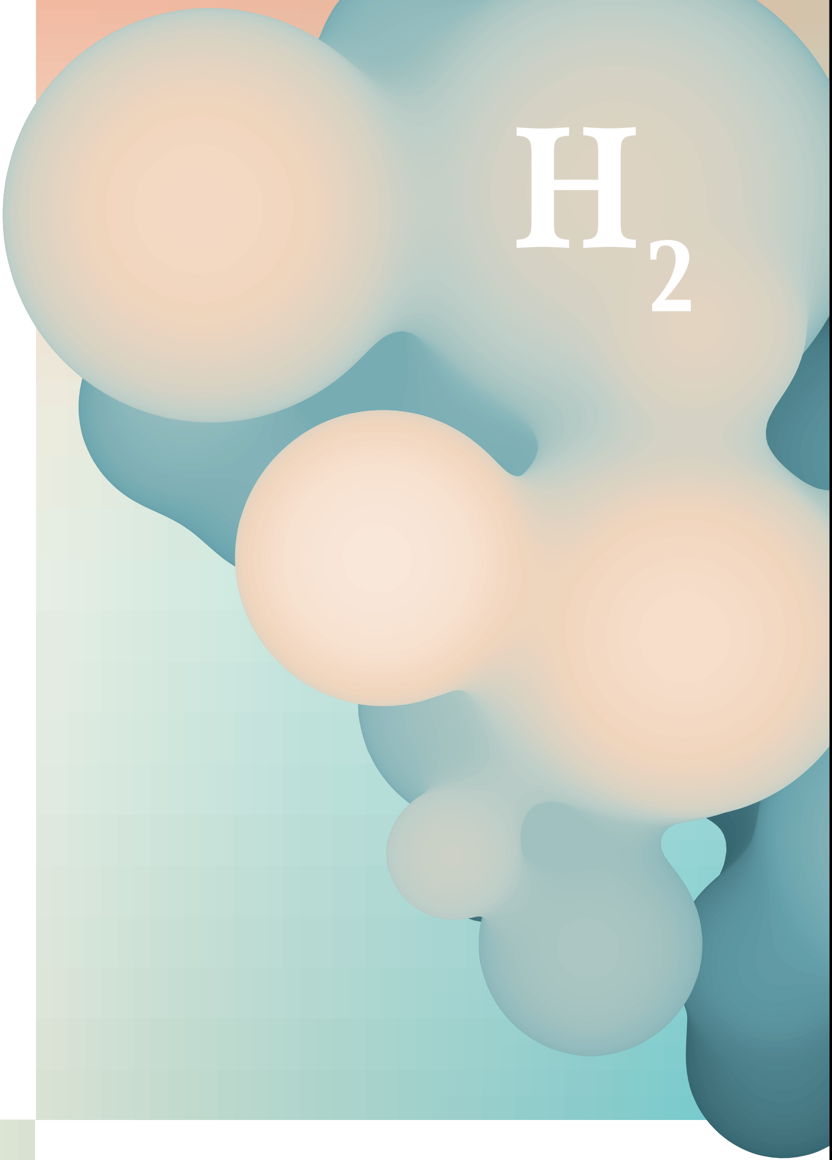

Offshore wind and power-to hydrogen in the Baltic Sea Region

BOWE2H
Strategic Roadmap

Interreg
Baltic Sea Region

Co-funded by
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ENERGY TRANSITION
BOWE2H

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

BOWE2H Strategic Roadmap

Descpription

The Baltic Sea Region holds significant potential for offshore wind-energy and green-hydrogen production, both critical components in achieving climate neutrality by 2045. This Strategic Roadmap, produced in the framework of the Interreg BSR project BOWE2H, outlines the current status, challenges, and opportunities for expanding offshore-wind and hydrogen production, and underscores the crucial need for strategic investment and regional cooperation.

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Disclaimer

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Table of contents

1. Executive summary ... 1

2. Introduction ... 2

3. Offshore wind and green hydrogen in the Baltic Sea Region: status quo and potential ... 3

3.1 Offshore wind-power production around the Baltic Sea today ... 3
3.1.1 Political framework ... 3
3.1.2 Current offshore wind-power production ... 4

3.2 Hydrogen production in the Baltic Sea today ... 5
3.2.1 The economics of hydrogen ... 6
3.2.2 Current and potential hydrogen applications ... 9

3.3 The current status of the hydrogen industry ... 10

4. Country profiles ... 12

4.1 Denmark ... 12
4.1.1 Today's electricity market in Denmark ... 12
4.1.2 Energy-transition goal ... 12
4.1.3 Offshore-wind energy in Denmark ... 12
4.1.4 Green hydrogen in Denmark ... 13

4.2 Sweden ... 14
4.2.1 Today's electricity market in Sweden ... 14
4.2.2 Energy-transition goal ... 14
4.2.3 Offshore-wind energy in Sweden ... 14
4.2.4 Green hydrogen in Sweden ... 15
4.2.5 Transnational projects ... 15

4.3 Finland ... 16
4.3.1 Today's electricity market in Finland ... 16
4.3.2 Energy-transition goal ... 16
4.3.3 Offshore-wind energy in Finland ... 16
4.3.4 Green hydrogen in Finland ... 17
4.3.5 Transnational projects ... 17

4.4 Estonia ... 18
4.4.1 Today's electricity market in Estonia ... 18
4.4.2 Energy-transition goal ... 18
4.4.3 Offshore-wind energy in Estonia ... 19
4.4.4 Green hydrogen in Estonia ... 19

4.5 Latvia ... 20
4.5.1 Today's electricity market in Latvia ... 20
4.5.2 Energy-transition goal ... 21
4.5.3 Offshore-wind energy in Latvia ... 21
4.5.4 Green hydrogen in Latvia ... 21

4.6 Lithuania ... 22
4.6.1 Today's electricity market in Lithuania ... 22
4.6.2 Energy-transition goal ... 24
4.6.3 Offshore-wind energy in Lithuania ... 25
4.6.4 Green hydrogen in Lithuania ... 27

4.7 Poland ... 28
4.7.1 Today's electricity market in Poland ... 28
4.7.2 Energy-transition goal ... 28
4.7.3 Offshore-wind energy in Poland ... 29
4.7.4 Green hydrogen in Poland ... 31

4.8 Germany ... 32
4.8.1 Today's electricity market in Germany ... 32
4.8.2 Energy-transition goal ... 33
4.8.3 Offshore-wind energy in Germany ... 33
4.8.4 Green hydrogen in Germany ... 33

5. Vision for the Baltic Sea region ... 35

5.1 Offshore wind-energy potential ... 35
5.1.1 A Baltic dynamo ... 36
5.1.2 Transnational offshore-wind energy plans ... 37
5.1.3 Kriegers Flak ... 37
5.1.4 Kriegers Flak Combined Grid Solution ... 38
5.1.5 Energy Island Bornholm ... 39
5.1.6 ELWIND ... 40
5.1.7 Åland ... 43

5.2 Green-hydrogen potential ... 43

5.3 Comprehensive vision and cross-border benefits ... 44
5.3.1 Setting the stage ... 44
5.3.2 Solving the equation ... 47

6. Key obstacles to overcome ... 48

6.1 Obstacles to the expansion of offshore-wind energy ... 48
6.1.1 Denmark ... 48
6.1.2 Sweden ... 48
6.1.3 Latvia ... 49
6.1.4 Lithuania ... 49
6.1.5 Poland ... 49
6.1.6 Germany ... 50

6.2 Obstacles to the expansion of green hydrogen ... 50
6.2.1 Denmark ... 50
6.2.2 Sweden ... 50
6.2.3 Latvia ... 51
6.2.4 Lithuania ... 51
6.2.5 Poland ... 52
6.2.6 Germany ... 52

7. Recommendations ... 53
7.1 Policy and regulation (National and EU) ... 53
7.2 Local and regional government ... 53
7.3 Industry ... 54
7.4 Grid ... 55
7.5 Research ... 55

8. Sources ... 57

9. Annex: Interviews 66

9.1 Sweden 66
9.1.1 Local public authorities 66
9.1.2 National public authorities 67
9.1.3 Infrastructure operators 68
9.1.4 Private companies 69
9.1.5 Research institutions 69

9.2 Lithuania 70
9.2.1 Local public authorities 70
9.2.2 National public authorities 71
9.2.3 Infrastructure operators 72
9.2.4 Private companies 73
9.2.5 Research institutions 74

9.3 Poland 75
9.3.1 Local public authorities 75
9.3.2 National public authorities 76
9.3.3 Infrastructure operators 77
9.3.4 Private companies 79
9.3.5 Research institutions 80

9.4 Germany 82
9.4.1 Local public authorities 82
9.4.2 National public authorities 82
9.4.3 Infrastructure operators 82
9.4.4 Private companies 83
9.4.5 Research institutions 84

Table of figures

Figure 1: Current and planned offshore-wind farms in the southern Baltic Sea 4

Figure 2: The stages of the construction of a wind farm 5

Figure 3: Levelised cost of hydrogen production with different energy sources in 2021, 2030 and 2050 7

Figure 4: Hydrogen production costs in USD per kilogram 7

Figure 5: The major planned hydrogen pipelines around the Baltic Sea 11

Figure 6: Proposed offshore-wind farms in Estonia 19

Figure 7: Electricity Balance in 2022 24

Figure 8: Electricity Balance in 2023 25

Figure 9: Annex on the Responsible Use of the Sea and Coast indicating the territory allocated to the development of renewable energy 25

Figure 10: The first two territories indicated for offshore-wind development in Lithuania 26

Figure 11: Production and use of hydrogen from fossil fuels in industry in Lithuania in 2015-2021 27

Figure 12: Planned Polish energy mix according to the Assumptions for the update of Poland's Energy Policy until 2040 29

