BOWE2H METASTUDY

Offshore wind and power-to-hydrogen in the Baltic Sea Region

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This study has been carried out under the auspices of the Interreg Baltic Sea Region project BOWE2H, which consists of the Latvian Association of Local and Regional Governments, the German Offshore Wind Energy Foundation, the Energy Agency Southern Sweden, the Lithuanian Energy Agency, and the Institute for Climate protection, Energy and Mobility (IKEM) as the lead partner.

The metastudy is a component of the BOWE2H output Strategic Roadmap, which will provide state-of-the-art actionable know-how for target groups and stakeholders to use in their efforts to foster offshore wind power and hydrogen generation so as to help create an integrated, safe and prosperous Baltic Sea Region.

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Executive summary

Given the great potential of the Baltic Sea Region to produce renewable power and its relatively low domestic consumption of electricity, it is well placed to export a great deal of energy to the rest of Europe either as electricity or embedded in products such as steel or energy carriers such as hydrogen. As such, the Baltic Sea Region is central to the EU‘s ambition to quickly and smoothly advance the energy transition. The Interreg BSR Baltic Offshore Wind Energy to Hydrogen (BOWE2H) project aims to build on this observation to catalogue and disseminate the resulting opportunities while bringing together stakeholders from across the region and beyond in networking environments that can facilitate cross-border learning and partnerships.

Most of the necessary decarbonisation of our societies will come through a switch to renewable energy, wholesale electrification and the deployment of low-carbon fuels for hard-to-abate sectors. Hydrogen and its compounds are an oft-mentioned candidate for this green fuel of the future, and offshore wind – with its high capacity but large distance to population and industry centres – a good way to produce it. There are several challenges to reaching the full potential of this combination, however. They include high costs, technical and logistical challenges associated with the installation and maintenance of offshore wind facilities, and the need for supportive policy and regulatory frameworks. Solutions need to be found to these challenges faster than any such wholesale transformation has mustered in the past. The years 2030 and 2050 are major target dates for large-scale achievements in the hydrogen and offshore wind strategies of most countries as well as the European Commission.

Some 90 million tonnes of hydrogen are produced in the world today, almost entirely with fossil fuels. This consumes 6% of the world‘s natural gas and 2% of its coal, and generates more than 800 million tonnes of carbon dioxide (as much as Germany) every year. Almost all of this hydrogen today is produced for conversion into ammonia for use as fertiliser. This will change in the future, with global demand expected to rise to more than 600 million tonnes a year by 2050. At this point, hydrogen will meet 12% of the world‘s total energy use and mitigate 12% of the carbon dioxide emissions in industrial applications and 26% in transport, respectively.

For the industry to scale up, comprehensive policy must be in place at all levels of government and at a European scale. There are estimates that cumulative subsidies of some US$150 billion will be required in Europe by 2030, and that US$500 billion will be deployed worldwide by that date on clean-hydrogen production, hydrogen-distribution facilities and industrial plants. The European Commission and largest producers aim to increase the EUs manufacturing capacity for electrolysers tenfold by 2025, with the target of achieving a yearly hydrogen production capacity of 10 million tonnes.

Massive increases in electrical generation and transmission capacity will be required to produce all this additional hydrogen on top of the increased demand created by the expected electrification of societies in the coming decades. Much of this will come from offshore wind. The industry association WindEurope expects that the EU can have an offshore wind power generation capacity of 370 GW by 2050, of which the Baltic Sea can host 83 GW. The EU Commission has a target of 300 GW capacity for offshore wind by 2050, ranging between 240 and 440 GW depending on the scenario. A high proportion of the EU’s GDP will need to be invested into energy infrastructure every year to achieve this.

Given the sparse population in the countries of the Baltic Sea Region, the many competing uses of maritime space, and the varying national priorities, it is important that the coming infrastructure and policy transformation take place in close cooperation between states and the European Union. This is well underway. A number of transnational power generation and transmission initiatives are already implemented or planned in the Baltic Sea: they include Kriegers Flak, the ELWIND offshore wind farm and the Bornholm Energy Island. Similarly, three hydrogen pipeline systems – the Nordic Hydrogen Route, the Nordic-Baltic Hydrogen Corridor and the Baltic Sea Hydrogen Collector – are also in the planning stages. These initiatives demonstrate some of the possibilities and opportunities of cross-border cooperation that are available in a sea surrounded by land on all sides such as the Baltic.

There is a serious need for continued investment in offshore wind and hydrogen, as well as supportive policy and regulatory frameworks. These investments and policies will be critical in achieving Europe‘s decarbonisation goals and ensuring a sustainable energy future for the region and the world.

01 Introduction

Introduction

While the Baltic Sea Region may seem like it is nestled on the geographical periphery of Europe, it is central to the greatest challenge facing the continent and the world today: successfully completing the energy transition fast enough to ward off the worst effects of climate change. The region has great potential to generate a surplus of renewable electricity, which can be exported to the rest of Europe, used for local industrial manufacturing of products such as steel, or converted to hydrogen and used for energy storage and transport.

Against the background of the amplifying climate crisis, widespread economic stagnation, escalating energy poverty, growing inequalities between and inside countries, and increasing assertiveness of autocracies on the world stage, the generation, transmission and deployment of renewable energy have never been more important or topical. This trend is likely to only grow stronger in the coming decades.

The importance of an energy transition is well established today, not least in European policy circles. Most of the necessary decarbonisation of our societies and economies will come through i) a switch to renewable energy sources, ii) the electrification of most fossil fuel applications and iii) the replacement of the rest with low-carbon fuels. There is a logical link between these principles: since most truly renewable energy sources are intermittent, and often concentrated in areas with low population density, a great deal of energy can be generated in regions or at times where matching supply and demand is difficult, leading to a potential excess of energy that can be used to produce low-carbon fuels, which in turn can be deployed in hard-to-abate sectors.

One unavoidable issue of particular relevance to the Baltic Sea Region is, of course, the current political situation in Russia and its aggression in Ukraine. This has once again placed the region – especially Estonia, Lithuania, Latvia, Poland and Finland – on a sadly familiar historic fault line. While there appears to be no imminent physical threat to these countries, there is a particular sense of urgency – and perhaps a special complexity given that many of them have historically been so strongly dependent on Russian energy – for these countries to minimise their dependence on imported hydrocarbons from Russia. The fact that Russia has direct access to the Baltic Sea makes the situation more complex still.

To contribute to a transnational solution to this multiform challenge and opportunity, the Interreg Baltic Sea Region project Baltic Offshore Wind Energy to Hydrogen (BOWE2H) is drafting a Strategic Roadmap for the combined implementation of offshore wind and hydrogen generation in the Baltic Sea Region. This visionary blueprint will aim to showcase the potential, the obstacles and the solutions to a massive deployment of these technologies in the Baltic Sea Region, with a special eye on cross-border opportunities and challenges. Keeping track of considerations linked to policy, the grid, the energy industry and broad-based prosperity, the Roadmap will provide state-of-the-art actionable know-how for target groups to use and build on.

This metastudy is the first step in the Strategic Roadmap, which is itself one of the two major deliverables of BOWE2H. The metastudy is intended to provide an overview of the current state of offshore wind and hydrogen technology, as well as the policy environments that frame and support their development in Europe. It highlights the significant potential for Baltic offshore wind to supply a large share of Europe‘s electricity needs, and to produce green hydrogen that can be used in a variety of applications, including transportation, manufacturing and power generation.

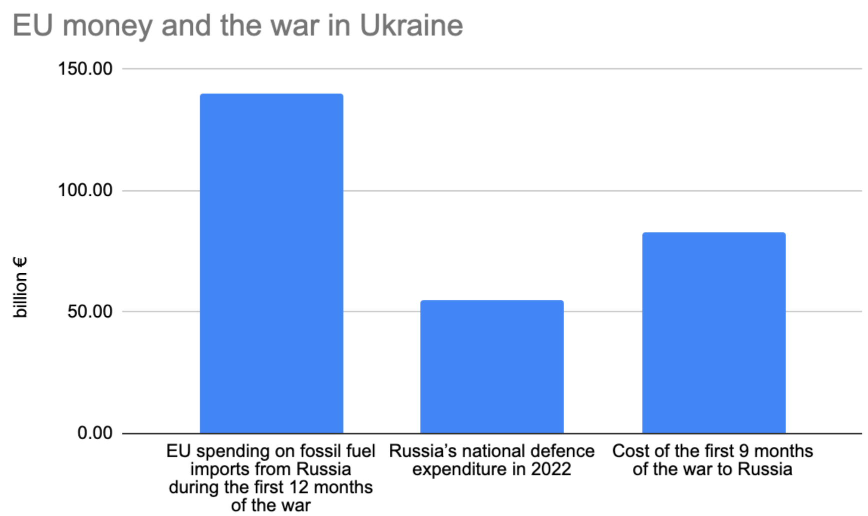
The first part of the metastudy is divided into sections describing the overall background and motivation for the project, the general state of affairs in offshore wind power generation in Europe and the current status of hydrogen production and deployment. The second part looks at the latest developments and future plans for each of the countries in the Baltic Sea Region.

Tragedy and opportunity

Russia's war of aggression in Ukraine has given the lie to many comfortable preconceptions, not least Europe's view of its own energy supply and security. In the first 12 months of Russia's war of aggression, EU countries spent some €140 billion on Russian fossil fuel imports.[1] At €55.2 billion, Russia's nominal national defence expenditure in 2022 was far less than half that.[2] (The war itself has been calculated by Forbes to have cost Russia $83 billion more in the first nine months[3] – still comfortably less than European payments for Russian hydrocarbons.) The Economist reckons that the war is costing Russia $61.75 billion a year.[4] This is disastrous in both moral and pragmatic terms, and underlines the pressing need for more physical and energy security across Europe and in the Baltic Sea in particular.

However, the turmoil and disruption caused by the war have also resulted in opportunities. Measuring factors ranging from fossil-fuel consumption and energy efficiency to the deployment of renewables, The Economist calculated that the war in Ukraine is likely to have accelerated the green transition by some five to ten years. The world's existing production capacities for oil and gas are already almost fully used and investment in new projects is falling, while exploration and production costs have grown by 30% since 2017. Average contract prices for intermittent renewables in Europe were 77% below wholesale prices between December 2021 and October 2022. The average wholesale price in Germany from 2000 to 2022 was €50 per megawatt-hour, meaning a typical solar plant became profitable after 11 years – but at a price of €257 per megawatt-hour in December 2022, the same solar plant would pay off its costs in less than three years.[5] With careful policy support, this is likely to lead to paradigmatic expansion already in the medium term.

The war has also changed and focused minds for strategic reasons, not least in the Baltic Sea Region. Finland and Estonia, among others, have accelerated their hydrogen strategy during 2022.[6] The European Union's REPowerEU strategy, in which hydrogen figures heavily, was adopted in response to the Russian aggression. It aims to wean EU countries off fossil fuels faster. Among other things, the strategy calls for a quadrupling of hydrogen production capacity by 2030, with measures like 30% of EU primary steel production being decarbonised on the basis of green hydrogen by that date.[7]



1 Centre for Research on Energy and Clean Air, 'Financing Putin's War'.

2 Teplyakov, 'Russia's Military Expenditures Doubled so Far in 2023'.

3 Datsenko, 'За дев'ять місяців Росія витратила на війну $82 млрд'.

4 The Economist, 'Russia's Economy Can Withstand a Long War, but Not a More Intense One'.

5 The Economist, 'War and Subsidies Have Turbocharged the Green Transition'.

6 Gasgrid, 'Gasgrid Finland to Develop a National Hydrogen Infrastructure – Enabling the Creation of New Investments and Jobs, and Supporting Finland's Energy Security and Self-Sufficiency'; Paulus, 'Estonia Is Preparing for a Hydrogen Economy'.

