in Åland. + **Installation vessel fleet** for large turbines are built to satisfy vessel demand in 2030's.	- Adverse trends in **CAPEX** project environment continue, decreasing the competitiveness of offshore wind power globally. - **Grid connections** to mainland are not available for Åland offshore wind power sites in the 2030's. - Projects' timelines experience delays e.g., due to **supply chain issues and installation vessel shortages.**
Energy Market Development Nordics & Global	+ The **hydrogen backbone** is realized, providing direct access to the European and Nordic markets from a P2X facility. + **Hydrogen demand** in the Nordics and globally grows to anticipated level due to green hydrogen utilisation in industrial processes and transportation sector. + **Global hydrogen production cost** remains over 2 €/kg, retaining cost competitiveness of P2X projects in the Nordic region.	- The **hydrogen backbone is not realized**, leaving grid connections and hydrogen derivatives as the only routes-to-market. - **Realized hydrogen demand** in the Nordics and Europe are lower than anticipated. - **Global hydrogen production costs** are less than 2 €/kg. - **Competing energy technology** investments, such as nuclear see a boom in late 2025's and 2030's.
Political European & Global	+ Geopolitical, Trade Policy and European Energy Security are on a favourable path. European energy markets are strong and large amount of hydrogen and its derivatives consumed are domestic production.	- Geopolitical, Trade Policy and European Energy Security trends have negative effect on the energy markets. Domestic hydrogen provision is not secured, and the trade is focusing heavily on hydrogen import.

Contribution to local factors promotes reaching of the maximum potential of the offshore windfarms

- There is no significant difference in the benefits of hydrogen production in Åland compared to mainland Finland or Sweden*. Thus, **local hydrogen and the production of its derivatives could be promoted as it would bring the most value to the region of Åland.**
- There are several key elements and action points listed below for the **government of Åland to promote offshore wind business locally.**

Hydrogen pipeline is identified to be important route-to-market and its favourable development should be promoted. The Baltic Sea Hydrogen Collector is project initiated by Gasgrid Finland Oy and Nordion Energi AB together with the wind power developers OX2 in Sweden and Copenhagen Infrastructure Partners in Denmark. The government of Åland should take active role in the consortium or be active partner to the consortium to ensure its connectivity with local projects.

Preparing of potential hydrogen (and derivatives) production locations in Åland. Safety requirements and connectivity with offshore wind farms should be considered while preparing the sites. The potential sites should be prepared so that there is possibility connect both Southern and Northern offshore wind projects with hydrogen production. Onshore hydrogen pipeline should be considered if there are challenges in onshore electricity transmission.

Ports need to be prepared to ensure sufficient possibilities of loading and bunkering of different fuel types. In addition, the ports need to prepare for the possibility of increased maritime traffic due to fuel export. The ports are the only way to export hydrogen and its derivatives to markets before hydrogen backbone is constructed or remain as such if the hydrogen backbone plans/construction will be terminated. For this reason, the ports have a key role as route-to-market. The government of Åland should consider creating a local cluster consisting of ship operators and fuel distributers (& the government of Åland) to drive this important change.

Grid connection(s) to mainland Finland or Sweden is identified to be a key factor to ensure sufficient route-to-market. Discussion of electricity export from territorial waters of Åland to mainland Finland or to Sweden should be initiated by government of Åland with Finnish and Swedish Transmission System Operators (TSOs) and governmental decision makers.

*In the perspective of offshore wind farm located in the sea areas of Åland.

There are several factors which the government of Åland should follow to ensure the right direction of actions

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Energy market development
The energy markets and hydrogen economy are developing fast. The progress in European Hydrogen Backbone plans and its implementation, development of hydrogen demand, electricity markets (and interconnector development) should be updated regularly to understand the development of offshore wind power competitiveness in a large perspective.

Offshore wind production costs
Technology development, component price development, availability of installation vessels and possible issues with supply chain have a high impact on the profitability of offshore wind business cases. Active discussions with offshore wind developers enables real-time information gathering in this perspective.

CO_2

Development of CO2 transportation and distribution (technology and costs)
The availability of biogenic CO2 have an impact on possibilities to produce different derivatives of hydrogen. Products containing carbon (such as e-methane and e-methanol) are dependent on cost effectiveness of CO2 transportation as the possibility to obtain biogenic CO2 is limited locally in Åland. It is a possible scenario that only hydrogen and ammonia are viable products in Åland.