Figure 13: Planned renewable-electricity generation according to the Assumptions for the update of Poland's Energy Policy until 2040 29

Figure 14: Potential areas for offshore wind-energy development in Poland (grey: areas designated in the Polish maritime spatial plan; blue and green: other areas considered in the PWEA report). 30

Figure 15: Expansion of offshore power in Germany in 2030, 2035 and 2045 33

Figure 16: IPCEI Hy2Infra map of projects in seven member countries 34

Figure 17: Draft of German maritime spatial plan with location of SEN-1 in the North Sea 34

Figure 18: Possible distribution of the 370 GW offshore wind power generation capacity in the EU and candidate states in 2050 36

Figure 19: The four BEMIP advanced offshore hubs 37

Figure 20: Kriegers Flak Combined Grid Solution offshore-wind farms and cables 38

Figure 22: ELWIND project 41

Figure 23: Overview of the ELWIND project sites 41

Figure 24: Scenarios for offshore wind development in the Baltic Sea region 42

Figure 25: Overview of planned offshore-wind park sites in the maritime spatial plans of Latvia and Estonia and possible supply corridors. 42

Figure 26: Population density in the Baltic Sea Region 46

Table of tables

Table 1: Today´s electricity market in Sweden 14

Table 2: Energy generation capacity by source in Estonia 18

Table 3: Electricity produced in Latvia 21

Table 4: Sources of Lithuania´s total energy consumption in 2022 23

Table 5: Shares of renewable-energy sources 24

Table 6: Phase I projects in Poland 30

Table 7: Phase II projects in Poland 31

Table 8: Consumption of primary energy in TWh in Germany in 2023 32

Table 9: Baltic Sea Region population and GDP 45

Table 10: Comparison of offshore wind-energy production and energy consumption (2022) in the Baltic Sea Region 46

1. Executive summary

The Baltic Sea Region holds significant potential for offshore wind-energy and green-hydrogen production, both critical components in achieving climate neutrality by 2045 – especially for the EU Member States surrounding the Baltic Sea: Denmark, Sweden, Finland, Estonia, Latvia, Lithuania, Poland and Germany. This Strategic Roadmap, produced in the framework of the Interreg BSR project BOWE2H, outlines the current status, challenges, and opportunities for expanding offshore-wind and hydrogen production, and underscores the crucial need for strategic investment and regional cooperation.

Offshore-wind energy in the Baltic Sea Region

The Baltic Sea is uniquely positioned to harness offshore-wind energy thanks to its shallow waters, short distances to shore, and high wind speeds. As of 2023, only 3.1 GW of offshore wind capacity is installed in the region, which is far below the potential of 93 GW. The region aims to increase capacity to 19.6 GW by 2030, a goal shared by the eight Baltic Sea nations.

Offshore wind energy is more consistent and powerful than onshore, and its location in offshore environments minimizes concerns regarding its proximity to human settlements. The European Union's renewable energy strategy aims to reach 300 GW of offshore wind by 2050, positioning offshore wind as a cornerstone of the region's energy transition.

Green hydrogen: the perfect complement to offshore-wind energy

Green hydrogen, produced through the electrolysis of water using renewable electricity, is essential for decarbonising sectors such as transport, heavy industry, and heating – areas that are difficult to electrify directly. Offshore wind provides the power needed for green hydrogen production, and in turn, hydrogen offers a flexible energy storage solution, helping to balance the grid by storing excess electricity for later use.

While green hydrogen remains in its early stages, with current production primarily fossil-fuel-based, it is projected to play a key role in reducing emissions. Countries in the Baltic Sea Region, such as Denmark, Sweden, and Finland, are developing national hydrogen strategies with ambitious goals for electrolyser capacity and hydrogen production by 2030 and beyond.

Key challenges

Scaling up offshore wind and green hydrogen production in the Baltic Sea Region faces several significant challenges. One major obstacle is the complex and slow permitting process for both offshore wind and hydrogen infrastructure, which varies across countries. To accelerate deployment, it is essential to harmonise regulations and streamline approval processes.

In addition, the region's energy grid requires modernisation and expansion to handle the increased electricity generated by offshore wind and to support the transport and storage of hydrogen. Investments in grid capacity, hydrogen storage facilities, and pipelines are critical for ensuring the smooth integration of these renewable energy sources.

Public acceptance of offshore wind farms and hydrogen technologies also presents a challenge. Concerns regarding the visual impact of wind farms, potential health risks, and the economic benefits for local communities remain barriers to broader support. To address this, comprehensive public education campaigns are necessary to build trust and foster acceptance of these projects.

Finally, cross-border cooperation is crucial given the Baltic Sea's shared maritime space. Coordinated, transnational projects are required to maximise efficiency and cost-effectiveness. Collaborative infrastructure efforts, such as interconnectors and shared wind farms, will be key to unlocking the region's full renewable energy potential.

Strategic vision for the Baltic Sea Region

The roadmap proposes a comprehensive, cross-border strategy to align national ambitions with regional cooperation. This includes developing a coordinated offshore grid that connects wind farms across multiple countries, enabling efficient power distribution and supporting large-scale green hydrogen production.

By optimising the region's shared resources, aligning regulatory frameworks, and investing in infrastructure, the Baltic Sea Region can become a global leader in offshore wind and green hydrogen, accelerating its path toward climate neutrality.

2. Introduction

Offshore wind energy and green hydrogen production represent a powerful combination for achieving climate neutrality in the Baltic Sea Region, particularly in the EU Member States of Denmark, Sweden, Finland, Estonia, Latvia, Lithuania, Poland, and Germany. The vast wind resources of the Baltic Sea offer an unparalleled opportunity to generate clean, renewable electricity through offshore wind farms, while green hydrogen – produced using this electricity – serves as a versatile energy carrier that can decarbonise hard-to-electrify sectors such as heavy industry, transport, and heating.

By leveraging these two technologies in tandem, the Baltic Sea Region can significantly accelerate its energy transition and meet its climate goals. Offshore wind provides a steady, scalable power source, while hydrogen adds flexibility to the energy system by storing excess electricity and enabling energy to be used when and where it's needed. This combination can help balance the grid, enhance energy security, and reduce dependency on fossil fuels.

Transnational cooperation is critical to fully unlock the potential of offshore wind and hydrogen in the region. The Baltic Sea's shared maritime space and interconnected energy markets require coordinated action across borders to develop infrastructure, harmonise regulations, and streamline project approvals. By working together, the countries surrounding the Baltic Sea can optimise resource sharing, accelerate innovation, and deploy large-scale projects more efficiently. Moreover, joint efforts will ensure that the region remains on track to achieve climate neutrality by 2045, setting an example of how regional cooperation can drive the green energy revolution across Europe.

In short, the synergy between offshore wind and hydrogen, combined with strong cross-border collaboration, offers the Baltic Sea Region a path to a sustainable, climate-neutral future.

3. Offshore wind and green hydrogen in the Baltic Sea Region: status quo and potential

The first section of this report provides a comprehensive overview of the current status of offshore-wind energy and green-hydrogen production in the Baltic Sea Region. It examines the infrastructure, technological advancements and policy frameworks that are currently shaping the region's renewable-energy landscape.

3.1 Offshore wind-power production around the Baltic Sea today

Wind energy is one of the major renewable-energy sources that can help mitigate global heating. The European Union's decarbonisation objectives are strongly dependent on an increase in wind-energy capacities.[1] In 2023, the revised EU Renewable Energy Directive boosted the Union's target for the proportion of energy (not just electricity) originating in renewable sources to 42.5% by 2030.[2] To reflect this target, the EU Wind Power Action Plan stated that Europe's wind capacity must grow from 204 GW in 2022 to over 500 GW in 2030.[3]

For reasons of cost and convenience, most wind-energy capacity in Europe and elsewhere has traditionally been installed onshore; in 2022 offshore-wind power made up just 8% of all wind-energy capacity in Europe in 2022.[4] According to WindEurope, 3.7 GW of offshore-wind energy was installed in European waters in 2023, bringing the total to 34.2 GW.[5]

Wind is more constant and intense offshore than on land, however, and spared many of the acceptance issues that are commonly raised in close proximity to human settlements.[6] This makes it a very important element in the decarbonisation toolbox. The EU strategy on offshore renewable energy envisions an increase in offshore wind levels to 60 GW by 2030 (requiring 6.66 GW of new capacity to be installed every year from 2025 to 2030) and 300 GW by 2050 to achieve a climate-neutral future.[7]

3.1.1 Political framework

At the Baltic Sea Energy Security Summit in 2022, the heads of government of the eight countries[8] around the Baltic Sea formally agreed that the sea basin has a potential of 93 GW for offshore wind power.[9] The 3.1 GW of capacity currently installed in the Baltic Sea Region represents just three per cent of that potential, leaving the region's vast possibilities nowhere near fully harnessed. As a first step, the countries declared their ambition to increase Baltic offshore wind-power levels sevenfold to at least 19.6 GW by 2030, which would be enough energy to power 20 million households with electricity.[10]

The Baltic Energy Market Interconnection Plan (BEMIP), which implements the energy aspects of the EU Strategy for the Baltic Sea Region, has played an integral role in the policy frame for offshore-wind energy in the Baltic Sea Region since it was first established in 2008.[11] In its most recent work programme, the BEMIP member states emphasised the importance of cooperation at a regional level to advance the development of offshore-wind energy at the lowest possible cost for all stakeholders. The work programme also explicitly mentions the intention to establish a coordinated offshore grid, to boost cross-border cooperation linked to maritime spatial planning and environmental assessments as well as financing, and to accelerate joint transnational offshore projects through knowledge pooling and intergovernmental agreements.[12]

1 European Commission, 'European Wind Power Action Plan'.

2 Dumortier, *Regulation (EU) No 910/2014 on Electronic Identification and Trust Services for Electronic Transactions in the Internal Market (EIDAS Regulation).*

3 European Commission, 'European Wind Power Action Plan'.

4 European Commission.

5 WindEurope, 'Offshore Wind in Europe - Key Trends and Statistics 2023'.

6 European MSP Platform, 'Offshore Wind Parks and Maritime Safety in the EEZ of the Baltic Sea Region | The European Maritime Spatial Planning Platform'.