7 European Commission, 'REPowerEU Plan'.

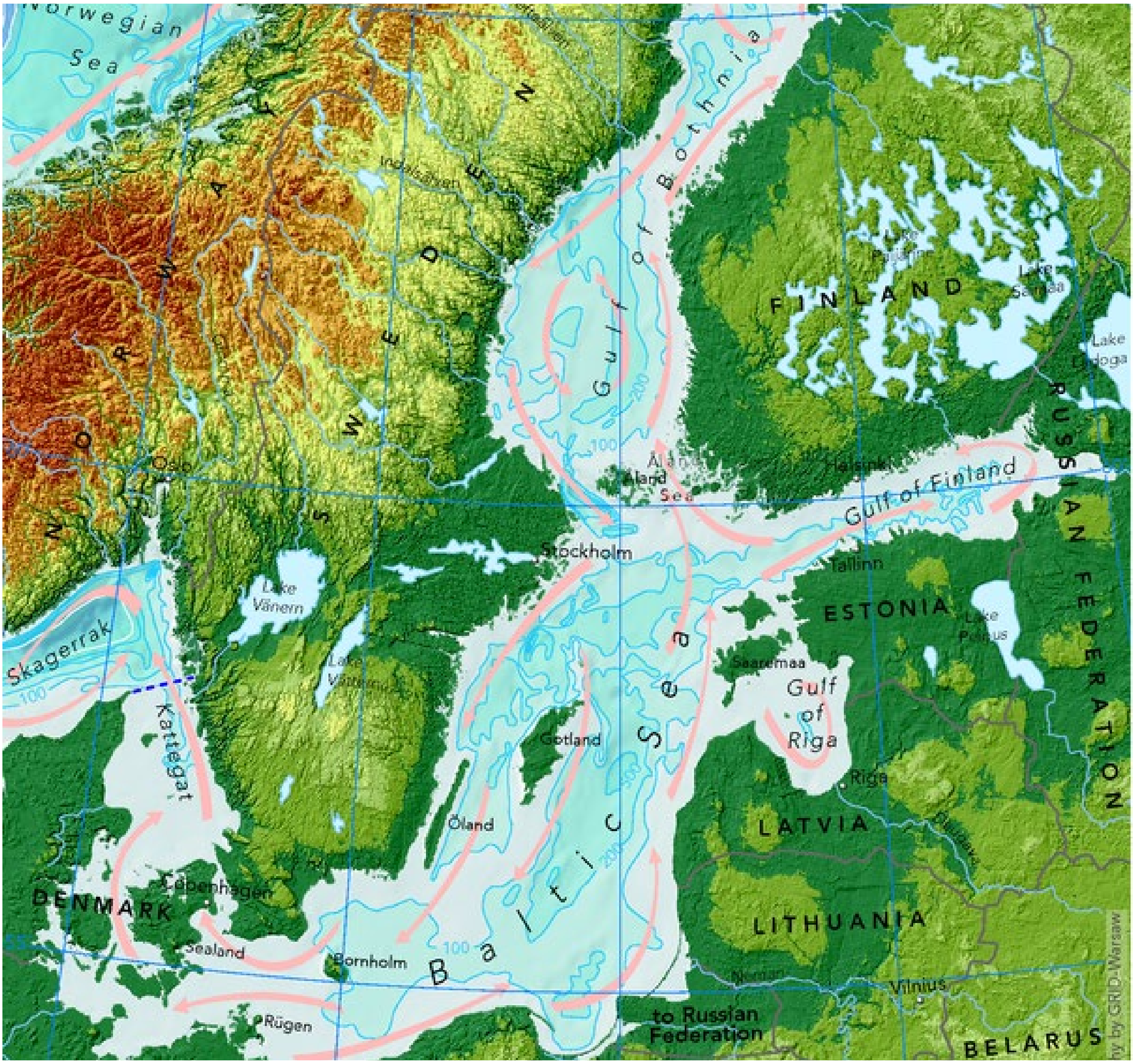
02

Offshore wind power

Offshore wind power

The European Commission expects the EU market for renewable electricity to increase by around 450 GW by 2030 and 1500 GW by 2050. This is an average of several scenarios considered in the supporting documents for the European Commission's Communication "A Clean Planet for All", published in late 2018, which laid out the EU's strategic energy vision for 2050. All the scenarios considered assume lower demand for energy overall, but substantially higher demand for electricity, in 2050, due to wholesale electrification of most sectors and the development of e-fuels.[8]

The same source expects that wind power will be the dominant technology in 2050, representing 51-56% of the power production in all decarbonisation scenarios (a substantial expansion over the 26% expected in 2030 and 9% in 2015). Offshore wind is expected to account for 240-440 GW in 2050 (compared to 460-700 GW for onshore wind). According to the Commission, Such [...] massive growth will certainly represent an investment challenge but also an opportunity for the rejuvenation of the power generation infrastructure and for development of economic activity and supply chains in Europe.



The Baltic is a marginal sea, with the shore never far away

8 European Commission, 'A Clean Planet for All'.

A high proportion of the EU's GDP – 2.8%, ranging from €175 to 290 billion, depending on the year – would need to be invested into energy infrastructure every year.[9]

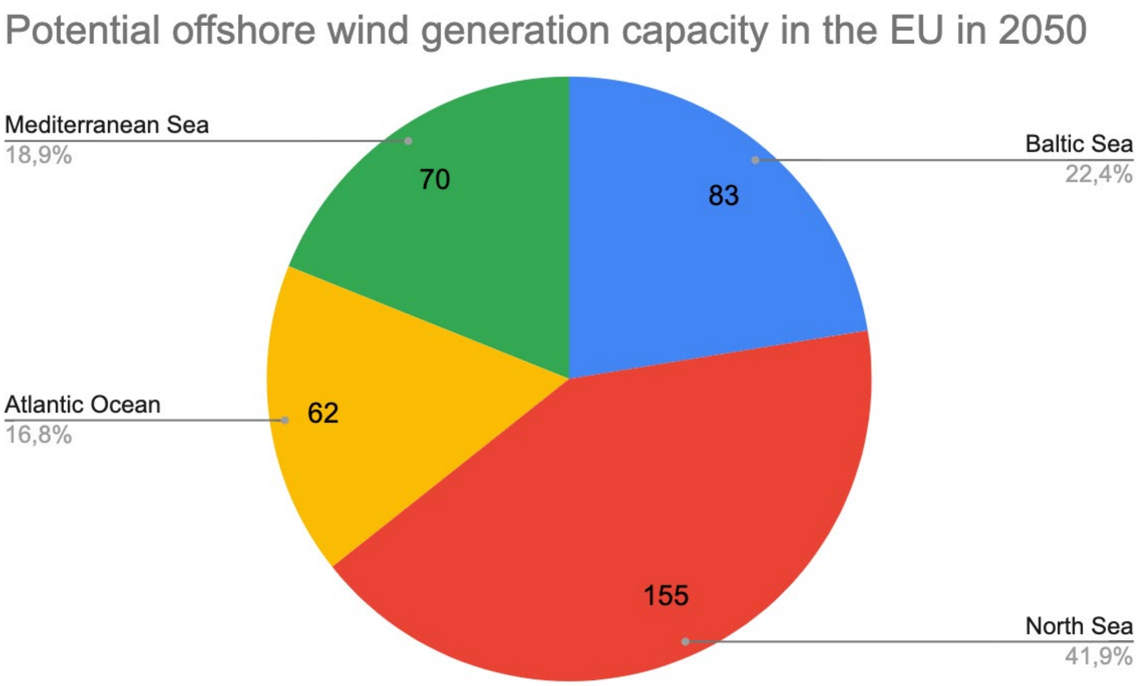
The "EU Strategy to harness the potential of offshore renewable energy for a climate neutral future", devised by the Commission in late 2020, stipulates a target of 300 GW capacity for offshore wind in 2050 and calls for an integrated regional grid planning and development, noting that insufficient offshore grid development could seriously imperil swift deployment. The Strategy also explicitly mentions offshore hydrogen production and hydrogen pipelines as an option to deliver offshore energy on-shore, and calls for them to be considered in electricity and gas grid planning.[10]

A Baltic dynamo

Wind power will be a crucial component of the energy supply of the future, not least in cloudy northern Europe, and much of that will be installed offshore to reduce acceptance issues and benefit from higher and more constant wind speeds. Moreover, offshore wind facilities in a marginal sea like the Baltic can be connected to multiple countries at the same time, allowing power to be dispatched where it is most needed at a given moment, and creating electricity connections between two shores independently of how much power is being generated on the offshore wind farms at a given time.

In many ways, the Baltic Sea is an ideal site for offshore wind power production – it has relatively shallow waters, short distances to shore and high wind speeds. Most of the regions bordering it are sparsely populated, however, and its shores are far from major industrial centres. This makes the electricity generated through offshore wind facilities in the Baltic Sea a good candidate for exporting to Central Europe and Germany (although this will require major upgrades to transmission grids) or conversion into hydrogen for storage and later use as fuel or reconversion back into electricity.

The association WindEurope, which promotes the deployment of wind energy in Europe, has theorised how the potential capacity for offshore wind generation called for in the Commission's strategy "A Clean Planet for All" could be distributed across Europe's coasts. Basing its analysis on the most ambitious scenario in the strategy, WindEurope assumes 450 GW of offshore wind capacity throughout Europe in 2050 in its report "Our Energy, Our Future". Of this amount, a possible capacity of 370 GW is implied for the post-Brexit EU and candidate countries, including 83 GW considered feasible in the Baltic Sea. By comparison, the North Sea excluding the UK could host 155 GW, the Atlantic seaboard excluding the UK 62 GW, and the whole Mediterranean, including candidate countries Montenegro, Albania and Turkey, 70 GW.[11]



Possible distribution of the 370 GW offshore wind power generation capacity in the EU and candidate states in 2050

9 European Commission.

10 European Commission, 'An EU Strategy to Harness the Potential of Offshore Renewable Energy for a Climate Neutral Future'.

11 Freeman et al., 'Our Energy, Our Future'.

To fulfil the vast potential of the Baltic Sea, WindEurope expects that the annual rate of consenting will have to increase by 2.2 GW (covering 430 km²) each year in the mid-2020s, by 3.4 GW (670 km²) per year in the late 2020s and 3.6 GW (720 km²) in the 2030s. These amounts are required to achieve 83 GW by 2050, but there is nothing preventing a higher installed capacity by that date, assuming it makes economic and political sense.[12]

The agreement on 30 August 2022 of the Heads of Government and Energy Ministers of the eight countries in the Baltic Sea Region to boost offshore wind power capacity from 2.8 GW today to 19.6 GW in 2030 is a promising signal. Some of the major obstacles they explicitly recognised include the need to speed up bureaucratic processes like permitting and building a resilient European supply chain, as well as ensuring sufficient investment in grid and port infrastructure.[13]

The technology required to make ample use of the Baltic Sea's potential in offshore wind is quickly maturing. The largest wind farms being installed in the North Sea have more than one gigawatt of capacity (equivalent to a typical nuclear plant); the biggest one yet (Dogger Bank in the UK exclusive economic zone) will clock in at 3.6 GW when it reaches full capacity in 2026. Five offshore wind projects in the United Kingdom were awarded contracts in July 2022 at a price of €44 per megawatt-hour – less than a sixth of the UK's and a fifth of Germany's wholesale electricity price at that time.[14], [15]

Existing and planned transnational initiatives in the Baltic Sea

There are a number of offshore wind power generation and transmission facilities that are planned, owned or operated by more than one country in the Baltic Sea. They include Kriegers Flak, the ELWIND offshore wind farm between Estonia and Latvia and the Bornholm Energy Island. Several more are in the planning stages, and others are under serious consideration. The potential gains and opportunities arising from a jointly planned (so-called 'meshed') offshore power transmission grid that would seamlessly connect current and planned offshore wind farms were explored in the Interreg Baltic Sea Region project Baltic InteGrid.[16]

12 Freeman et al.

13 WindEurope, 'Baltic Sea Countries Sign Declaration for More Cooperation in Offshore Wind'.

14 The Economist, 'Can the North Sea Become Europe's New Economic Powerhouse?'

15 Statista Research Department, 'Average Monthly Electricity Wholesale Price in Germany'.

16 Belltheus Avdic and Ståhl, 'Baltic InteGrid: Towards a Meshed Offshore Grid in the Baltic Sea'.

03 Hydrogen and the energy transition

Hydrogen and the energy transition

Green hydrogen – produced without fossil fuels or with carbon capture, utilisation and storage – has been touted for some time as one of the indispensable keys to a successful energy transition. As of late 2022, at least 26 governments had a dedicated national hydrogen strategy.[17] The International Energy Agency (IEA),[18] the International Renewable Energy Agency (IRENA)[19] and the European Union[20] all publish regular studies and strategy documents related to the deployment and expansion of clean hydrogen.