7. Summary and conclusions

Offshore wind projects in Åland are heavily linked to the hydrogen economy

- **The value of the sea areas is highly dependent on the development of the hydrogen economy** which is a key driver for increasing electricity demand. Other drivers are electrification of the industry sector, energy usage of data centers, electric cars and heating of buildings.
- **The highest value of offshore wind projects are estimated to be reached through power purchase agreements** with the industry sector **or with combined hydrogen (and its derivatives) production projects.** The demand for power purchase agreements will increase due to EU regulation for green hydrogen production. The value of electricity sales in the wholesale market is presum ably lower due to cannibalization effect of wind production and high investment cost of offshore wind projects.
- **Future hydrogen and its derivatives trading will be a global market** as the products can be shipped all around the world. **Local competitiveness is dependent on the development of the hydrogen backbone or an individual pipeline** which enable efficient transportation to the offtakers in Europe. The price competition in hydrogen derivatives will be more challenging in a case without hydrogen backbone as there won't be a similar benefit of cost-efficient transportation. This applies especially to e-ammonia, which could be produced worldwide. In a case of e-methane and e-methanol (or other derivatives containing carbon) production Nordic countries may have competitive advantage due to the availability of biogenic CO2 sources.

*Possible subsidies are not included in the analysis

There are several uncertainties related to the market development, but the Government of Åland can promote favorable infrastructure development locally

- The energy markets and hydrogen economy are developing fast and the future competitiveness is dependent on several factors. **The main uncertainties are related to a) hydrogen demand that is driven by EU targets and their realization, b) development of hydrogen backbone, c) global cost of hydrogen production, transportation and conversions, d) cost development of offshore wind projects (including cost of capital) and e) political environment**. Any negative trend in these factors could decrease the value of the sea areas significantly.
- **Securing routes-to-the-market is a key element in all of the potential business cases** of offshore wind projects in Åland. Thus, grid connections to mainland Finland or Sweden are crucial for the projects. In an ideal case, there would be an interconnector through wind farms between Finland and Sweden.
- There is no significant difference in the cost of hydrogen production between Åland and mainland Finland or Sweden*. Thus, **local hydrogen and the production of its derivatives could be promoted as it potentially brings the most value to the region. The vital routes-to-market are the hydrogen backbone for pure hydrogen and ports for exporting hydrogen derivatives** (such as e-ammonia, e-methanol and e-methane). The government of Åland should take actions to ensure that all the export possibilities could be secured and to prepare potential locations for hydrogen and its derivatives production inland.
- Åland-specific disadvantages for hydrogen projects are its limited possibilities for excess heat utilization and limited availability of local biogenic CO2 sources that could be utilized for hydrogen derivatives containing carbon (such as e–methane and e-methanol). **Any solutions for excess heat utilization or cost-efficient CO2 transportation improve the potential business cases in the area.**

*From the perspective of offshore wind farm located in the sea areas of Åland.

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Appendix

Principles for coordination of offshore wind power and maritime

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Overview

- New guidelines for the coordination of offshore wind power and maritime, as well as maritime and shipping infrastructure were published 13.11.2023 by the Finnish Transport and Communications Agency Traficom and the Finnish Transport Infrastructure Agency due to the technological development and planning interests of offshore wind power.
- The purpose of the guide is to help different parties in offshore wind power projects and to secure the operating conditions of Finnish merchant shipping and to ensure safe maritime operations in such a way that the current risk level of maritime safety does not increase significantly due to wind farms being built near waterways, shipping transport areas, shipping safety devices or shipping radars or radio stations.
- The common guide describes the procedures of Traficom and the Finnish Transport Infrastructure Agency during the planning, evaluation and approval processes of offshore wind farm projects, and provides background to the agencies' requirements in offshore wind power projects. Wind power farms in sea areas have effects on the safety and the smoothness of maritime operations.

Implications on Offshore Wind

- From the point of view of maritime operations, the wind farms planned for the sea area can affect e.g. the functionality of the transport system, maritime radar and radio systems, and maritime safety. As an authority, Traficom plays a central role in these: e.g. Traficom must be requested to confirm changes related to the fairway, which may be required by the wind farm planned for the sea area. Wind power plants can also affect the functionality of communication networks based on the use of radio frequencies or, from an aviation perspective, create air navigation obstacles.
- The Finnish Transport Infrastructure Agency plays a key role in wind power projects both as the state operator of the waterways and as the party responsible for ensuring the conditions for winter maritime operations and as the orderer of vessel traffic control services. The Finnish Transport Infrastructure Agency also takes care of the availability of ice-breaker assistance in the Finnish water area if ice conditions so require.
- The guide also takes into account e.g. the Finnish Border Guard's point of view, essential matters related to maritime safety, maritime rescue and environmental damage prevention measures.

Source: https://www.traficom.fi/sites/default/files/media/regulation/Merituulivoimaohje_EN.pdf

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