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

8 Denmark, Estonia, Finland, Germany, Latvia, Lithuania, Poland, Sweden

9 Euractiv, 'EU's Baltic Sea Countries Agree Offshore Wind Power Capacity Boost'.

10 The Baltic Sea Energy Security Summit, 'The Marienborg Declaration'.

11 European Commission, 'PA Energy – Baltic Energy Market Interconnection Plan (BEMIP) Action Plan for Competitive, Secure and Sustainable Energy'.

12 European Commission, 'BEMIP Offshore Wind Work-Program'.

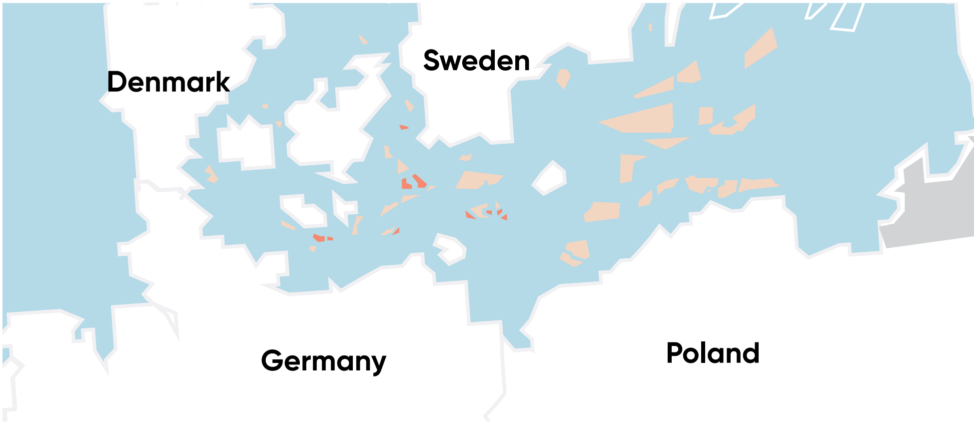

Figure 1: Current and planned offshore-wind farms in the southern Baltic Sea[13]

3.1.2 Current offshore wind-power production

There are eight fully operating wind farms in the Baltic Sea, so far situated only off the coasts of Germany and Denmark as shown in Figure 1. The largest existing wind park is the Danish project Kriegers Flak, which is owned and operated by Vattenfall. Boasting 72 turbines with a total capacity of 604 MW, the park was commissioned in 2021 and is a prime example of transnational cooperation, as discussed in more detail below.[14] In German waters, five fully operational wind farms off the coast of the island of Rügen together account for 1.4 GW.[15] The largest of them, Arkona, has a capacity of 385 MW and can thus power 400,000 households per year.[16]

Building an offshore wind-power project

A typical offshore wind-power project is built according to the phases as shown in Figure 2. This lengthy process includes the determination of locations through environmental and spatial planning followed by the acquisition of grid and building permits as well as by feasibility studies. Developing and operating companies subsequently take over the design and final decisions on the wind farm as the main stakeholders. This process is often organised through auctions.[17]

The installation phase comprises the final construction of the wind park and turbines themselves as well as the connection to the grid infrastructure and the final commissioning.[18] Relevant infrastructure includes local ports, which are crucial to the supply chain, the logistics and overall support, and central to the operation and maintenance of offshore-wind farms.[19]

13 4C Offshore, ‘Global Offshore Renewable Map’.

14 See section Transnational offshore-wind energy and green hydrogen – Kriegers Flak in this report.

15 Deutsche WindGuard, ‘Status Des Offshore-Windenergieausbaus in Deutschland’.

16 RWE, ‘Offshore-Windpark Arkona | Betriebsstandort von RWE’.

17 Cecchinato, ‘Boosting Offshore Wind Energy in the Baltic Sea’.

18 Cecchinato

19 WindEurope, ‘Offshore Wind Ports Platform’.

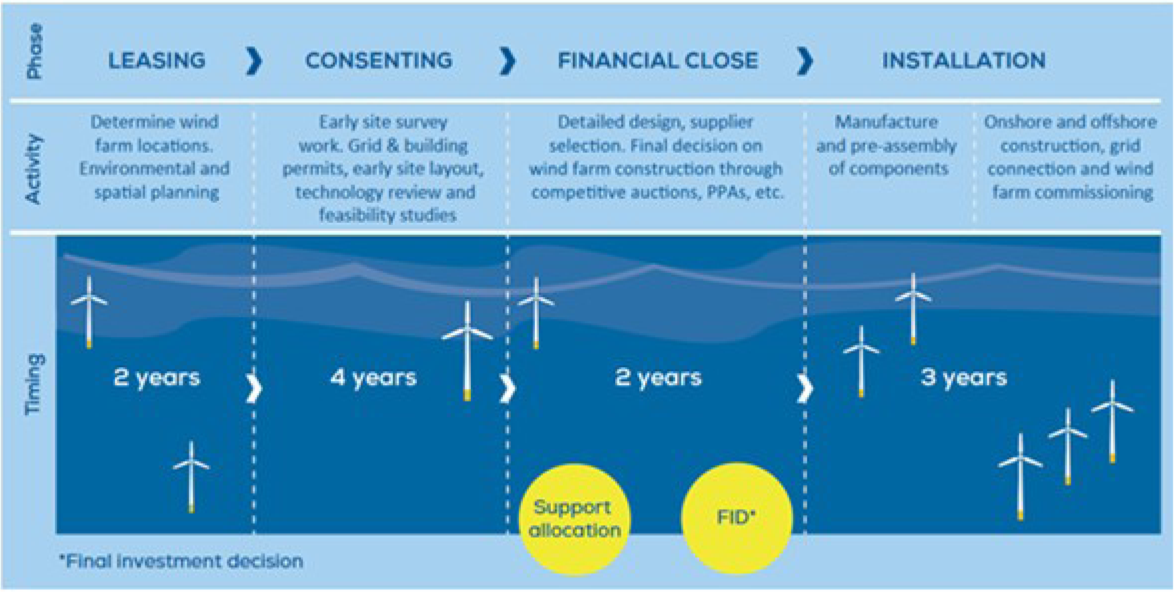

Figure 2: The stages of the construction of a wind farm[20]

3.2 Hydrogen production in the Baltic Sea 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.[21]

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. 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 reach maturity and achieve wide deployment between 2030 and 2050.[22]

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.[23]

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, along with substantial investment in facilities for hydrogen transport, distribution and storage, as well as hydrogen refuelling stations. The revised Trans-European Networks for Energy Regulation of 2022 on guidelines for trans-European energy infrastructure further calls for the incorporation of hydrogen into continental strategies for energy infrastructure, including the repurposing of existing natural gas pipelines.[24]

Taxing carbon

A substantial and transparently levied carbon tax that covered most of the world's developed economies would greatly contribute to resolving the problem of greenhouse gas emissions by stimulating innovation and adaptation through the free market. If carbon-heavy activities actually bore the cost of the damage they wreak on the world, productive investment and

20 Cecchinato, ‘Boosting Offshore Wind Energy in the Baltic Sea’.

21 The Economist, ‘Creating the New Hydrogen Economy Is a Massive Undertaking’.

22 European Commission, ‘A Hydrogen Strategy for a Climate-Neutral Europe’.

23 Hydrogen Council, ‘Hydrogen Investment Pipeline Grows To $500 Billion In Response To Government Commitments To Deep Decarbonisation’.

24 European Parliament and Council, ‘EU Regulation 2022/869 on Guidelines for Trans-European Energy Infrastructure’.

consumption would focus on cleaner activities, eventually pricing greenhouse-gas emissions out of existence. However, this would require a prodigious amount of political will throughout the world as well as rigorous control and information on the carbon embedded in all imported products, making the concept politically and technically difficult.

The European Union is gradually implementing a carbon price in its internal market and complementing it with the 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.[25] At the time of writing, the exact workings and effects of this regime are still being established. There are also plans for more subsidies to boost green economic activities and regulations which discourage greenhouse-gas emissions.

3.2.1 The economics of hydrogen

A 2020 study by the research consultancy BloombergNEF expects that, in the ideal circumstances, wholesale introduction of green hydrogen throughout the economy could by itself eliminate a third of all the carbon dioxide emissions linked to the use of fossil fuels by 2050 (with electrification eliminating much of the rest). This assumes that the carbon price will rise to USD160 per tonne of carbon dioxide, that carbon capture, utilisation or storage (CCU/CCS) will be deployed on a substantial scale, and that the cost of delivered hydrogen will drop to USD1/kg, however – all very ambitious and perhaps unlikely measures.[26]

The technology used 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.