The European Commission's seminal strategy "A Clean Planet for All" considers a number of studies, and formulates several scenarios of its own with different rates of decarbonisation, electrification and carbon capture and storage in Europe in 2050. The average of the various scenarios shows a reduction in greenhouse gas emissions of 82% compared to 1990 (and 71% compared to 2015).[21]

This is driven mainly by increased efficiency (25% on average), electrification and hydrogen production. The latter is expected to account for 29.2% of all electricity use in 2050 (for a total of 632 TWh per year). The most ambitious scenario results in a reduction of 95% over 1990 and sees the production of hydrogen and synthetic fuels account for 47.8% of all electricity use in 2050 (1407 TWh per year). The truly hard-to-abate emissions are expected to be mostly process-related – from cement and lime production to chemical industries and iron and steel manufacturing (the latter of which can also be made green through the deployment of hydrogen or other green fuels based on hydrogen).[22]

IRENA – referring to the whole world rather than just Europe – sees less room for hydrogen in 2050 but still expects it to contribute some 10% of global mitigation (and represent 12% of final energy demand) in its optimistic 1.5 °C Scenario. IRENA, too, expects hydrogen to decarbonise sectors where other options are not feasible due to cost or technological advancement, especially heavy industry, long-haul transport and energy storage.[23]

Hydrogen production today

Around 90 million tonnes of hydrogen are produced in the world every year. This is done almost entirely with fossil fuels, using up 6% of the world's natural gas and 2% of its coal, and generating more than 800 million tonnes of carbon dioxide, the equivalent of Germany's annual emissions. Almost all of this hydrogen is produced for conversion into ammonia for use as fertiliser.[24]

All this is set to change: in the economy of the future, green hydrogen and hydrogen carriers will play a key role in decarbonising most or all of the sectors that cannot easily be electrified. And this needs to happen faster than any such wholesale transformation has happened in the past – the European Commission's hydrogen strategy calls for renewable hydrogen technologies to be enabled to reach maturity and achieve wide deployment between 2030 and 2050.[25]

Countries representing 80% of the world's GDP currently have net zero targets, which imply the adoption of a hydrogen economy, and more than 30 countries have concrete hydrogen strategies. Europe still accounts for more than 50% of announced projects, but all other regions are growing faster proportionally. Furthermore, there are increasing trade flows between supply and demand centres.[26]

The EU's hydrogen strategy, adopted in 2020, calls for an electrolyser production capacity of 80-120 GW powered by solar and wind energy by 2030, as well as substantial investment in facilities for hydrogen transport, distribution and storage, as well as hydrogen refuelling stations. The revised TEN-E Regulation of 2022 on guidelines for trans-European energy infrastructure further calls for the incorporation of hydrogen into continental strategies for energy infrastructure, including by repurposing existing natural gas pipelines.[27]

17 International Energy Agency, 'Hydrogen – Analysis'.
18 International Energy Agency.
19 International Renewable Energy Agency, 'Hydrogen'.
20 European Commission, 'Hydrogen'.
21 European Commission, 'A Clean Planet for All'.
22 European Commission.
23 International Renewable Energy Agency, 'Hydrogen'.
24 The Economist, 'Creating the New Hydrogen Economy Is a Massive Undertaking'.
25 European Commission, 'A Hydrogen Strategy for a Climate-Neutral Europe'.
26 Hydrogen Council, 'Hydrogen Investment Pipeline Grows To $500 Billion In Response To Government Commitments To Deep Decarbonisation'.
27 European Parliament and Council, 'EU Regulation 2022/869 on Guidelines for Trans-European Energy Infrastructure'.

Taxing carbon

A substantial and transparently levied carbon tax that covered most of the world's developed economies would go a long way to resolving the problem of greenhouse gas emissions by simply harnessing innovation and adaptation in the free market. However, this would require a prodigious amount of political will throughout the world, and rigorous control and information on the carbon embedded in all imported products, making the concept politically and technically extremely difficult.

The European Union is currently working on implementing such a carbon price in its internal market and complementing it with a Carbon Border Adjustment Mechanism, set to enter into force in its transitional phase on 1 October 2023 (initially to cover cement, iron & steel, aluminium, fertiliser, electricity and hydrogen) and fully on 1 January 2026;[28] the exact workings and effects of this regime remain to be established. There are also, however, plans for subsidies to boost green economic activities and regulations which discourage greenhouse gas emissions.

The economics of hydrogen

A 2020 study by the research consultancy BloombergNEF expects that, in the ideal circumstances, the wholesale introduction of green hydrogen could eliminate a third of all the carbon dioxide emissions linked to the use of fossil fuels by 2050 (electrification eliminating much of the rest). This assumes the carbon price to rise to US$160 per tonne of carbon dioxide, carbon capture, utilisation or storage (CCU/CCS) to be deployed on a substantial scale, and cost of delivered hydrogen to drop to $1/kg, however – all very ambitious and perhaps unlikely measures.[29]

The relevant technology for the generation of hydrogen – whether electrolysers, storage & transport facilities, ammonia conversion or practical applications – is still lagging behind the level of sophistication reached in offshore wind power generation. The main issues standing in the way of a green hydrogen economy are production cost, transport & storage cost, and demand & the availability of applications.

Production costs

Hydrogen is starting to catch up, however: the cost of alkaline electrolysers made in North America and Europe fell by 40% between 2014 and 2019, and there are systems made in China that are already as much as 80% cheaper than that. The other main component of the production cost of green hydrogen is electricity, which is also becoming cheaper as more renewable power generation facilities come online. If costs continue to fall, BloombergNEF suggests that fully renewable hydrogen could be produced for US$0.7 to $1.6/kg in much of the world by 2050, making it competitive with natural gas prices in Germany and Scandinavia.[30]

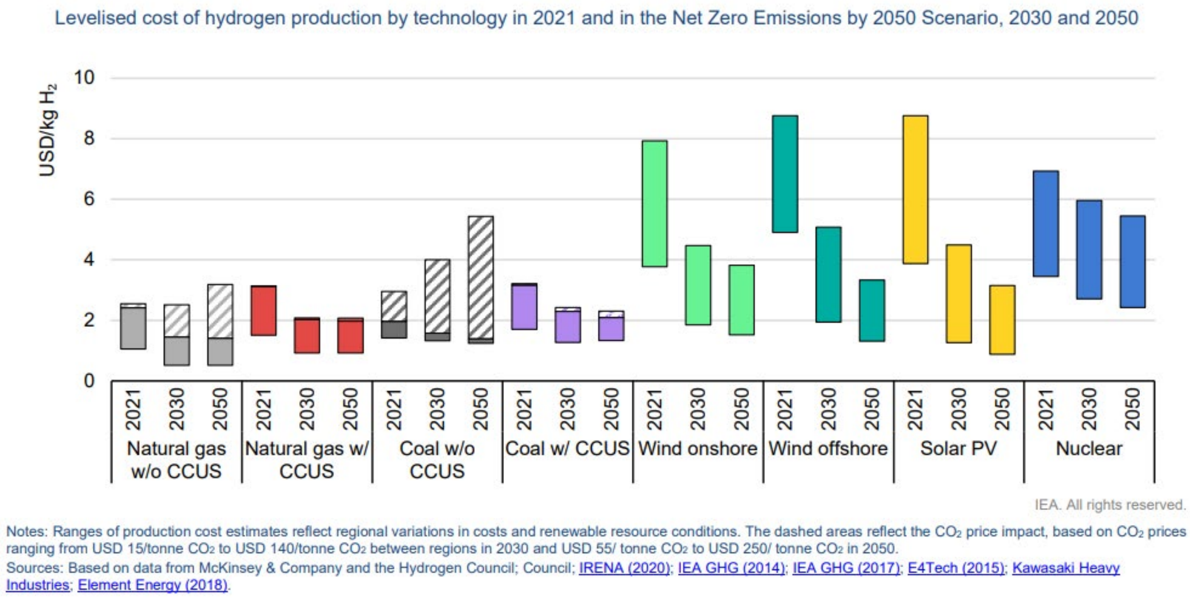
The table below shows the projected levelised cost of hydrogen production with different energy sources in 2021, 2030 and 2050. The striped areas in the columns related to fossil-fuel-powered production show the range of prices that would result from different levels of carbon pricing (this is absent in the columns referring to production with carbon capture, utilisation and storage (CCUS), which is assumed here to be entirely carbon-neutral). This shows that, in the absence of a substantial and consistently levied carbon price, truly renewable hydrogen (made with wind or solar power) will not be cost-competitive with fossil hydrogen in 2030, but may become so in 2050.[31]

28 European Commission, 'Carbon Border Adjustment Mechanism'.

29 BloombergNEF, 'Hydrogen Economy Outlook'.

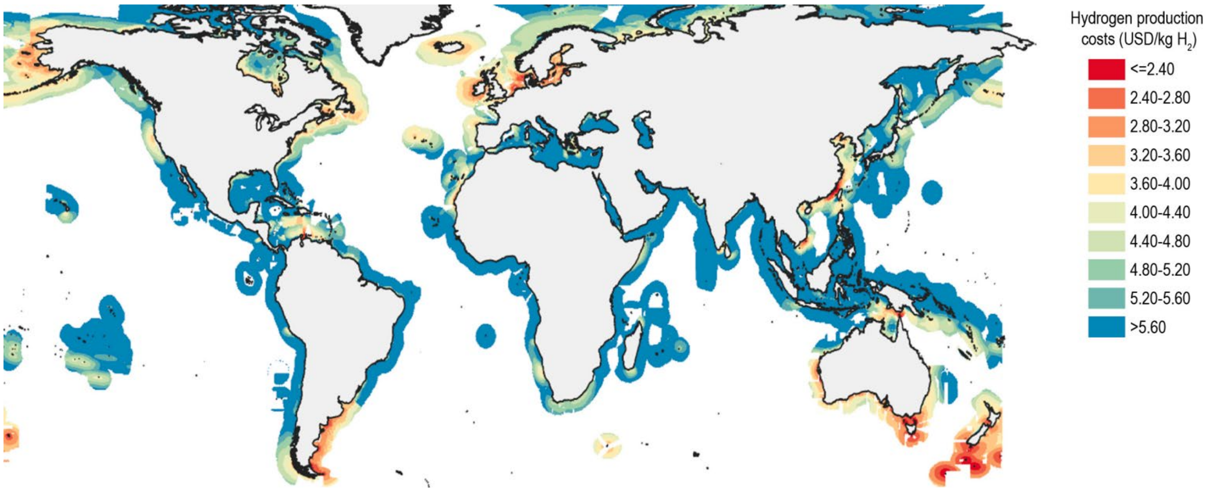
30 BloombergNEF.

31 International Energy Agency, 'Global Hydrogen Review 2022'.



Levelised cost of hydrogen production in 2021, 2030 and 2050

According to some measures, the Baltic Sea Region is one of the areas in the world best suited for the generation of hydrogen specifically through offshore wind (see map below).[32]



Hydrogen production costs in US$ per kilogram

Transport and storage

A commonly cited issue with hydrogen is its low energy density, which makes it comparably difficult to store and transport. If the global economy today replaced all natural gas by hydrogen, it would require three to four times more storage infrastructure. By 2050 that would require investment in the order of US$637 billion. However, large-scale long-term storage of hydrogen gas in onshore underground geological features is affordable.[33] There appears to be substantial capacity for such storage in the Baltic Sea Region – in Poland alone, underground storage (mostly in salt caverns located in the central and southern parts of the country) provides a capacity in excess of three billion cubic metres.[34] Another economical option is small-scale storage

32 International Energy Agency.

33 BloombergNEF, 'Hydrogen Economy Outlook'.

34 Małachowska et al., 'Hydrogen Storage in Geological Formations—The Potential of Salt Caverns'.

in pressurised containers. Liquid hydrogen and conversion to ammonia are prohibitively expensive now but may become reasonably affordable in the long term.[35]

In places with large-scale geological storage possibilities, any hydrogen produced with renewable power that would otherwise be curtailed could be stored on a large scale and used to power gas turbines and produce electricity as the need arises. According to BloombergNEF, this could cost as little as US$1.1 to $1.9/kg by 2050 in most locations and would be competitive with natural gas with a carbon price of $32 per tonne of carbon dioxide.[36]

Transport is another headache. According to the International Energy Agency, repurposing existing natural gas pipelines to hydrogen would cost 50-80% less than building new ones, but practical experience is limited. Liquid natural gas (LNG) terminals cannot be converted as yet, but comparable ones can be built for hydrogen instead at a cost of around 50% more. (LNG terminals can be repurposed for ammonia at just 11-20% of additional cost, however). Given uncertainty about future demand for hydrogen, such large-scale investments can be difficult to justify.[37]

Carbon capture, utilisation and storage

The topic of carbon capture, utilisation and storage (CCUS) is quite vexed. For one thing, while carbon capture and utilisation is usually envisaged and deployed differently from carbon capture and storage, they are often lumped together under a single appellation. For the purposes of this study, they are considered jointly as all processes based on the sequestration of carbon dioxide emitted during the use of fossil fuels.

As seen in the graph above, producing hydrogen with CCUS is theoretically quite affordable compared to using renewable energy. Given the major climate benefits, this should be a no-brainer. In practice, however, the picture is more complex. CCUS has been widely discussed at least since it was included in the United Nations' Clean Development Mechanism (CDM) international carbon offset scheme in 2005, but has not reached wide deployment.

For one thing, it is not yet mature or proven enough to guarantee absolute safety and efficiency. In 1986 environmental conditions led to the massive release of a 100-300-tonne natural deposit of carbon dioxide from Lake Nyos in Cameroon, which led to the death of 1,746 people and 35,000 livestock. Partly for this reason, countries such as Norway have expressed opposition to the idea of storing captured carbon dioxide under the seabed.[38] Indeed, any major facility of this type would be vulnerable to sabotage by ruthless countries or organisations.