3.2.1.1 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 in the first half of the 2020s 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 more affordable as more renewable power generation facilities come online. If costs continue to fall, BloombergNEF suggests that fully renewable hydrogen could be produced for USD0.7 to $1.6/kg in much of the world by 2050, making it competitive with natural-gas prices in Germany and Scandinavia.[27]

Figure 3 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 CCU/CCS, 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.[28]

25 European Commission, 'Carbon Border Adjustment Mechanism'.

26 BloombergNEF, 'Hydrogen Economy Outlook'.

27 BloombergNEF.

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

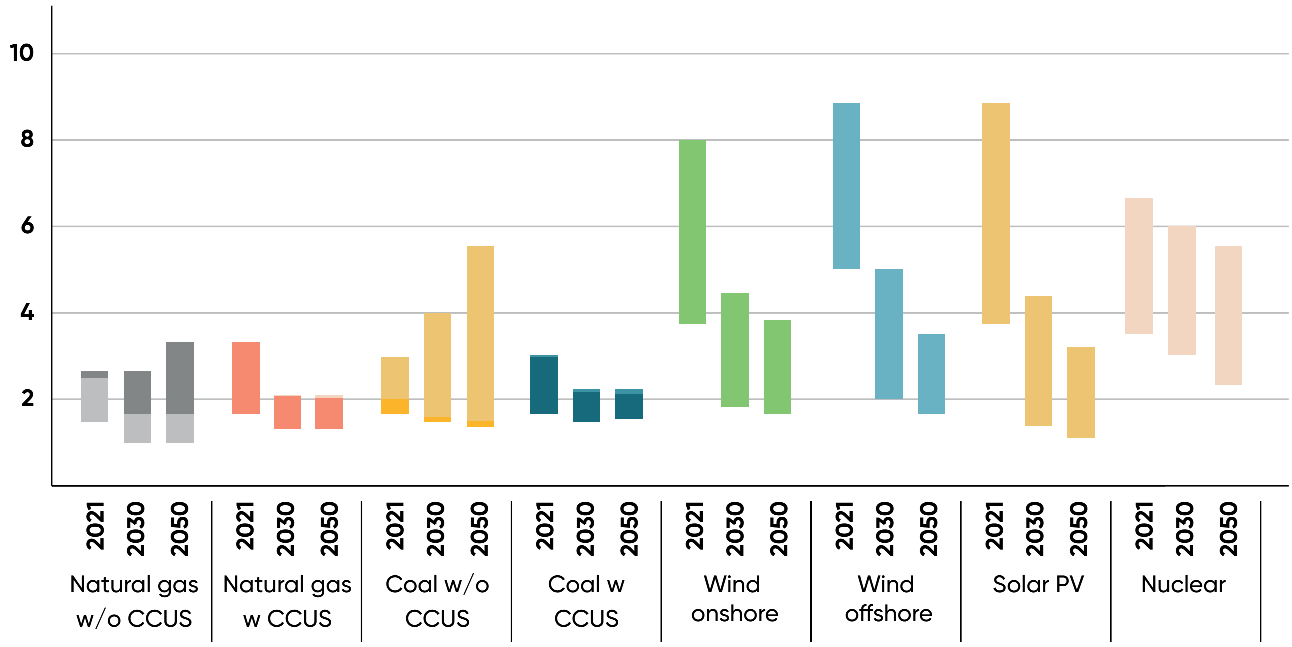

Figure 3: Levelised cost of hydrogen production with different energy sources in 2021, 2030 and 2050[29]

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 Figure 4).[30]

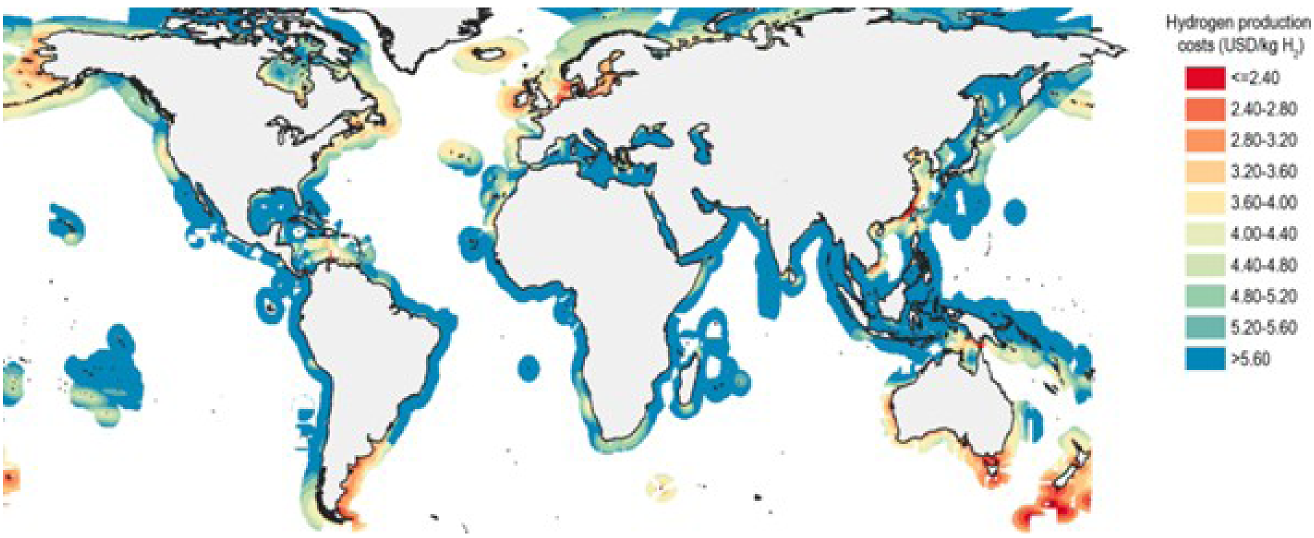

Figure 4: Hydrogen production costs in USD per kilogram[31]

29 International Energy Agency.

30 International Energy Agency.

31 International Energy Agency.

3.2.1.2 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 USD637 billion. However, large-scale long-term storage of hydrogen gas in onshore underground geological features is affordable.[32]

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.[33] Another economical option is small-scale storage in pressurised containers. Liquid hydrogen and conversion to ammonia are prohibitively expensive now but may become reasonably affordable in the long term.[34]

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 USD1.1 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.[35]

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 terminals cannot be converted as yet, but comparable ones can be built for hydrogen instead at a cost of around 50% more. (Liquid natural gas terminals can be repurposed for ammonia at an additional cost of just 11-20%, however). Given uncertainty about future demand for hydrogen, such large-scale investments can be difficult to justify.[36]

Carbon capture, utilisation and storage

The topic of carbon capture, utilisation and storage (CCU/CCS) 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. As seen in Figure 3, producing hydrogen with fossil energy combined with CCU/CCS 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. CCU/CCS has been widely discussed at least since it was included in the United Nations' Clean Development Mechanism international carbon-offset scheme in 2005, but has not reached wide deployment thus far.

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.[37] Moreover, any major facility of this type would be vulnerable to sabotage by ruthless countries or organisations.

Cost is another major issue. Direct-air capture of just 20% of the carbon dioxide emitted by the United States in a given year would consume the country's entire annual electricity production. All CCU/CCS facilities that have been established so far have ended up generating net emissions of carbon dioxide due to the energy intensity of the process. Direct-air capture powered by plentiful 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.[38]

The International Energy Agency tends to heavily feature CCU/CCS solutions in all its predictions and scenarios, but has also stated that "the history of CCUS has largely been one of unmet expectations".[39] An Environmental, Social & Governance risk briefing in early 2022 by Allianz Global Corporate & Specialty, a multinational financial services company, 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 licence 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 CCU/CCS.[40] The International Renewable Energy Agency (IRENA) at any rate expects that green hydrogen will become cheaper than hydrogen with CCU/CCS in the coming five to ten years.[41]

32 BloombergNEF, 'Hydrogen Economy Outlook'.

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

34 BloombergNEF, 'Hydrogen Economy Outlook'.

35 BloombergNEF.

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

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

38 Sekera and Lichtenberger, 'Assessing Carbon Capture'.

39 International Energy Agency, 'A New Era for CCUS'

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

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

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]

3.2.2 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 expects that global demand will rise to 614 million tonnes a year by 2050, when hydrogen will meet 12% of the world's total energy use. The growth is expected to 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, such as 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 so-called direct reduction, however, makes it possible to largely decarbonise the process.

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 USD1.3 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 emerging markets such as 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 all of 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 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 NH_3) and methanol (CH_3OH) and that producing all these fuels in a climate-neutral way therefore requires the availability 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.[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]

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 °C 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 Dieselloks ersetzen will'.

48 Deutsche Bahn, 'H2goesRail'.

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.

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, increasing inefficiency, it can reduce some of the difficulties in transport, storage and use which result from the chemical structure of pure hydrogen, decreasing inefficiency in other ways.

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. (Of course, if this carbon is captured from the atmosphere during the production process, it does not result in the net addition of carbon dioxide to the atmosphere the way fossil fuels, which are dug out of the ground, do.) Moreover, e-fuels are currently far more expensive than other fuels, at least in smaller-scale applications like personal vehicles. By comparison, non-carbon-based fuels like pure 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.

3.3 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 the scale of the European Union. Some USD150 billion of cumulative subsidies need to be deployed globally by 2030.[52]

In May 2022, the European Commission and largest producers committed to increase the EU’s 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]

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 USD500 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 (Figure 5). The Nordic Hydrogen Route, a connection across the Bay of Bothnia between Finland and Sweden, was announced 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, respectively). The second is the Baltic Sea Hydrogen Collector, 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]

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?’

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’.

Figure 5: The major planned hydrogen pipelines around the Baltic Sea.[56]

Once completed – optimistically 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.[57]

56 Becker, 'Vorbereitungen für Wasserstoffpipelines kommen voran'.

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

4. Country profiles

4.1 Denmark

4.1.1 Today's electricity market in Denmark

Denmark's total use of electricity in 2022 was 32 TWh, corresponding to 5,4 MWh per capita. The same year Denmark generated 19 TWh of electricity from wind, while bioenergy and waste represented 8.1 TWh, solar accounted for 2.2 TWh and hydro produced 0.2 TWh. With 60% of electricity use, wind energy has one of the highest shares in the world. Renewable energy sources overall made up 81% of the electricity generation.[58] The country is a net importer of electricity, mainly from Sweden and Norway. There are also interconnectors to the Netherlands and Germany, with large flows going in both directions. In 2022 18.7 TWh was imported and 17.4 exported.[59]

Denmark was a global pioneer in modern wind energy. Political decisions and great wind conditions in the 1980s made a base for a large expansion. The density of wind turbines is high, with approximately 6,300 turbines installed in a relatively small country. The early expansion led the way for many new companies, such as Vestas and Siemens, which are well known brands today. Today, Danish wind industry has a large global market share and generates many jobs in Denmark and abroad.

4.1.2 Energy-transition goal

The Danish government is committed to end the extraction of oil and gas in the North Sea by 2050. In 2022, the government decided to advance the goal of climate neutrality to 2045 and achieve a 110% reduction of emissions compared to the levels from 1990 (including carbon capture, utilisation and storage).[60] The goal to phase out fossil fuels was reaffirmed by the Agreement on Green Power and Heat (June 2022), setting ambitions to achieve 100% use of green gas across all sectors.

4.1.3 Offshore-wind energy in Denmark

According to a mid-year report from the 2023 WindEurope Offshore Wind Statistics, Denmark has a cumulative capacity of 2,653 MW of grid-connected offshore wind power projects, including connections to 17 wind farms and 672 turbines. Forty-one new foundations were installed in the first half of 2023, with an estimated capacity of 350 MW as of 30 June 2023.[61] In terms of cumulative installations, offshore-wind energy in Denmark today has a capacity of 2.3 GW.[62]

The Danish legislature decided to move forward with the construction of two energy islands in June 2020. An artificial island in the North Sea is envisaged as a base for offshore-wind farms supplying 3-4 GW of power, with a 10 GW long-term expansion potential. The second energy island will be built upon the island of Bornholm in the Baltic Sea, serving as a hub for surrounding offshore-wind farms and supplying 3 GW of energy to an estimated 3.3 million households.[63] The islands are a pioneer project that will require the deployment of existing knowledge into a completely new context. The Danish Energy Agency is leading a project that will transform the two energy islands from a vision to reality after political agreement on them has been reached. In May 2022 Denmark signed the Esbjerg Declaration alongside other European countries, raising offshore wind commitments to achieve 65 GW by 2050.[64]

Tendering for the North Sea energy island was postponed in June 2023 due to the cost of the concept, which grew larger as plans for the artificial island continued to develop. More focus will be directed instead to the implementation of the Bornholm energy island, along with many other initiatives that fit under the Baltic energy island umbrella.[65]

Denmark has clear ambitions to produce more green electricity, both for its own current & future needs and for export. Most

58 International Energy Agency, *Denmark 2023.*

59 Danish Energy Agency, 'Energy in Denmark, 2022'.

60 International Energy Agency, *Denmark 2023.*

61 WindEurope, 'Offshore Wind Energy 2024 Mid-Year Statistics'.

62 Williams and Zhao, 'Global Offshore Wind Report 2023'.

63 Danish Energy Agency, 'Denmark's Energy Islands'.

64 Williams and Zhao, 'Global Offshore Wind Report 2023'.

65 Baltic Energy Island, 'Baltic Energy Island'.

of this is supposed to come from offshore-wind farms. In addition to today's capacity of 2.3 GW, a tender was opened in April 2024 for 6 GW more.[66] This tender, administered by the Danish Energy Agency, DEA, has many innovative components, such as "over-planting", which gives developers an option to build more wind turbines than the grid has capacity for. This choice was made to boost local power-to-x capacity.

4.1.4 Green hydrogen in Denmark

The Danish Energy Agency opened a power-to-X tender in April 2023 to encourage the development of 100-200 MW of electrolyser capacity with an allocated budget of DKK 1.25 billion (€167.6 million). The maximum bid price is DKK 120/GJ hydrogen (€1.93/kg of hydrogen). The bidding process is controlled by a ceiling of DKK 70/GJ (€1.13/kg of hydrogen). In this way, the government aims to ensure that the supported amount of hydrogen stays within a certain budgetary limit. Those who succeed in the bidding process are said to be granted fixed bonuses for a ten-year contract.[67]

The power-to-X process produces a lot of surplus heat which will be integrated into the local district-heating grid. It is anticipated by the Copenhagen Infrastructure Partners that the surplus heat produced by 1 GW electrolysis of marine fuels such as green ammonia can supply up to 15,000 average homes with green district heating. The utilisation of surplus heat is, under favourable conditions, furthermore expected to reduce the overall cost of hydrogen production by 5-10%.[68]

It is estimated that the Danish Energy Agency's tender will raise electrolyser capacity by a total of 144 MW (equivalent to 14,900 tonnes per year of hydrogen) if the bids are equal to the controlling budget of €1.13/kg hydrogen. Consequently, hydrogen production and the additional electrolyser capacity would increase if bids were even lower. This will contribute to the country's goal of achieving 4-6 GW of electrolyser capacity by 2030. Based on current developments, Denmark is expected to reach 7.2 GW of capacity by 2030.[69]

66 Danish Energy Agency, 'Denmark's Largest Tendering Procedure for Offshore Wind Power Is Launched'.

67 Williams and Zhao, 'Global Offshore Wind Report 2023'.

68 GH2, 'GH2 Country Portal - Denmark'.

69 Williams and Zhao, 'Global Offshore Wind Report 2023'.

4.2 Sweden

4.2.1 Today's electricity market in Sweden

The national electricity consumption of Sweden was 135 TWh in 2023.[70] The consumption has been at this level since the mid-1980s. In the same year, the Swedish energy sector produced 163 TWh, of which 28 TWh were exported. The country's electricity production was spread across six sectors whose shares are presented in the following table.

Energy source	Share of total electricity production
Hydro	40 %
Nuclear	29 %
Wind	21 %
Solar	2 %
Bioenergy	6 %
Remainder (mainly incineration of waste)	2 %
Total	**163 TWh**

Table 1: Today´s electricity market in Sweden.

4.2.2 Energy-transition goal

Sweden plans to achieve net-zero greenhouse-gas emissions by 2045 and negative emissions after that. A climate law that guides all large decisions by the government to be in line with this target is in place to ensure the success of these ambitious goals. In addition, all electricity production in Sweden is supposed to be fossil free by 2040. This goal changed in 2023 from the initial phrasing of requiring "completely renewable" energy to merely "fossil-free" energy, which also includes nuclear energy. The country has also set a target for emissions from transport to be 70% lower in 2030 compared to 2005, excluding domestic flights. Under today's trends, it is unlikely that this target will be met, and a new target is under discussion.

Regarding national energy use, the target is a 50% increase in energy efficiency, thus halving total energy consumption per unit of GDP by 2030 compared to 2005. Seeing that 89% of Sweden's electricity production is currently already derived from renewable or nuclear energy, the country is on a promising path to achieve its national targets.

4.2.3 Offshore-wind energy in Sweden

At the moment, Sweden produces 210 MW or 0.56 TWh of offshore wind electricity yearly through the 56 turbines installed within three wind-far projects, namely Bockstigen, Kårehamn and Lillgrund.[71] There is a planning goal of an additional 25 GW, corresponding to 120 TWh/year, of offshore-wind power. This means that maritime spatial plans must provide suitable space for wind power to fulfil at least this volume.

70 Swedish Energy Agency, 'Energiläget 2022 – En översikt'.

71 Svartengren, 'Tillstånd och prövning'.

Today, there are already ambitious projects in development corresponding to a much higher potential volume. More precisely, applications for grid connections reached 125 GW in Swedish waters during 2022. Many of these projects have submitted permit applications, of which three have been granted said permits. Kriegers Flak, a project with 45 turbines mentioned in detail elsewhere in this report, is for the time being the only existing project in the Baltic Sea.

4.2.4 Green hydrogen in Sweden

At 180,000 tonnes per year, the production of hydrogen in Sweden is not currently very substantial. This hydrogen is mainly (almost 67%) produced through the reforming of natural gas and industrial waste streams, while just under 3% is produced via electrolysis. There are a number of production units getting started in 2024 that may change these statistics, however. For example, Ovako steel in Hofors initiated test runs with the largest electrolyser in Sweden (20 MW) in September 2023, with a total capacity of 3,000 tonnes per year.

Another initiative that has gotten attention worldwide is Hybrit. This joint venture between a mining concern (LKAB), a steel manufacturer (SSAB) and a power producer (Vattenfall) aims to produce fossil-free steel by deploying green hydrogen. The first prototype is currently in operation and the first batches of steel have already been delivered. Since only a very small share of electricity production in Sweden is based on fossil fuels, all hydrogen produced through electrolysis in the country can be considered green.

Sweden's future plans for the expansion of hydrogen production are considerable. The hydrogen required for the Hybrit steel project alone (at full capacity) will require 50-70 TWh of electricity per year to produce. There are other mining and steel projects with concrete plans, such as H2-Steel. In total, it would require up to 114 TWh of electricity to replace all fossil fuels in the Swedish mining, iron and steel industries with hydrogen.[72]

The petrochemical sector also uses a great deal of hydrogen. Today, this mainly originates from fossil fuels. However, the oil company Preem is investigating possibilities to produce and use green hydrogen with an electrolysis capacity of 0.6 GW. The hydrogen would be used to produce liquid biofuels (e-fuels).

4.2.5 Transnational projects

Kriegers Flak, described in more detail below, is one of the transnational offshore-wind farms planned in Swedish waters close to Denmark and Germany and adjacent to the German wind farm EnBW Baltic. Unfortunately, these projects are not yet coordinated, although there are clear potential synergies and possibilities to transfer electricity between the existing wind farms.

South Victoria is a future transnational project planned by RWE close to Polish waters. The possibility to have a grid connection both to Sweden and Poland is being investigated. Nevertheless, the wind farm has not yet received a permit from the Swedish Government, and is facing legal challenge due to possible conflicts with nature areas.