Cost is another major issue. Capturing just 20% of the carbon dioxide emitted by the United States in a given year would appear to consume the country's entire annual electricity production. At any rate, all CCUS facilities that have been established so far have ended up producing net emissions of carbon dioxide due to the energy intensity of the process. Direct air capture powered by renewables could lead to a net reduction – but all the wind and solar energy generated in the United States in 2018 would suffice to capture just 2% of the country's annual emissions of carbon dioxide.[39]

The International Energy Agency (IEA) tends to heavily feature CCUS solutions in all its predictions and scenarios, but has also stated that „the story of CCUS has largely been one of unmet expectations".[40] An Environmental, Social & Governance (ESG) risk briefing in early 2022 by Allianz Global Corporate & Specialty, a multinational financial services company,

35 BloombergNEF, 'Hydrogen Economy Outlook'.

36 BloombergNEF.

37 International Energy Agency, 'Global Hydrogen Review 2022'.

38 Alliance Global Corporate & Security, 'CCUS Technologies'.

39 Sekera and Lichtenberger, 'Assessing Carbon Capture'.as the visible impacts of climate change mount, calls for mitigation through carbon drawdown are escalating. Environmentalists and many climatologists are urging steps to enhance biological methods of carbon drawdown and sequestration. Market actors seeing avenues for profit have launched ventures in mechanical–chemical carbon dioxide removal (CDR

40 'A New Era for CCUS'.

echoed many people‘s concerns by stating that „there is a risk of CCUS being marketed as a “zero-emissions” solution with a wrong perception or misuse of the technology as a license to ramp up emissions.“ They also point out as a major shortcoming that there are no regulations in most places today that would foster or require the use of CCUS.[41]

Even so, seemingly exciting new solutions have been multiplying in the recent past. For the time being none appear to have reached a level of maturity that would justify the hope that has been placed in the concept, but the research is ongoing and the appetite to deploy such technologies remains high.[42]

Current and potential hydrogen applications

As mentioned above, some 90 million tonnes of hydrogen are produced in the world every year. The International Renewable Energy Agency (IRENA) expects that global demand will rise to 614 million tonnes a year by 2050, when it will meet 12% of the world‘s total energy use. The growth will be driven by industrial and transport sectors in particular, where hydrogen would mitigate some 12% and 26% of the carbon dioxide emissions, respectively.[43]

Hydrogen can be deployed in several ways that would help decarbonise large swaths of the economy. One is steelmaking, which today accounts for around eight per cent of the world‘s greenhouse-gas emissions and is particularly difficult to electrify due to the high temperatures involved and the widespread use of coking coal (coke is an essential fuel and reactant in the blast furnace process for primary steelmaking). Applying hydrogen in a so-called direct reduction process, however, makes it possible to largely decarbonise it.

The Swedish industrial consortium Hybrit delivered the world’s first batch of green steel in 2021 and expects the process to be ready for industrial-scale application by 2026. Another Swedish company, H2 Green Steel, is planning to build a new fossil fuel-free steel plant in northern Sweden that will start production in 2024.[44] In October 2022, ArcelorMittal broke ground on what it claims to be a US$1.3 billion transition to direct-reduction-based steelmaking in Ontario, Canada, and reports similar plans for facilities in Spain, France, Belgium and Germany. (It is notable, however, that the company appears to have no such plans for its sites in developing countries, notably India.)[45]

Transport is another sector where hydrogen has great potential. For short distances, whether for cars, trucks or trains, battery-driven engines are usually the most efficient, but a battery drive often lacks the necessary reach for longer trips. In these situations, a hydrogen fuel cell drive can make sense. However, for the time being such applications are in the minority: for instance, there were 24 fuel cell buses and 385 battery-electric buses on Germany’s roads at the beginning of 2020.[46]

Trains may be a different story. While many lines are electrified – in Germany, for instance, the proportion is around 60% – most of the others are operated by trains with diesel engines. Those remaining lines are often not suitable for electrification – they may comprise valleys, bridges or tunnels that make new construction difficult and prohibitively expensive for less frequented regional branch lines. Electrification is also costly and has a long planning and execution time.[47] Deutsche Bahn is therefore working on trains that would run on fuel cells through the publicly funded H2goesRail project, which will by 2024 bring into regular service a fuel cell train with a range of around 800 kilometres and a max speed of 160 km/h which can be refuelled as quickly as electric trains.[48]

Hydrogen can theoretically also be used as fuel for watercraft. In early 2022, there were several pilot and demonstration projects for new renewable fuels in shipping, of which some 45 focused on hydrogen, 40 on ammonia and 25 on methanol (it should be noted that hydrogen is part of both ammonia (chemical composition NH3) and methanol (CH3OH) and that producing all these fuels in a climate-neutral way therefore requires the availability

41 Alliance Global Corporate & Security, ‘CCUS Technologies’.

42 Renssen, ‘CCU: Dangerous Distraction or Essential for the Energy Transition?’; Ellis, ‘Why Carbon Capture and Storage Is Key to Avoiding the Worst Effects of the Climate Emergency’.

43 Blanco and Taibi, Global Hydrogen Trade to Meet the 1.5 oC Climate Goal: Part I – Trade Outlook for 2050 and Way Forward.

44 Reuters, ‘Sweden’s HYBRIT Delivers World’s First Fossil-Free Steel’.

45 Nicholas and Basirat, ‘ArcelorMittal: Green Steel for Europe, Blast Furnaces for India’.

46 Umweltbundesamt, ‘Wasserstoff im Verkehr’.

47 tagesschau, ‘Wie die Deutsche Bahn ihre Diesselloks ersetzen will’.

48 Deutsche Bahn, ‘H2goesRail’.

of climate-neutral hydrogen). Most of the pure hydrogen projects focus on small vessels, while ammonia is considered for large vessels and methanol for both. Ammonia appears to be the closest to mass deployment in the medium term.[49]

In a more distant future, pure hydrogen or hydrogen-derived fuel may be used to power aircraft as well. The latter technology is more mature, cost being the main obstacle to wide adoption.[50] It is not clear when air travel can be expected to be decarbonised to a substantial degree.

The buildings sector has also sometimes been considered a candidate for hydrogen application. However, electricity, district heat and distributed renewables will be more efficient and less costly for decarbonisation in almost all cases.[51]

Carbon-based e-fuels

Hydrogen can be used directly as a fuel or for energy storage, but it can also be converted to other fuels. While this naturally requires additional energy and therefore represents an inefficiency, it can reduce some of the difficulties in transport, storage and use which result from the chemical structure of pure hydrogen.

E-fuels (from „electric fuels“) are synthetic fuels produced with renewable energy. They are always hydrogen-based, and the hydrogen required is extracted from water through electrolysis. The pure hydrogen can be used as a fuel itself, or can be combined with nitrogen or carbon captured from the air to produce ammonia (NH3) or carbon-based fuels such as methane (CH4). A major advantage of certain types of e-fuels, especially e-diesel and e-petrol, is that they can be used in existing combustion engines with little to no modification.

However, e-fuels are not a panacea against climate change. For one thing, carbon-based e-fuels are chemically equivalent to their fossil counterparts and thus emit carbon dioxide (and possibly other pollutants) into the atmosphere. In this sense, they recycle the carbon they contain, which was originally captured from the atmosphere, whereas fossil fuels result in the net addition of carbon dioxide to the atmosphere. Moreover, they are currently far more expensive than other fuels, at least in smaller-scale applications like personal vehicles. By comparison, non-carbon-based fuels like hydrogen and ammonia do not emit any carbon dioxide during use.

Research and development are continuing and it is expected that the production process will become more efficient and cost-effective, making e-fuels a more viable option for reducing carbon emissions in the future.

The current status of the hydrogen industry

While hydrogen seems to be on everybody‘s lips right now, governments are only just starting to put in place policies to enable the transformations required for it to replace fossil fuels on any substantial scale. A lot of measures have been poorly funded: many promising use cases in industry, for instance, only receive one-off grants for demonstration projects instead of large-scale investment. For the industry to scale up, comprehensive policy must be in place at all levels of government and at a European scale. Some US$150 billion of cumulative subsidies need to be deployed by 2030.[52]

In May 2022 the European Commission and largest producers committed to increase the EUs manufacturing capacity for electrolysers tenfold by 2025, with the target of achieving yearly hydrogen production capacity of 10 million tonnes. A dozen projects have already been announced with the three largest together adding up to 20 GW. The Danish firm Topsøe alone claims to have a total list of orders amounting to 86 GW.[53]

49 Kilemo, Montgomery, and Leitão, 'Mapping of Zero Emission Pilots and Demonstration Projects'.

50 International Energy Agency, 'Global Hydrogen Review 2022'.

51 International Energy Agency.

52 BloombergNEF, 'Hydrogen Economy Outlook'; International Energy Agency, 'Global Hydrogen Review 2022'.

53 The Economist, 'Can the North Sea Become Europe's New Economic Powerhouse?'

According to the Hydrogen Council, an industry consortium, there were some 359 big projects to develop clean-hydrogen production, hydrogen-distribution facilities and industrial plants underway around the world in mid-2021. Their combined electricity demand will be hundreds of gigawatts, similar to entire large economies. The cumulative total of public and private investment they are set to receive will be some $500 billion by 2030.[54]

As mentioned above, the physics of hydrogen means that transport and storage are a major issue that needs to be resolved. Three projects attempting to contribute to a solution to this problem were launched in 2022. Nordic Hydrogen Route, a connection across the Bay of Bothnia between Finland and Sweden, was launched in April by the Finnish and Swedish gas transmission system operators Gasgrid and the Swedish Nordion Energi. The other two projects were signed in December 2022. The first – Nordic-Baltic Hydrogen Corridor, a hydrogen pipeline linking Finland to Germany through the Baltics and Poland to Germany – was agreed upon by gas transmission system operators in Finland, Estonia, Latvia, Lithuania, Poland and Germany (Gasgrid, Elering, Conexus Baltic Grid, Amber Grid, GAZ-SYSTEM and ONTRAS). The second is the Baltic Sea Hydrogen Collector (BHC), also launched by the Finnish and Swedish gas transmission system operators Gasgrid and Nordion Energi together with the two Danish private companies OX2 and Copenhagen Infrastructure Partners. This plan connects mainland Finland to Germany via Åland and Sweden, with a potential branch to the future Baltic energy island Bornholm.[55]

<map of the three routes?>
Once completed around the end of the 2020s, the Baltic Sea Hydrogen Collector and the Nordic-Baltic Hydrogen Corridor will be connected to each other and the Nordic Hydrogen Route. They will foster decarbonisation, regional green industrialisation and European energy independence, complementing the EU hydrogen strategy and REPowerEU and supporting climate targets such as the EU Green Deal and the Fit for 55 package.[56]

54 Hydrogen Council, 'Hydrogen Investment Pipeline Grows To $500 Billion In Response To Government Commitments To Deep Decarbonisation'.

55 Vanttinen, 'Hydrogen Infrastructure Projects Launched to Connect Finland and Central Europe'.

56 Vanttinen.

04

Barriers and opportunities in the countries of the Baltic Sea Region

Barriers and opportunities in the countries of the Baltic Sea Region

Mechanisms will need to be agreed on a Europe-wide basis for the transmission and trading of offshore wind energy, including energy generated in one country's EEZ, transmitted across another and supplied to a third. This is perhaps especially important for countries around the Baltic Sea, which will need substantial investment in port and onshore transmission infrastructure. The scale of this transformation will require significant investment.

Estonia, Latvia and Lithuania are facing a particular challenge in terms of the interconnection and system synchronisation of their grids with those of the rest of mainland Europe. There are already contingency plans to disconnect them from the former Soviet grid and attach them to the broader ENTSO-E power grid which covers 39 European countries. Lithuania's grid operator has already stated that this could be done in 24 hours if necessary. There are interconnectors with Poland and Scandinavia, but additional local infrastructure will still be required, and Latvia in particular appears to be lagging in this regard. The planned Harmony Link submarine power cable link between Lithuania and Poland still needs to be completed.[57]

Denmark

Denmark plans to reduce its greenhouse gas emissions by 70% in 2030 compared to their 1990 level and to reach carbon neutrality by 2050.[58] Onshore and offshore wind play a major part in this. Denmark's national transmission system operator for electricity and natural gas estimates that Danish waters alone could host enough offshore wind power capacity to produce more than twice as much electricity as Denmark could require, even once society is fully electrified.