There are also several initiatives for transnational hydrogen pipelines which involve Sweden. These are described in more detail in the Hydrogen section above.

72 Gode et al., 'Efterfrågan På Fossilfri El - Analys Av Högnivåscenario'.

4.3 Finland

4.3.1 Today's electricity market in Finland

In 2022, the total consumption of electricity in Finland amounted to 81.7 TWh – of which 44.2% was consumed by industry and construction, 23.9% by households and agriculture, 18.7% by services and public consumption, and 2.8% by transmission and distribution losses.[73]

Finland is a net importer of electricity, with the level of net imports fluctuating over the year, depending on the availability of domestic hydro generation and electricity prices in the Nordic electricity market. Between 2010 and 2021, net electricity imports ranged from 11 TWh to 20 TWh, representing 14% to 31% of the country's electricity supply. Electricity imports used to be predominantly sourced from Russia, constituting an average of 88% of net imports from 2005 to 2011. However, since 2012, the primary source of imports has shifted to Sweden, which accounted for 87% of net imports from 2012 to 2021 (in 2012, a new interconnection with Sweden increased import capacity by 40%). Imports from Norway remain minimal, amounting to just 0.26 TWh in 2021.[74]

In 2022, the share of fossil-free electricity produced in Finland reached 89%. That year nuclear energy stood as the primary source of electricity generation in Finland, constituting 29.7% of the total electricity produced, while hydropower accounted for 16.3% of energy production, net imports constituted 15.3%, biomass 14.8% and wind power 14.1%. The remaining energy was generated from coal, peat, gas and other sources (including solar power).[75]

4.3.2 Energy-transition goal

In July 2022, Finland amended its Climate Change Act to include a mandatory target of achieving carbon neutrality by 2035. This updated Act imposes binding goals for reducing greenhouse gas (GHG) emissions, excluding those from land use, landuse change, and forestry (LULUCF), by 60% by 2030, 80% by 2040, and 90-95% by 2050. Furthermore, the Act mandates the creation of various documents detailing specific measures necessary to meet these objectives.[76]

In 2022, renewable-energy sources made up 41.8% of Finland's total energy consumption, while fossil fuels and peat combined contributed 33.7%. Nuclear energy accounted for 20.4%, with net imports constituting 3.5% of the total energy consumption. The discontinuation of natural gas supply from Russia in May 2022 led to a significant reduction, with consumption nearly halving compared to the previous year, and ultimately amounting to 3% of the total energy consumption in 2022.[77]

The National Climate and Energy Strategy (NCES) serves as the primary framework for outlining the steps necessary to fulfil both Finland's and the European Union's (EU) 2030 energy and climate objectives. [78]

4.3.3 Offshore-wind energy in Finland

Currently, there is only one offshore-wind farm operating in Finland – the 44 MW Tahkoluoto facility commissioned in 2017 and operated by Suomen Hyötytuuli. In December 2022, Metsähallitus – the Finnish manager of state land and water assets – reached an agreement with Vattenfall for the development and construction of Finland's first offshore wind project in the open sea area, named Korsnäs.[79] The Korsnäs offshore-wind farm is planned to reach the capacity of 1.3 GW with a potential annual production of 5 TWh. It is expected to start operation in the 2030s.

In November 2023, the Finnish Government adopted a resolution to commence the tendering process for five more offshore wind-farm projects. The total area to be included in the procedure spans approximately 860 km2, with a calculated maximum capacity of around 7.5 GW.[80] The tendering processes (which is estimated to take a year) for two offshore wind projects have

73 Tilastokeskus, 'Statistics Finland'.

74 nternational Energy Agency, 'Executive Summary – Finland 2023 – Analysis'.

75 nternational Energy Agency.

76 International Energy Agency.

77 Finnish State Treasury, 'Energy Consumption'.

78 Finnish Ministry of Economic Affairs and Employment, 'Carbon Neutral Finland 2035 – National Climate and Energy Strategy'; International Energy Agency, 'Executive Summary – Finland 2023 – Analysis'.

79 Metsähallitus, 'Korsnäs Offshore Wind Farm'.

80 Finnish Government, 'Metsähallitus Launches Auctions Concerning Large-Scale Offshore Wind Power Projects'.

already been initiated in November 2023. The process for the other three sites is planned to be launched in 2024.[81] Additionally, there are plans to expand the Tahkoluoto offshore-wind farm up to 45 turbines with a capacity of 11-20 MW each. In total this could increase the capacity of Tahkoluoto up to 900 MW.[82]

4.3.4 Green hydrogen in Finland

Currently, 99% of hydrogen produced in Finland derives from fossil sources, mainly natural gas. The current production of hydrogen amounts to nearly 150,000 tonnes/year (or 5.0 TWh). Eighty-eight per cent of hydrogen currently used in Finland is deployed for refining oil and biofuels. Finland plans to assess the effectiveness of Carbon Contracts for Difference (CCfD) assistance in fostering a low-carbon industry.[83]

On 9 February 2023, the Finnish government adopted a resolution on hydrogen which sets a target of producing 10% of the entire EU's emissions-free hydrogen in 2030. According to the NCES, the objective for electrolysis equipment used in hydrogen production is to achieve a capacity of at least 200 MW by 2025 (compared to 9 MW in 2021) and a minimum of 1,000 MW by 2030, assuming sufficient hydrogen-technology commercialisation.

The projects being considered in late 2024 include:

- Neste (Finland's largest oil company) is currently working on a 120 MW electrolyser project aimed at producing green hydrogen at their Porvoo refinery in Finland. Green-hydrogen production could commence there as early as 2026;[84]
- P2X Solutions is currently building Finland's inaugural industrial-scale green-hydrogen and synthetic-methane production facility of 20 MW in Harjavalta, planned to open in 2024;[85]
- Plug Power intends to build three green-hydrogen production facilities in Finland, aiming to produce 850 tonnes per day of green hydrogen, equivalent to 2.2 GW of electrolyser capacity, by the end of the decade. The final investment decision for these projects is expected to be made by 2025/2026.[86]

4.3.5 Transnational projects

Finland is involved in the development of several transnational projects in hydrogen, not least the transnational hydrogen pipelines mentioned in the Hydrogen section above, as well as Europe's first significant cross-border hydrogen-valley project BalticSeaH2. This will centre on southern Finland and Estonia and involve 44 project partners from all eight Baltic Sea Region countries as well as Norway. BalticSeaH2 is intended to facilitate 20 demonstration and 10 investment cases, highlighting various sectors within the hydrogen economy and totaling over four billion euros in investments. The potential hydrogen production is expected to eventually reach 100,000 tonnes per year.[87]

81 Metsähallitus, 'Metsähallitus to Launch the Competitive Tendering Process for Two Offshore Wind Power Projects'.

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

83 Finnish Ministry of Economic Affairs and Employment, 'Carbon Neutral Finland 2035 – National Climate and Energy Strategy'.

84 Neste Corporation, 'Neste Moves Forward in Its Renewable Hydrogen Project in Porvoo, Finland | Neste'.

85 P2X Solutions, 'Work Began on P2X Solutions' Site for the Green Hydrogen Plant in Harjavalta – P2X Solutions'.

86 Plug, 'Plug Power Makes Major Strategic Move into Finland's Green Hydrogen Economy with Its Proven PEM Electro-lyzer and Liquefaction Technology'.

87 Gasgrid, 'Finland into the Most Attractive Hydrogen Economy Country in the World'.

4.4 Estonia

4.4.1 Today's electricity market in Estonia

Estonia's electricity consumption in 2022 was 7.7 TWh.[88] Total production capacity in 2023 was 2.5 GW, broken down across different sources as shown in Table 2.[89] Estonia imported 12.9% of its electricity in 2022.[90]

Energy source	Capacity
Onshore wind	317 MW
Hydro	8 MW
Solar	510 MW
Oil shale	1330 MW
Waste	17 MW
Natural gas	110 MW
Shale gas	78 MW
Biomass	152 MW
Other	20 MW
Total	**2,542 MW**

Table 2: Energy generation capacity by source in Estonia.

4.4.2 Energy-transition goal

Estonia's goal is to become climate-neutral by 2050 at the latest. In 2022, the share of renewable electricity in Estonia's electricity consumption was 29%. In 2022, there were 319 MW of wind ener-gy-production capacity installed on land in Estonia, approximately 500 MW of solar energy-production capacity and 351.8 MW of cogeneration plant-production capacity. The amount of wind energy-production capacity connected to the electricity grid may double by 2025.

In the Elektrilevi distribution network, solar energy-production capacity has increased from 38 MW in 2018 to more than 600 MW in 2022, and is expected to more than double again by 2030. It is difficult to estimate the potential of solar parks, but it is clear that the emergence of the hydrogen economy would also contribute to the growth of renewable electricity-production volumes. By 2030, the share of renewable energy is planned to increase from 38% to 65%.[91]

88 Enerdata, 'Estonia Energy Information'.

89 ENTSO-E Transparency Platform, 'Installed Capacity per Production Type – Estonia'.

90 Estonian Competition Authority, 'Elektri- Ja Gaasituru Aruanded'.

91 Parliament of Estonia, Energiamajanduse korralduse seadus.

4.4.3 Offshore-wind energy in Estonia

Estonia has set the goal of covering all its electricity consumption with renewable-energy sources by 2030.[92] It is working to remove barriers that prevent this, such as restrictions on the maximum permitted height of facilities or reserved transmission capacities in which no actual transmission takes place. The Action Programme of the Government of the Republic 2022-2023 specifies that the process of planning, environmental-impact assessment and permits will be audited under the lead-ership of the Green-Transition Coordinator of the State Chancellery, with the aim to accelerate the implementation of renewable-energy projects. A steering group and four working groups were formed at the State Chancellery to perform the audit and develop solutions. The steering group de-cided to focus on finding priority wind energy-development areas and speeding up permit proce-dures.

The capacity of offshore-wind farms could reach an estimated 3 GW in 2030. Construction is planned in maritime areas TP 1, TP 2, TP 3 and TP 4 located north and northwest of Hiiumaa (see Figure 6).[93]

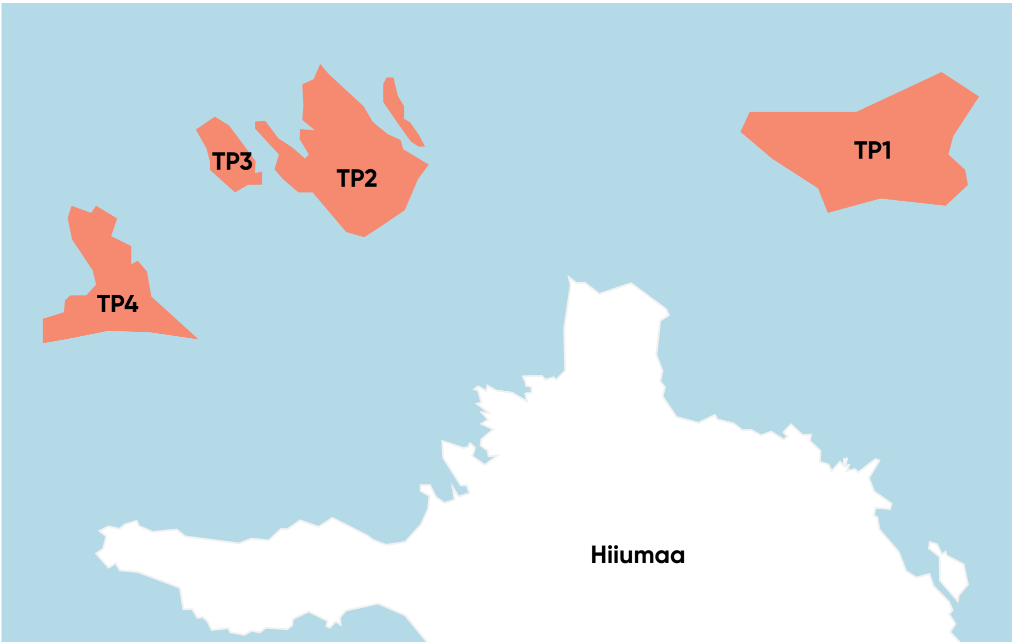

Figure 6: Proposed offshore-wind farms in Estonia.

4.4.4 Green hydrogen in Estonia

As most other countries in the Baltic Sea Region, Estonia has very little green hydrogen production as of 2024; however, it plans to have a capacity of 1 GW by 2030. To decarbonise its gas network, the country will need to produce 2 TWh per year of biomethane and over 1,100 tonnes per year of green hydrogen by 2030, with 1% of transport being fuelled by hydrogen or e-fuels by then.

Two support measures have been introduced to foster the production and deployment of hydrogen in Estonia. The first one, adopted in 2021, aimed to promote the use of green hydrogen in public transport. It calls for the creation of a green-hydrogen production unit, delivery infrastructure and a hydrogen-consuming taxi fleet by the end of 2024. The expected upshot is annual production of over 30 tonnes of green hydrogen for use in public transport, resulting in a decrease in annual greenhouse-gas emissions of more than 1,000 tonnes of carbon dioxide-equivalent per year. The measure included a subsidy to the amount of €5 million distributed from funds raised by the emissions-trading system.

The aim of the second hydrogen-support measure was to test a range of complete supply chains for green-hydrogen deployment, from production to final consumption, in Estonia. This is implemented through pilot projects which aim to reduce greenhouse-gas emissions and were selected via a com-petitive bidding process. The funding originates in the Recovery and Resilience Facility (RRF), the centrepiece of NextGenerationEU, and amounts to €50 million. The activities will be implemented by March 2026.

92 Parliament of Estonia.

93 Estonian Climate Ministry, 'Loode-Eesti rannikumere tuulepargi keskkonnamõju hindamine'.

Several companies are developing hydrogen-production technologies and have planned production, distribution, cylinder-storage and use projects in the hydrogen value chain. Companies generally support the gradual development of pilot projects, the creation of enabling norms and legal frame-works, and the growth of long-term demand. The preliminary studies for the development of the transmission infrastructure were initiated in cooperation with neighbouring countries in 2023 and are carried out by the Estonian grid company Elering.

The state has decided to grant non-refundable subsidies to three hydrogen value-chain technology projects for research and development activities to the amount of nearly €67 million based on an IPCEI notification. In addition, the state supports projects to create a hydrogen value chain in the transport sector and the chemical industry with almost €54 million. The calculation of the share of renewable electricity available for hydrogen production and the possible final consumption is part of the process of updating the energy economy development plan (ENMAK 2035), which will be completed by 2026.[94]

Currently, hydrogen is produced at the University of Tartu (8-10 kg per day are planned in 2024) and for cooling the generators of Eesti Energia's thermal plants in Narva. Utilitas Eesti AS and UG Investments are developing a green-hydrogen pilot project in public transport that should be ready in 2024. The port of Sillamäe has the capacity to receive and export ammonia. At the end of 2022, it was possible to order two passenger cars that use hydrogen as fuel in Estonia: the Toyota Mirai and the Hyundai NEXO. Mobile hydrogen-refuelling options have been introduced as pilot projects, Alexela AS has assessed the possibility of offering hydrogen on a commercial basis and coming up with refuelling options when demand arises.[95]

4.5 Latvia

4.5.1 Today's electricity market in Latvia

Latvia's national consumption of electricity was 7.4 TWh in 2021 and 7.1 TWh in 2022. This was divided roughly equally among industry and construction (34%), households (31%) and legal enti-ties (30%), with smaller shares falling to agriculture and fisheries (3%) and transport (2%). Local energy production declined even more than consumption, with just 67.5% of the country's con-sumption covered by local energy generation in 2022. Imports therefore increased to 2.3 TWh, or 30.4% more than in 2021.[96]

In 2022, 4.8 TWh of electricity were produced in Latvia, which was 14.5% less than the year before. Despite this overall decrease, production through renewable resources showed a significant boost, mainly through wind-power plants, which increased production by 34.5%. The large Daugava hy-droelectric-power plant produced 1.3% more compared to 2021, while smaller hydroelectric power plants increased production by 13.3%. The most considerable increase was achieved by solar-power plants, which more than doubled their production with an increase of 122%. However, at 0.11%, they still contribute only a fraction of Latvia's total electricity balance.[97]

Latvia has experienced a drop in the production of fossil fuels, and a decrease of 36.9% in electricity produced by large cogeneration stations . The contribution of small cogeneration stations also con-tinues the steady decline observed for the last six years, with a 67.5% drop in 2022. Furthermore, biomass as well as biogas produced less electricity, with decreases of 5.9% and 9.4% respectively.[98]

Changes in the national production structure are mainly due to high gas prices. The large cogenera-tion plants operated in minimum mode from March to August of 2022, as additional wind and solar power plants were connected to existing grids.[99]

94 Kallas, Järvan, and Sikkut, 'Eesti Vesiniku Teekaart'.

95 Kallas, Järvan, and Sikkut.

96 AST, 'Elektroenergijas Tirgus Apskats'.

97 AST.

98 AST.

99 AST.

Electricity produced in Latvia	2022, MWh	Compared to 2021
Daugava Hydroelectric-Power Station	2,653,033	+1.3%
Thermal-power plants	1,215,715	-36.9%
Wind-power plants	188,364	+34.5%
Cogeneration (up to 10 MW)	73,260	-67.5%
Biomass (up to 10 MW)	344,055	-5.9%
Biogas (up to 10 MW)	237,283	-9.4%
Small hydroelectric-power stations (up to 10 MW)	77,678	+13.3%
Solar-power plants	5,262	+122.2%
Total electricity produced	**4,794,651**	**-14.5%**

Table 3: Electricity produced in Latvia.

4.5.2 Energy-transition goal

Latvia aims to achieve climate neutrality by 2050. The most prominent types of renewable-energy resources in Latvia are fuel wood (firewood, wood residues, fuel chips, wood briquettes, wood pel-lets) and hydro resources. As in previous years, the share of natural-gas consumption is decreasing while the proportion of renewable energy in the total consumption of energy continues to increase. The year 2022 saw a 2.1% increase in the use of renewable energy, bringing renewable energy to 43.3% of the total.

4.5.3 Offshore-wind energy in Latvia

There are no offshore wind energy projects in place as of 2024, Latvia has potential of 15 GW of off-shore wind which it plans to leverage as soon as possible.

4.5.4 Green hydrogen in Latvia

The Ministry of Climate and Energy in Latvia (with a specially established Consultative Board on Climate, Environment and Energy) is still working on Latvia's Energy strategy 2050. The Strategy will include a section of green hydrogen, as informed by Latvia's Strategy to Achieve Climate Neu-trality by 2050 – a document which aims to specify the appropriate electricity mix and capacity package in the years 2023 and 2050.[100]

Various actors in the industry have joined forces within the Hydrogen Alliance Latvia, which focuses on joint efforts and collaboration in facilitating new innovation and cooperation initiatives and a unified goal of promoting hydrogen as a path to energy independence and a possible future technol-ogy leading the way to net zero emissions. The alliance features stakeholders of all levels – SMEs, public bodies, universities, and laboratories – and has presented the key principles for hydrogen development.[101]

100 Climate Change Laws of the World, 'Latvia's Strategy to Achieve Climate Neutrality by 2050'.

101 Martinsons, 'Hydrogen in Latvia'.

While the overall institutional and legislative framework for hydrogen production is still develop-ing, there are ambitious future plans in some local governments. As major nodes for production, storage and demand, ports are centrepieces of hydrogen valleys. A hydrogen plant is planned by 2029 in Liepaja which should be able to produce approximately 150,000 tonnes of hydrogen per year. Liepaja was chosen as the site of the hydrogen plant because of its large port and plans for nearby wind farms. Moreover, there are plans to create a new programme for the training of quali-fied specialists in cooperation with local training institutions. The total investment could amount to about a billion euros, with possible room for government support.[102]

The freeport of Ventspils administration has signed an agreement to explore the potential for con-struction of a plant for the making of green hydrogen and derived products. At the same time, pro-ject promoters will explore opportunities for marketing and export, as well as identify potential cooperations with existing entrepreneurs in Ventspils.