Offshore wind

To achieve WindEurope's optimistic prediction of 35 GW of offshore wind capacity for Denmark in 2050, the country will have to speed up its grid upgrades. Since 25 GW would be traded, cross-border interconnection and offshore hybrid projects will be a crucial part of this process. Moreover, the sheer scale of the offshore wind power build-out might lead to substantial cumulative environmental impact. As with other Nordic countries and Germany, the considerable number of areas that are excluded from development means that the expansion will be more expensive than it would otherwise be.[59]

Before the new Climate Agreement on Green Electricity and Heat was agreed among all political parties in June 2022, the 2030 target for offshore wind was 8.9 GW in all (from 2.3 GW in early 2023). The new target is 12.9 GW, a fivefold increase from today's capacity. Nine gigawatts – enough capacity to power nine million households – are planned to be put out to tender in 2023. These projects include the Bornholm Energy Island and must be sent to government tenders. They are not part of the projects that have applied under Denmark's „open door" scheme, which was recently suspended due to possible incompatibility with EU law.[60]

The "open door" procedure allows developers to apply to set up offshore wind farms on their own initiative. This creates more flexibility with regard to project location, generation capacity and grid connection. Among other things, the procedure makes it possible for developers to place projects close to areas with large industrial electricity demand, facilitating corporate renewable Power Purchase Agreements (PPAs). This system, which does not in itself comprise any public subsidy element, has been praised for enabling more cost-competitive projects and more efficient site selection.[61]

Hydrogen

Denmark is also introducing a state aid scheme worth some €170 million which will support the upscaling of the production of renewable hydrogen and derivatives, such as green ammonia, methanol and e-Kerosene through P2X technologies. The aid will be awarded through a competitive bidding process to be concluded in 2023. Beneficiaries will have to show they comply with EU criteria for the production of renewable fuels, which will include deploying the additional renewable electricity needed to produce the relevant P2X energy carriers. The new electrolysers should have a capacity of 100-200 MW and are expected to reduce carbon dioxide emissions by some 70,000 tonnes in manufacturing, mobility and energy applications.[62]

57 Naylor, 'Baltics Race to Replace Russian Power Links'.

58 European Commission, 'Commission Approves €170 Million Danish Scheme'.

59 Freeman et al., 'Our Energy, Our Future'.

60 Durakovic, 'Denmark to Auction Off 9 GW of Offshore Wind in 2023'.

61 WindEurope, 'Pause to Danish Offshore Wind Scheme Is Absurd'.

62 European Commission, 'Commission Approves €170 Million Danish Scheme'.

Estonia

Offshore wind

Estonia's government is planning for 100% of the electricity consumed in the country by 2030 to come from renewable resources.[63] In fact, Estonia has set itself the goal of eventually becoming the world's largest producer of wind energy per capita. This will naturally require a very fast and very ambitious rollout – something the government is trying to achieve by drastically simplifying the development process. Estonia is adopting an integrated planning permit system with much shorter deadlines and the objective that projects deemed to be of major societal importance should be completed within three years.[64]

As an example, the developer of the 1,200 MW Saare-Liivi offshore wind farm submitted a building permit application in 2021 and the environmental impact assessment (EIA) has already been completed – accelerating the process by a year or so. The permits for construction are expected to be obtained in 2025 and the wind farm should be producing electricity no later than 2028.[65]

Estonia is also establishing a 100-square-kilometre marine testbed on the north coast of the island of Saaremaa where companies are invited to develop new offshore wind farm technology. And the port of Tallinn is building a €53 million 310-metre dock adjacent to a 10-hectare area to service offshore wind farms which should be completed in 2025.[66]

There is great interest in the areas available for the development of offshore wind farms under Estonia's maritime spatial plan. As of summer 2022, the regulation which will determine which applications for development win the upcoming auctions is at the public consultation stage, and the first auctions should be taking place during the first half of 2023. Auctions will be organised once Estonia's Consumer Protection and Technical Regulatory Authority (TTJA) publishes an official planning notice for a given area and will involve applications submitted within 60 days. Most of the expressions of interest so far have involved offshore wind farms in the Gulf of Riga and the southernmost tip of the island of Saaremaa. The starting auction price for a hypothetical 1,000-megawatt offshore wind farm on around 200 square kilometres is expected to be around €5 million.[67]

Hydrogen

Estonia expects that it will eventually have a total capacity of 7 GW in offshore wind, which should cover the country's energy needs twice over. The surplus is likely to be used at least in part to produce and export hydrogen. The so-called Hydrogen Valley Estonia (HVE) initiative – a comprehensive national strategy aiming to achieve a large-scale hydrogen ecosystem – is meant to bring together production, consumption, distribution and deployment of hydrogen across a range of sectors, not least for industrial uses.[68]

Energy independence is a major motivator; according to Marek Alliksoo, spokesperson for the Estonian Hydrogen Valley ecosystem and board member at the Estonian Hydrogen Association, „If someone were to cut all your wires elsewhere, you would still be a green island in the middle, and you would be able to survive." This could partly resolve the above mentioned issue of transmission – according to certain experts, using hydrogen for large-scale energy transmission could be up to 20 times cheaper than building corresponding electric cables. Any surplus energy could also be exported to Central Europe in the future.[69]

Challenges

As in Latvia and Lithuania, timely investment in port infrastructure is a major challenge for the expansion of offshore wind power in Estonia which should be addressed as early as possible. According to WindEurope, Internal grid enhancement in particular is important for Estonia, as so much of its local demand will be covered by offshore wind power, and this electricity must be brought ashore safely and efficiently.[70]

63 ERR, 'Estonia Sets 2030 Target for Renewable-Only Electricity'.

64 Liive, 'Estonia's Emerging Offshore Wind Tech Innovation and Manufacturing Hub'.

65 Memija, 'Estonian Offshore Wind Project Moves Forward'.

66 Liive, 'Estonia's Emerging Offshore Wind Tech Innovation and Manufacturing Hub'.

67 ERR, 'Offshore Wind Farm Applications Come from Both Outside and inside Estonia'.

68 Paulus, 'Estonia Is Preparing for a Hydrogen Economy'.

69 Paulus.

70 Freeman et al., 'Our Energy, Our Future'.

Finland

Finland‘s ambitious aim to reach carbon net zero by 2035 has been underpinned by a major expansion of (mostly onshore) wind in the past ten years. From less than 1% a decade ago, wind power now supplies some 10% of Finland's electricity and is planned to reach at least 27% by 2025. By the end of 2022 the country had around five gigawatts of capacity, most of it onshore. But there are a range of plans and projects that will give offshore wind a huge boost in the coming years.[71]

Offshore wind

The one existing offshore wind farm in Finnish waters, the 42 MW nearshore Tahkoluoto wind farm, was commissioned in 2017, and the Finnish Government is planning to substantially expand it to a capacity of up to 900 MW. The main new site being developed is at Korsnäs: the initial plans for this wind farm site foresaw a capacity of 1.3 GW, but this will potentially now go up to 3 GW.[72] An installed capacity of 1.3 GW is calculated to correspond to an annual production of around five terawatt-hours – equivalent to the annual electricity consumption of two million apartment homes, or the heating requirements of 250,000 individual electrically heated houses. The Korsnäs wind farm will start operations in the early 2030s.[73]

In November 2022, there were 13 offshore wind power projects planned in Finland, with a total expected output of nearly 13.5 gigawatts – more than 3.2 GW more than what had been in the pipeline in the spring.[74]

Hydrogen

Finland has greatly accelerated its hydrogen strategy during 2022. Three infrastructural complexes to transport hydrogen to Sweden, Germany and Poland across and around the Baltic Sea have been agreed with the neighbouring countries and should be commissioned in the late 2020s.[75] They will link up with three planned hydrogen production hubs, the first of which – a €500 million plant in Kokkola on the west coast – will have a capacity of 300 MW and is slated for completion in 2027.[76]

Challenges

Like the other Nordic countries, and especially Sweden, Finland has a lot of exclusion zones in its offshore areas due to military radar issues, particularly in its southern waters. Other challenges include the lack of revenue stabilisation mechanisms for projects and an inadequate regulatory framework for grid connection.[77]

Germany

The German government recently boosted the climate protection targets previously set in the latest version of the Climate Protection Act and formulated the explicit goal of achieving climate neutrality in 2045. The targets for 2030 were also raised in the modified Climate Protection Act, which now stipulates that greenhouse gas emissions are, by 2030, to be reduced by 65% compared to their 1990 levels.[78]

Offshore wind energy

Offshore wind energy will play a central role in reaching these climate action targets. Targets specifying faster expansion of offshore wind energy generation capacity in Germany have been set through an amendment to the Offshore Wind Act (Wind-auf-See-Gesetz). These provide for a total capacity of offshore wind turbines to be increased to a total of at least 30 GW by 2030, at least 40 GW by 2035 and 70 GW by 2045.[79]

71 WindEurope, 'Finland to Build Two Large-Scale Offshore Wind Farms'.

72 WindEurope.

73 Vattenfall, 'Vattenfall Gets to Build Finland's First Large Offshore Wind Farm'.

74 Baltic Wind, 'FWPA: Over 13 GW Offshore Wind Planned in Finland'.

75 Vanttinen, 'Hydrogen Infrastructure Projects Launched to Connect Finland and Central Europe'; Gasgrid, 'Gasgrid Finland to Develop a National Hydrogen Infrastructure – Enabling the Creation of New Investments and Jobs, and Supporting Finland's Energy Security and Self-Sufficiency'.

76 Vanttinen, 'New Finnish Hydrogen Plant'.

77 Freeman et al., 'Our Energy, Our Future'.

78 Bundesministerium für Wirtschaft und Klimaschutz, '30 Gigawatt bis 2030'.

79 Deutsche WindGuard, 'Status Des Offshore-Windenergieausbaus in Deutschland'.

Germany currently counts a total of 28 offshore wind farms in operation. Their total installed capacity at the end of 2022 was 8.1 GW, and an additional 0.2 GW are currently under construction in early 2023. Affirmative investment decisions have already been made for new projects with a combined capacity of 1.6 GW. And an additional 3.8 GW of capacity has been awarded a contract or entitled to grid connection under the Energy Industry Act.

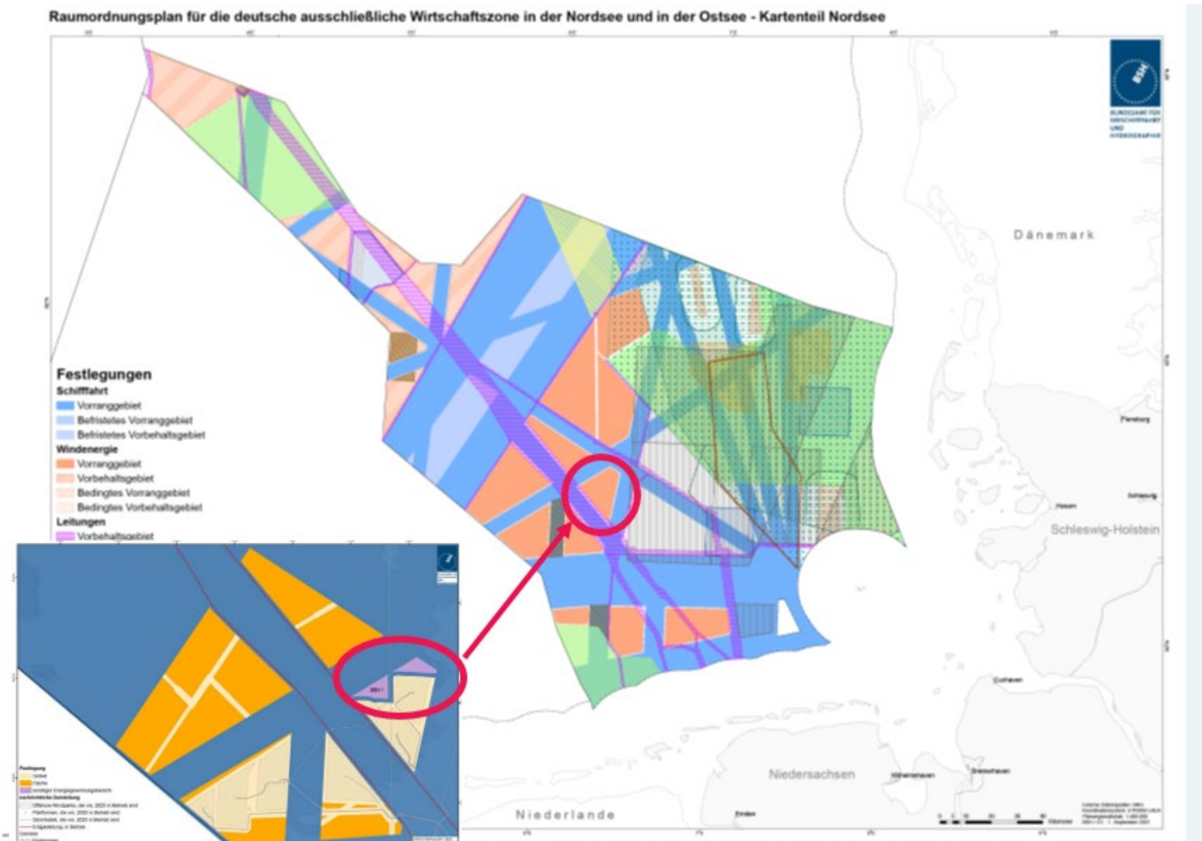
Germany's new Spatial Development Plan, which implements the acceleration measures of the Offshore Wind Act, was published in January 2023. To speed up the expansion, the density of offshore wind power generation facilities was increased in the existing areas and further promising locations were identified. A total capacity of 36.5 GW can be installed on these areas.[80]

Germany's Spatial Development Plan now also lays the foundation for a European offshore power grid through which individual wind farms can be interconnected. Another important new component in the plan is a designated area for the production of hydrogen through electrolysis with a capacity of 1 GW, which is to be connected via a hydrogen pipeline.

Hydrogen

The German government adopted its National Hydrogen Strategy in June 2020. This states that hydrogen is a major energy carrier of the future, setting targets that are no less ambitious than the expansion targets for offshore wind energy. The action plan within the strategy lists 37 measures intended to ramp up the production and marketing of green hydrogen. These measures cover the categories production, fields of application, research & education, pan-European action and international partnerships.[81]

Much of Germany's hydrogen production via offshore wind energy is expected to take place in the North Sea. A sonstiger Energiegewinnungsbereich (SEN-1, or first area for special energy production) was designated for this purpose in the current spatial development plan. It is located some 100 kilometres from the coast and measures 27.5 square kilometres.



Source: BSH

The world's first offshore hydrogen test site, SEN-1 in the North Sea [82]

80 Bundesministerium für Wirtschaft und Klimaschutz, '30 Gigawatt bis 2030'.

81 BMWi, 'Die Nationale Wasserstoffstrategie'.

82 Bundesamt für Seeschifffahrt und Hydrographie, 'Flächenentwicklungsplan 2023 Nordsee'.

A previous draft of the spatial development plan included an area designated for hydrogen production in the Baltic Sea as well (SEN-2), but this has been dropped in the current draft. Even so, there are still ambitions to promote hydrogen production in the Baltic Sea. For example, a 100 MW electrolyser at the port of Rostock is under discussion. In addition, a range of research projects on hydrogen generation are being conducted in the Baltic Sea. Germany's goal is to have a 10 GW total electrolysis capacity fed by offshore wind by 2030.

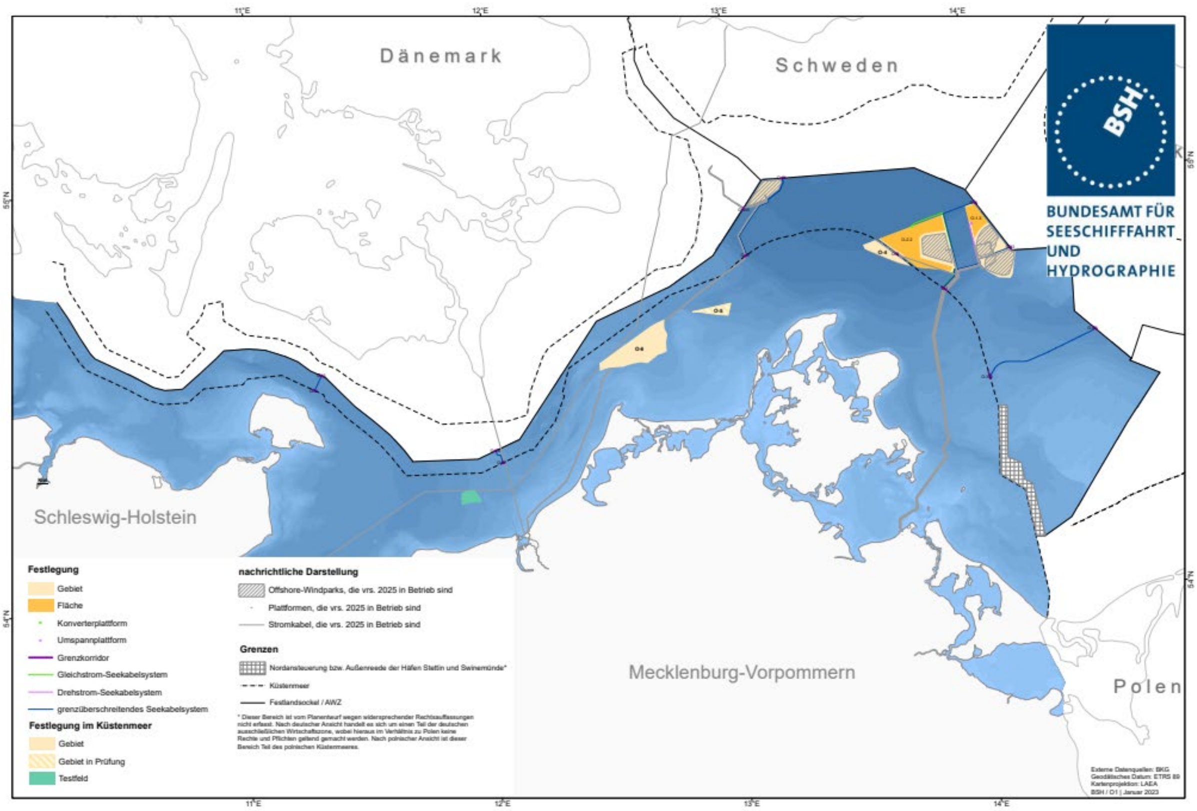
The total predicted future demand for green hydrogen in Germany requires more renewable electricity than the country is likely to be able to generate in the foreseeable future. To meet demand, the government is planning to rely to some extent on imported power and international cooperation.

Challenges

Most offshore wind energy In Germany is produced in the North Sea, which is home to more than 80 % of the country's turbines. With 232 turbines and grid feed-in of 1,096 MW, the Baltic Sea plays a less important role. Enabling new sites is tricky given that almost three-quarters of Germany's Baltic EEZ are within 22 km of the coast, where offshore wind projects currently cannot be built. Unless this is remedied, Germany will struggle to reach the most optimistic scenarios for its offshore wind buildout.[83]

Another issue is that Germany's ambitious expansion targets can only be reached through a strong supply chain. A scarcity of the right materials, a lack of capacity in shoreside facilities and shipyards, or the threat of a shortage of skilled workers could seriously undermine the ambitious expansion targets. Part of a terminal in Hamburg was recently sold to China, which could have a negative impact on capacity.

Offshore wind farm development tends to be very international, with experts from a range of countries – often the UK or Spain – flying in for a given project and flying out to the next one. There is no real institutional training for new workers: Germany, otherwise generally keen on vocational training, provides no clearly recognised Ausbildung for offshore wind workers. There is clear potential for investing more into training, for instance through relevant research & development or better benefits to attract talented staff.



Spatial Development Plan for Germany's Baltic Sea EEZ[84]

83 Freeman et al., 'Our Energy, Our Future'.

84 Bundesamt für Seeschifffahrt und Hydrographie, 'Flächenentwicklungsplan 2023 Ostsee'.

Latvia

Latvia's National Energy and Climate Plan 2021-2030 is a policy planning document which defines targets and measures that need to be taken to achieve those targets. One of the main objectives of the country's energy and climate policy is that at least 50% of the final energy consumption to come from renewable energy sources. An update is being considered, and is likely to comprise changes related to plans for renewable energy production, including the development of offshore wind farms. Latvia has launched a new Ministry of Climate and Energy which is charged with elaborating energy policy. The new minister has underlined that the main priority is to substantially increase renewable energy production to make the most of Latvia's many available resources. This includes first and foremost the development of wind farms and solar energy. A longer-term perspective is to explore opportunities for renewable energy exports to Central Europe, where energy production is characterised by structural changes related to a movement away from coal and natural gas.

Offshore wind

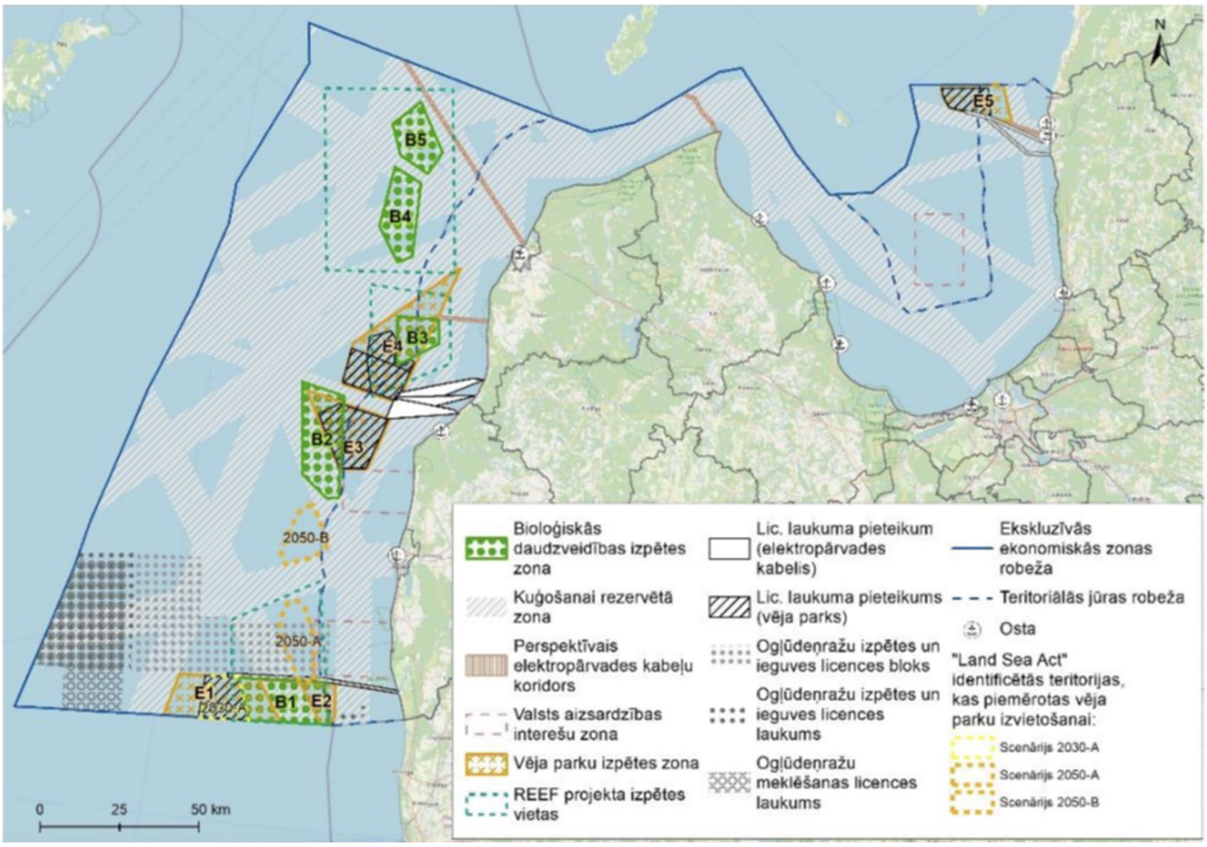
Latvia is sometimes said to harbour the second biggest offshore wind energy potential in the Baltic Sea. The current Maritime Plan defines five wind farm research areas with a total area of around 1,650 square kilometres, or approximately 6% of Latvia's total exclusive economic zone. Applications for licences have been received in all but one of these research areas.

In 2022, the state-owned enterprise Latvenergo signed a Memorandum of Understanding with the leading renewables company RWE to join forces on the development of offshore wind farms in Latvia.

Challenges

Biodiversity and the environment are major considerations during the planning phases of the offshore wind energy build-out, since these two priorities present substantial overlap in marine space. The determination of the necessary protection status for marine habitats in Latvia's exclusive economic zone is underway.

According to WindEurope, Latvia, like Lithuania, is likely to be producing twice as much offshore wind power in 2050 than it will need to consume. Interconnections will need to remedy this to some extent, and hydrogen production capacity will also play its part.[85]



Latvia's Maritime Spatial Plan

85 Freeman et al., 'Our Energy, Our Future'.

Lithuania

Lithuania plans to achieve full energy independence by 2030, by which date 93% of all electricity will originate in renewable energy sources. As its neighbour Latvia, Lithuania is expected to produce much more offshore wind power in 2050 than it will consume.[86]

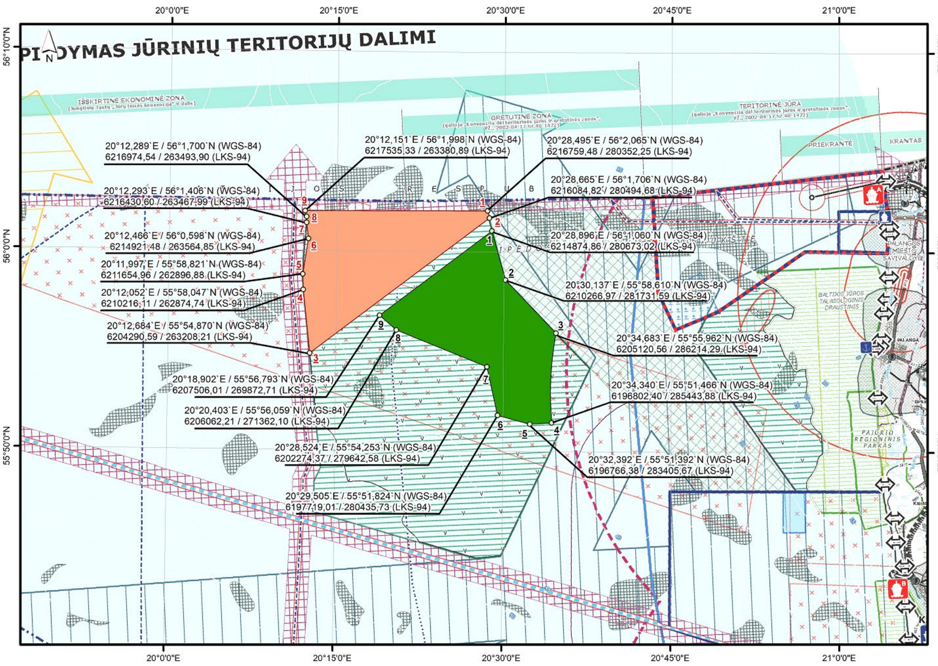
Offshore wind energy

Lithuania's offshore wind plans in the Baltic Sea are one of the most ambitious portions of the energy independence projects envisioned in the country's National Energy Independence Strategy. The offshore wind farms will significantly increase the production of electricity from renewable energy sources, thus reducing Lithuania's dependence on imports and ensuring low electricity prices for residents. The relevant addendum to Lithuania's general spatial plan foresees an area of 644.23 km2 in the country's exclusive economic zone being set aside for the development of offshore wind farms, with a potential of 3.4 GW. The national transmission system operator Litgrid has declared that the electricity grid will be more than up to the task in 2030, by then having a transmission capacity of 9.4 GW.

Lithuania intends to develop two wind farms in the Baltic Sea in the near future. The first one, planned on 136.39 km2 some 30 km from the shore near Palanga, will begin to operate in 2028. It will have a capacity of approximately 700 MW, generating up to 3 TWh of electricity per year – alone meeting up to a quarter of Lithuania's total electricity demand. This project is expected to attract more than one billion euros in investments and create at least 1,300 new jobs.

Much of the preparatory work has been accomplished since early 2022: the Parliament adopted a package of laws on offshore wind energy development, the Government approved the criteria for auction participants, and shallow and deep-sea seismic and hydrographic surveys were carried out in the development area. In early 2023, coordination procedures, including cross-border discussions, are being discussed, the National Energy Regulatory Council (NERC) is planning to approve the procedure for organising tenders and issuing authorisations, and Litgrid is planning to publish preliminary connection conditions. The Ministry of Energy expects to announce the auction for the Palanga offshore wind farm in September 2023, and to select the winner in early 2024.[87]

The second offshore wind farm in Lithuania's exclusive economic zone will cover some 120 km2 and have a capacity of up to 700 MW. All research, environmental impact assessments and other preparatory activities will be conducted by the developer, who will also be responsible for connecting to the landside electricity transmission grid and for addressing any imbalances resulting from the generated electricity. This project was fast-tracked through quick adoption of the relevant legal instruments, including procedural facilitation of the tender and the permits. The tender was announced by the National Energy Regulatory Council on 30 March 2023 and the results will be announced in the summer.



The areas designated for Lithuania's first (green) and second (orange) wind parks

86 Freeman et al.

87 Ministry of Energy of the Republic of Lithuania, Lithuanian Energy Agency, and EPSO-G, 'Offshore Wind Park'.

Specialised port in Klaipėda

The Klaipėda State Seaport Directorate and Klaipėda Sea Cargo Company (Klasco) signed an investment agreement in 2022 to expand the port infrastructure necessary for the coming development of offshore wind power plants. The new facilities, located on around 20 hectares on the Smeltė Peninsula, will cost some 27 million euros and will be used to build, assemble and store offshore wind power plants and their components. The government's decision to limit the average annual capital return of the Port Authority for investments in wind energy infrastructure to 2% has made it possible for the development to be implemented without an undue burden on future developers.

BaltHub

Lithuania is currently conducting an integrated energy system and cost effectiveness analysis of potential Baltic Sea energy hubs linking the Baltic-Nordic region and beyond. This project, known as BaltHub, can also serve as an interface between the onshore energy systems of the Baltic Sea countries, allowing for more efficient electricity transmission and better interconnections between national energy grids. BaltHub is funded by Nordic Energy Research (a platform for co-operative energy research and policy development under the auspices of the Nordic Council of Ministers) and is carried out on behalf of Lithuania by the Kaunas University of Technology (KTU). Lithuania's national transmissions system operator Litgrid is an observer.[88]

Hydrogen

Oil refineries, fertiliser producers, transport, electricity generation and heating are likely to account for most of the demand for green hydrogen in Lithuania, as elsewhere. The likely main centres for the development and production of green hydrogen are the port of Klaipėda and western and central parts of Lithuania. The country's demand for green hydrogenis predicted to reach 34,750 tonnes (1.16 TWh) in 2030, and 612,900 tonnes (20.41 TWh) in 2050. Four hydrogen fuelling stations are planned to be installed throughout the country by 2026.

A focus on the investment and legal environment, market opportunities, and scientific potential is necessary to make full use of the potential of hydrogen in Lithuania. The Alternative Fuels Law being debated in the Seimas in early 2023 anticipates a minimum of 5% of the final energy consumption in the transport sector to come from biomethane and green hydrogen in 2030. In addition, a draft of amendments to the Natural Gas Quality Requirements have been prepared and submitted for coordination, which provide for the provision of hydrogen to the natural gas transmission and distribution system.

The Lithuanian Confederation of Industrialists signed an agreement on 30 November 2020 together with 18 other organisations and the Ministries of Energy, Economic Affairs & Innovation, and Transport & Communications) to establish a hydrogen innovation platform, which will bring together public authorities, business associations and leading figures in the energy industry to implement innovative projects, prepare a long-term hydrogen strategy and help represent Lithuania's position within the EU. During its first year of operations, the platform expanded to 45 organisations.

The national green hydrogen guideline being developed by Lithuania's Ministry of Energy in 2023 has established a number of goals for 2030:

- Some 15% of the ammonia required for fertiliser production will come from green hydrogen.
- Hydrogen can be effectively incorporated into the transportation sector in at least five cities. Hydrogen will be used for public and heavy transport, and the first hydrogen-powered locomotives will be introduced.
- The Lithuanian natural gas network will be adapted to transport hydrogen.
- Hydrogen storage solutions, a network of fuelling stations, and information infrastructure in selected suitable areas will be implemented.
- Hydrogen competences will be developed through the co-operation of educational institutions, research institutes, and private businesses. More than 1000 new jobs are expected to be created in hydrogen industry development.

A legal regulatory environment will be established for hydrogen-related activities and will help introduce EU legislation in national law, adapt safety and health requirements to hydrogen production, supply, transportation, storage & use, and establish a low-carbon hydrogen certification programme.

A pilot project started in 2022 between the gas transmission system operators Amber Grid and Energijos skyrstymo operatorius (ESO), as well as the gas transport company SG dujos Auto will develop Power-to-Gas (P2G) technology for hydrogen production. This will entail a green hydrogen producing facility connected directly to the Lithuanian gas system for the first time. The green hydrogen is expected to start flowing by 2024. Infrastructure studies are being conducted to determine what proportion of green hydrogen can be safely and reliably injected into the grid and what proportion of conventional gas it can be mixed with. Experts have estimated that the share could be up to 10% under the current conditions, and that the gas grid should be able to transport pure hydrogen or a mixture of only hydrogen and methane by 2030.

88 Nordic Energy Research, 'BaltHub'.

Challenges

Project must respect Natura 2000 areas, such as the Klaipėda-Ventspils plateau, from which the area set aside for one wind farm has had to be moved back.

Lithuania's hydrogen sector suffers from the same weaknesses found elsewhere. There is still a lack of hydrogen storage solutions, limiting flexibility and the possibility to use hydrogen as compensation for intermittent power generation. Any failure to implement technical safety and health standards for hydrogen infrastructure along the entire value chain, from production and transportation to storage and use, as well as mechanisms for the development of hydrogen markets, in a timely manner, may ultimately hinder the development of the national hydrogen economy.

Poland

Offshore wind

Poland has major ambitions and lots of potential in offshore wind. Poland's first wind farm in the Baltic Sea is expected to start producing electricity as early as 2026. Preparatory work is already underway for the construction of the first wind farms in the Polish exclusive economic zone. In parallel, administrative procedures for further permits for so-called Phase II projects are also ongoing. The strong interest in this sector clearly indicates that offshore wind could become a strategic component of Poland's energy security and independence in the next decade. The development of offshore wind is also expected to strengthen the Polish economy, with a modern and strong supply chain. The Polish government recognises that the current geopolitical situation affects many aspects of energy policy and necessitates immediate and decisive steps, as well as a review of long-term policy assumptions. This has included a decision to eliminate energy imports from Russia as soon as possible and has led to an updated Poland Energy Policy 2040 (PEP2040), which takes into account energy sovereignty as a new pillar. Some new objectives include increasing technological diversification and the expansion of domestic sources and capacities, including further development of renewable energy sources, a consistent implementation of nuclear energy, and improvement of energy efficiency. Poland aims for around half of its electricity generation to come from renewable sources by 2040.[89] Installed capacity in offshore wind farms specifically is expected to reach 5 GW by 2030 and 11 GW by 2040.

According to the Polish Wind Energy Association, the total realistic potential of offshore wind energy in Poland is 33 GW. This analysis takes into account the potential of the areas indicated in the spatial development plan for Polish maritime areas (15.3 GW) as well as maritime areas not considered in the plan (17.7 GW). Making the most of the full offshore wind energy potential in Poland would cover up to 57% of the country's total electricity demand.[90]

Adopted in May 2021, Poland's maritime spatial plan defines basins with specific basic functions and permissible functions, and sets prohibitions, limitations and conditions for these functions. The plan allocates seven basins for the generation of renewable energy, further subdivided into 13 areas, for 11 of which there were ongoing permit proceedings in early 2023.[91] In addition, the Polish Government is preparing a revision of the maritime spatial plan, which will consider the new areas identified in PWEA's report cited above.

For the time being, Poland has put in place a support system for offshore wind power development based on the so-called right to settlement of a negative balance, which is subject to decisions by the national Energy Regulatory Office, the minister responsible for climate matters, and the European Commission. The first proper auctions for offshore wind farms will be held in 2025, 2027, 2029 and 2031, and will cover a total capacity of up to 12 GW (4 GW in each of the first two years and 2 GW in the latter two).[92]

The enabling legislation to enable this was still being prepared in early 2023. A legislative package adopted in December 2022 introduced a number of simplifications to the investment process which increase investment certainty, such as an extension of the period for which location permits are granted, new rules for indexing the amount of support provided, permission to settle part or all of the support in euros, etc.

89 Polish Ministry of Climate and the Environment, 'Założenia do aktualizacji Polityki energetycznej Polski do 2040 r. z marca 2022 r.'

90 Polish Wind Energy Association, 'Potential of Offshore Wind in Poland'.

91 Polish Ministry of Infrastructure, 'Ogłoszenia na podstawie art. 27c ustawy o obszarach morskich'.

92 Polish Government Legislation Centre, 'Projekt Ustawy o Zmianie Ustawy o Odnawialnych Źródłach Energii Oraz Niektórych Innych Ustaw'.

According to the PWEA, the administrative processes should be made even simpler. The association is developing proposals together with the private sector that can be presented to the government. These proposals will in turn form part of the expert consultations within BOWE2H, and the conclusions will be adopted as recommendations for Poland.

Nr	Investor	Project	Capacity in MW	Operation
1	Polenergia / Equinor	Bałtyk II	720	2027
2	Polenergia / Equinor	Bałtyk III	720	2027
3	PGE / Ørsted	Baltica 2	1498	2027
4	PGE / Ørsted	Baltica 3	1045	2026
5	RWE	FEW Baltic II	350	2026
6	PKN Orlen / NPI	Baltic Power	1200	2026
7	Ocean Winds	B Wind	200	2027
8	Ocean Winds	C Wind	200	2027
Total for Phase I			**5 933**	

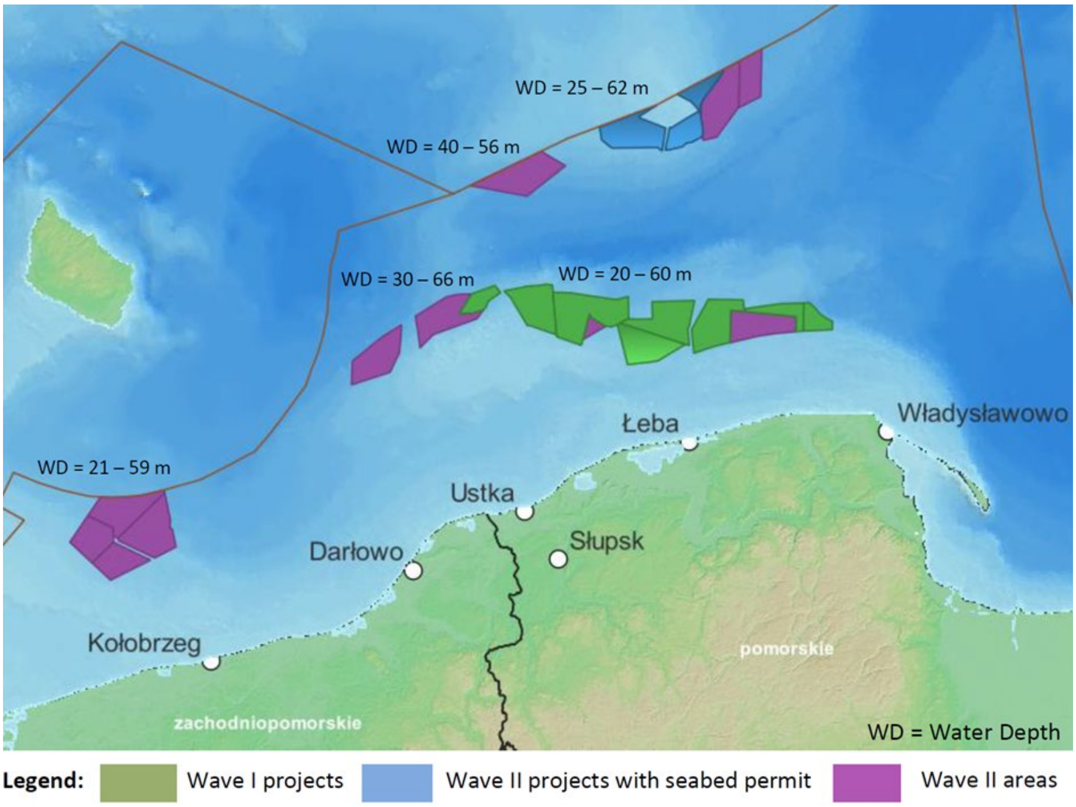
Contracts for Difference granted by the Polish Energy Regulatory Office during Phase I of the offshore wind power buildout

Nr	Investor	Project	Capacity in MW	Operation
1	Polenergia / Equinor	Bałtyk II	1560	2030
2	PGE	Bałtyk III	896	2031
Total			**2 456**	

Projects with planning permission which will be subject to auctions during Phase II of the offshore wind power buildout

Nr	Basin	Projected capacity in MW	Area in km²	Depth in m	Distance from shore in km
1	14.E.1	660	82.4	21-33	29
2	14.E.2	730	91.2	21.5-37	36
3	14.E.3	1007	125.9	31-54.5	42
4	14.E.4	1182	147.7	27-59	34
5	43.E.1	947	118.4	33.5-66	48
6	44.E.1	970	121.3	30-57	53
7	45.E.1	138	17.2	27.5-40	34
8	46.E.1	895	111.8	30-40	24
9	53.E.1	868	108.5	40-56	78
10	60.E.3	925	115.6	34-58	83
11	60.E.4	510	63.7	42-62	89
Total		**8830**			

Projects in the administrative procedure for a location permit



Areas designated for offshore wind farms in Poland's exclusive economic zone[93]

Hydrogen

Poland is the third-largest producer of grey hydrogen in Europe, and is planning to build on this to achieve an edge in renewable hydrogen. While this is likely to be a major challenge in terms of capital and organisation, the existing hydrogen markets and infrastructures will make it easier than starting from zero. The following strategic documents frame Poland's policy in terms of green hydrogen:

- the National Plan for Energy and Climate for 2021-2030, which identifies the potential of hydrogen in the energy sector, transport, gas transmission and announces support for research and development activities in the hydrogen economy
- the Polish Energy Policy 2040, which identifies the future role of hydrogen as an alternative to crude oil in transport, a tool for decarbonising industry and the gas network, and support for the development of renewable energy sources
- the letter of intent on building a hydrogen economy, signed on 7 July 2020 by the Ministry of Climate and 17 other organisations, including leading Polish companies
- The sectoral agreement for the development of the hydrogen economy, signed on 14 October 2021, which contains proposals for actions aimed at building demand in the market and recommendations for optimising the legal and institutional environment
- the Polish Hydrogen Strategy for 2030, with a perspective until 2040, adopted on 2 November 2021

The latter document defines the main goals and strategies for the development of the hydrogen economy in Poland and indicates six major objectives:

- implementation of hydrogen technologies in the energy and heating sectors;
- use of hydrogen as an alternative transport fuel in transport;
- support for decarbonisation of industry;
- production of hydrogen in new installations;
- efficient and safe transmission, distribution and storage of hydrogen;
- a stable regulatory environment.

Specific measures include the development of hydrogen in individual regions through the establishment of so-called hydrogen valleys and hydrogen value chains that cover everything from production and transport to storage and final use. Another focus are the use of Polish research and development potential and the development of production plants for hydrogen-powered vehicles and components necessary for the hydrogen economy.

93 H-BLIX, 'Offshore Wind Vessel Availability until 2030: Baltic Sea and Polish Perspective'.

The goals of the Polish Hydrogen Strategy for 2030 are as follows:

- 50 MW installed capacity for low-emissions hydrogen by 2025 and 2 GW by 2030 Installed capacity of the installation for the production of low-emission hydrogen;
- establishment of at least five hydrogen valleys;
- 100-250 hydrogen buses in use by 2025 and 800-1000 by 2030;
- creation of at least 32 hydrogen stations by 2025;
- signing of an official agreement to build a hydrogen economy (concluded on 14 October 2021);
- creation of a Hydrogen Valley Innovation Ecosystem;
- establishment of a Centre for Hydrogen Technologies.

The Ministry of Climate and the Environment is starting work on support instruments for the use of low-emission hydrogen in the economy. This is the next stage of preparations for the so-called Constitution for Hydrogen, a legislative package to regulate and support the construction of a hydrogen economy in Poland. On 6 November 2022, the Ministry furthermore awarded a public contract for the preparation of a study entitled Analysis of financial support instruments for the development of the hydrogen market in Poland, which concluded that the a hydrogen contract for difference would be the best suited to support the development of hydrogen technologies and the use of hydrogen in Poland.

Sweden

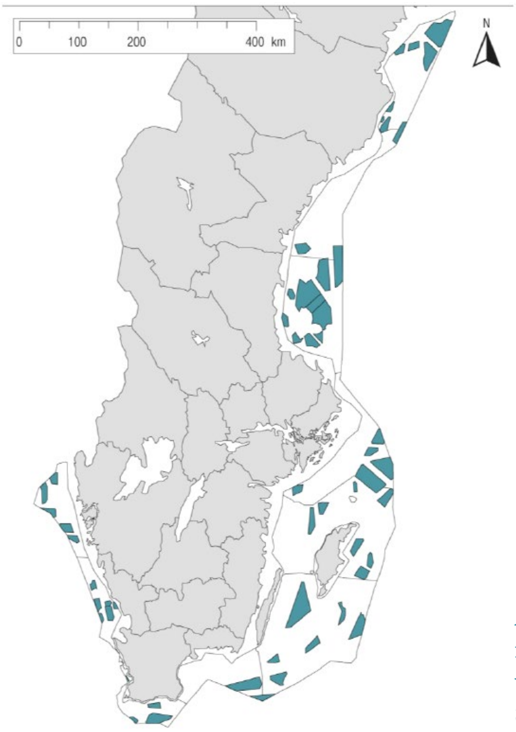
Sweden‘s main long-term national climate goal is zero net greenhouse gas emissions in 2045 (and negative emission beyond that year). A climate law that came into force in 2018 specifies that all major decisions taken by the parliament and government must be evaluated for their effect on the climate. Much discussed recently is the partial goal for 2030, which is looking increasingly difficult to achieve given today‘s policies. Regarding policies for energy and electricity, a proposal is being discussed to change the current national goal of 100% renewable electricity by 2040 to 100% “fossil free” electricity – that is, including nuclear power. The new Swedish government, elected in the autumn of 2022, is very positive towards nuclear power, and opposition parties have also been shifting their views in favour of this energy source lately.

There is no specific goal set for any given energy source, including wind power, and this is not likely to change in the near future. One thing on which most stakeholders do agree is that the demand for electricity will double in the next decades. It is commonly understood that electricity use will rise dramatically over the coming decades – from today‘s 140 TWh/year to 330 TWh in 2045, according to a recent study by Swedenergy.[94]

Offshore wind

The new Swedish government has a more negative view than the previous one on wind power, especially onshore wind. This was shown, among other things, in the cancelling of the previous government‘s subsidy policy intended to boost the offshore grid. Developers now once again have to build and finance cable connections to an onshore connection point themselves.

While this has sometimes led to its renewables credentials being put in question, the Swedish government does still recognise offshore wind energy as an important part of the country‘s future energy system. In 2022, the government assigned a task to the Swedish Energy Agency to identify areas corresponding to an additional 90 TWh/year of electricity production in Swedish territorial waters and exclusive economic zones (on top of the 30 TWh included in current maritime spatial plans). The proposed areas were presented in March 2023 and will now be published for referral, before being added to new revised maritime spatial plans in 2024.



Areas Suitable for offshore wind energy in Swedish waters

94 Energiföretagen Sverige and Swedenergy AB, ‘Sveriges Elbehov 2045’.

95 Swedish Energy Agency, ‘Nya områden för energiutvinning i havsplanerna’.

The areas presented in March as being suitable for offshore wind actually theoretically overshot the target threefold and could host wind farms capable of producing 350 TWh/year (corresponding to 90 GW of installed capacity). However, most of these areas are in conflict with other interests such as the Swedish Armed Forces, and it is not clear which ones will eventually be approved. This means that developers have to continue planning at their own risk and cost. The open door system used today has the benefit of letting developers freely choose any area to investigate for a potential offshore wind farm, but there are those who feel that an auction system with pre-approved areas similar to that found in countries like Germany or Poland would result in more predictability and better outcomes.

Even so, there is great interest from developers for offshore wind projects and many sites are being investigated throughout the Baltic Sea. Developers have made initial grid connection requests for offshore wind farms capable of producing the 350 TWh/year mentioned above. Projects with permits are few, however, with Kriegers Flak being the most well known.

As late as 2019, WindEurope was expecting that Sweden could realistically have offshore wind energy generation capacity of 20 GW by 2050, of which more than 17 GW would be destined for onshore consumption up to 100 km from the coast. This alone would require major grid expansion at sea – an actual expansion to 90 GW of capacity as outlined above would be uncharted territory. Possible environmental effects of large-scale offshore wind deployment and cumulative effects may also become an issue.[96]

Hydrogen

At 180,000 tonnes per year, the production of hydrogen in Sweden is not very high today. It is produced mostly through the reforming of natural gas (almost 67%) and industrial waste streams, while just under 3% is produced via electrolysis.[97] The interest in using hydrogen has grown rapidly over the past few years, however, and this new energy carrier is currently a very hot topic.

In 2021, the Swedish Energy Agency released a proposal for a national strategy for hydrogen, e-fuels and ammonia, which identified bottlenecks such as electrolysis capacity and electricity production.[98] The governmental initiative Fossil Free Sweden separately put forward a hydrogen strategy for fossil-free competitiveness in industry in the same year. Developed together with large industrial stakeholders, this document also highlighted areas such as infrastructure, grids, policies and competences.[99]

A large share of the forecasted increase in electricity use in Sweden in the coming years will be needed for the decarbonisation of steel production and other industry sectors. Hydrogen is expected to be a major component of this process. The Swedish steel producer SSAB delivered a first batch of fossil-free steel produced with hydrogen instead of coal during 2022.[100] Of course, using this technology at scale will require a huge amount of hydrogen; if that hydrogen is produced with hydrolysis, electricity consumption will increase proportionally (producing 1 kg of hydrogen requires approximately 50 kWh of electricity).

Several offshore wind energy developers – such as Ox2, Svea Wind and Njordr – have realised that hydrogen production in combination with their planned projects might be a good combination. Besides industrial use, hydrogen can be used as a means to balance wind power production with market needs. It can also be a way to reduce maximum electricity fed into the grid from the wind farms and thereby reduce the capacity required for the grid connection.

Challenges

As in the other Nordic countries, especially Finland, Sweden's main challenge in terms of offshore wind power expansion is to enable more sites for offshore wind by reducing conflicting interests, especially from the Swedish Armed Forces. For example, there are many exclusions currently caused by military radar issues.

Unlike many other countries, Sweden has not adopted an auction system for offshore wind energy with predefined and pre-developed areas in the sea suitable for wind power. It is open for developers to choose locations they find suitable, carry out feasibility studies and planning, and submit an application. It is even possible for two separate developers to submit applications for the same location. The new maritime spatial plans and recent report from the Swedish Energy Agency give some guidance to suitable locations, but developers still face a great deal of uncertainty as to whether a permit will be granted.

A challenge not specific to Sweden is how to handle the variable electricity production from wind power. Today‘s amount of wind power is balanced by hydro power in the north of Scandinavia, but the biggest offshore wind farms are likely to be in

96 Freeman et al., 'Our Energy, Our Future'.
97 Energigas Sverige, 'Statistik om vätgas'.
98 Hallonsten, 'Förslag till nationell strategi för fossilfri vätgas'.
99 Fossil Free Sweden, 'Vätgasstrategi för fossilfri konkurrenskraft'.
100 Reuters, 'Sweden's HYBRIT Delivers World's First Fossil-Free Steel'.

the south, leading to difficulties in balancing. Storage of energy in the form of hydrogen is likely to play an important role, but there will be a need for many more grid connections within the country and interconnectors to other countries.

Like in many other parts of Europe, energy and electricity prices have skyrocketed in Sweden during 2022. This was felt especially keenly in the southernmost of the four electricity regions into which the country is subdivided.[101] High electricity prices have been at the top of the political agenda in Sweden recently, with a range of short-term compensation packages being launched for both individuals and companies. The high prices have also led to a substantial decrease in electricity use during 2022 compared to the previous year (approximately 10% less in the southernmost electricity region).

The main reason is the influence of prices in adjacent parts of Europe, as well as the high ratio of consumption to production. The former element is highly correlated with the capacity of interconnectors. As more interconnectors means closer alignment with prices in northern Europe, the planned 700 MW HVDC Hansa Power Bridge grid interconnection to Germany (which may lead to higher power prices in southern Sweden) is currently being questioned, and the plan to commission it in 2028-2029 is likely to be delayed.

This may end up affecting other offshore wind projects in the Baltic Sea Region like the Bornholm energy project, where the German and Danish transmission system operators currently have an interest in including the Swedish TSO Svenska Kraftnät. There is a risk that these national considerations in terms of grid interconnectors ultimately hamper the EU ambitions for a more connected Europe.[102]

101 Svenska kraftnät, 'Elområden'.

102 European Commission, 'Electricity Interconnection Targets'.

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