In Latvia's capital Riga, the public transport operator has introduced hydrogen fuel cell-range ex-tenders in its unified electric-trolleybus system. The innovative "HyTrolley" pilot concept for trol-leybuses provides greater flexibility in the transport system, less noise, zero tailpipe emissions and better energy efficiency. The trolleybuses are powered by hydrogen produced by the only hydrogen fuelling station in the Baltics, with a 300 kg daily output and a storage capacity of 600 kg. This pro-ject kicked off the practical use of hydrogen as a fuel in Latvia. (It is important to note that the hy-drogen station produces grey hydrogen from natural gas, however.)[103]

The Dutch company Fokker Next Gen has signed a Memorandum of Cooperation with the Latvian Ministry of Economics to develop a hydrogen-fuelled aircraft project in Latvia in what would be a significant contribution to the development of the green-energy cluster on the Kurzeme coast. Working in close cooperation with Riga Technical University and Kurzeme coastal municipalities, Fokker Next Gen plans to develop a hydrogen-powered passenger aircraft model with a capacity of 120 to 150 passengers which could reach destinations up to 2,500 km away. The project is in its early stages and may create up to 100 new jobs in Latvia over the next three years. It has a strong emphasis on research, with work starting on the development of the Hydrogen Centre of Excellence in 2024. This will contribute both to the project itself and to the development of the industry as a whole.[104]

The Freeport of Ventspils signed a contract with a private company in 2023 for preliminary re-search linked to the construction of a green-hydrogen factory in Ventspils. The project implementa-tion will be time-consuming, involving risk analyses, environmental-impact assessments and identi-fication of potential options for cooperation with existing entrepreneurs in the city, through joint use of port infrastructure. The project is currently in an active phase of its environmental-impact assessment.

4.6 Lithuania

4.6.1 Today's electricity market in Lithuania

In 2022, Lithuania consumed 12.1 TWh of electricity, 5.4% less than in 2021. Industrial consump-tion declined by 10.7% from 4.48 TWh to 4.0 TWh, and agricultural consumption by 9%, from 0.27 TWh to 0.25 TWh. The electricity consumption of the transport sector fell by 5.3%, from 0.10 TWh to 0.1 TWh, and residential consumption decreased by 3.5%, from 3.41 TWh to 3.29 TWh. National electricity generation was 4.3 TWh in 2021 and 4.4 TWh in 2022, constituting 36% of total con-sumption.[105]

In 2022, Lithuania imported 11.22 TWh of electricity – 5.3% less than in 2021 – and exported 2.65 TWh – 7.7% less than the previous year. The war in Ukraine was a major cause for the significant change in electricity imports in 2022. Nevertheless, imports from Sweden and Poland grew by 35.1% (to 5.03 TWh) and 28.6% (1.10 TWh), respectively.

The sources of Lithuania's total energy (not electricity) consumption of 63.7 TWh in 2022 are bro-ken down across sectors in Table 4.[106]

102 City of Liepaja, 'Liepāja - Vēju Pilsēta'.

103 Martinsons, 'Hydrogen in Latvia'

104 LIAA, 'Sākumlapa - Latvijas Investīciju un attīstības aģentūra'.

105 Litgrid, 'Litgrid'.

106 Oficialiosios statistikos portalas, 'Pradžia - Oficialiosios Statistikos Portalas'.

Total	63.7 TWh
Coal and lignite	1.7 TWh
Firewood, wood for fuel and agricultural waste	7.1 TWh
Biogas and liquid biofuels (bioethanol, bio-ETBE (ethyl tertiary-butyl ester), biodiesel (methyl ester)	1.5 TWh
Secondary solid fuels (coke and semi-coke, coal, peat briquettes, charcoal, peat pellets)	0.4 TWh
Natural gas	6.8 TWh
Nuclear, hydropower, wind, geothermal, solar and chemical process energy	4.4 TWh
Petroleum products, total	26.0 TWh
Liquefied and non-liquefied petroleum gases	1.7 TWh
Light petroleum products (motor petrol, aviation petrol, kerosene and petrol jet fuel, naphtha)	4.4 TWh
Heavy petroleum products (diesel, fuel oil, gas oils for heating and bunkering of ships)	20.0 TWh
Ambient heat energy (total heat)	1.0 TWh
Electricity	12.2 TWh
Thermal energy	8.6 TWh

Table 4: Sources of Lithuania´s total energy consumption in 2022.

4.6.2 Energy-transition goal

The country aims to be climate neutral by 2050 at the latest and to derive 70% of its electricity sup-ply from renewable-energy sources by 2030.[107] There are indicators that 90-100% of electricity production from renewable-energy sources can be achieved by 2030.[108] This fact is important for the production of green hydrogen and other green fuels, as it means that electrolysers could be con-nected directly to the grid. Between 2021 and 2023, the share of electricity imports in meeting the country's electricity consumption demand has decreased from 65 to 52% thanks to growing renew-able-energy generation. In the same time period, the share of renewable electricity has increased by more than 60%, or 13 percentage points: from 19% in 2021 to 32% in 2023.[109]

The shares of renewable-energy sources are indicated in Table 5 and Figure 7 and Figure 8.

Year	Electricity generation	Onshore wind	Solar PV	Hydro- power	Thermal power plant	Other	Electricity consumption	Electricity import
TWh, 2023	5.5	2.4	0.7	0.9	0.9	0.7	11.7	6.2
TWh, 2022	4.5	1.5	0.4	1	1	0.6	12.2	7.8

Table 5: Shares of renewable-energy sources.

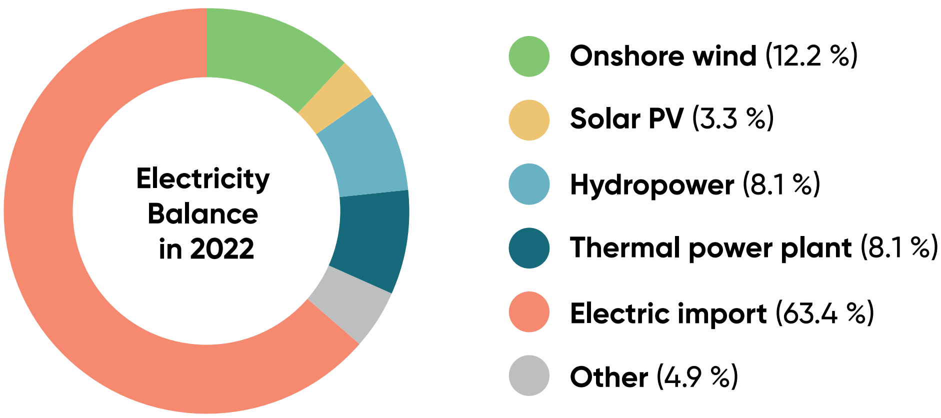

Figure 7: Electricity Balance in 2022.

107 Duburaitė, ‘Seimas skatina didinti energijos gamybą iš atsinaujinančių energijos išteklių’..

108 Lithuanian Energy Agency, ‘Tarpiniai modeliavimo rezultatai patvirtina: Lietuva iš elektros energijos importuotojos taps eksportuotoja jau 2030 metais’.

109 Litgrid, ‘Litgrid’.

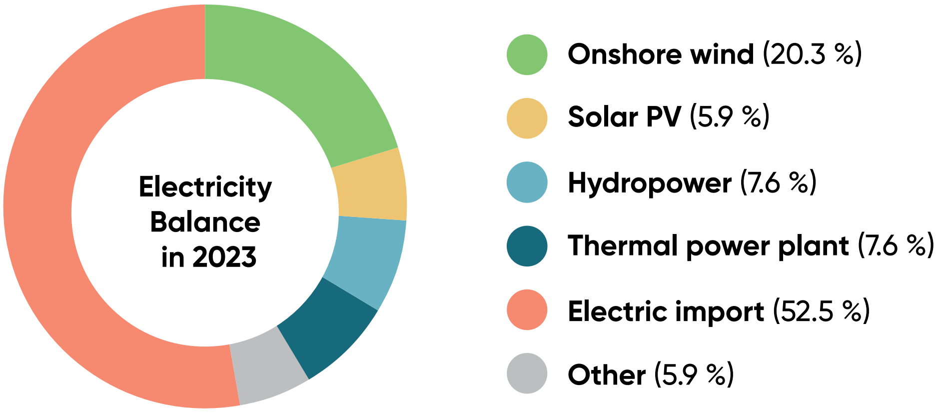

Figure 8: Electricity Balance in 2023.

4.6.3 Offshore-wind energy in Lithuania

The development of offshore-wind parks in the Baltic Sea is among the most important and ambi-tious projects laid out in Lithuania's National Energy Independence Strategy.[110] This buildout is meant to significantly increase production of electricity from renewable-energy sources, thus reduc-ing Lithuania's dependence on electricity imports, ensuring stable electricity prices for the resi-dents, and achieving a climate-neutral economy by 2050.

To enable conditions for the production of electricity from renewable-energy sources in the Baltic Sea and thereby increase the share of renewable energy in Lithuania's domestic energy production as well as its final balance of energy consumption, a pre-researched territory in the Baltic Sea was approved by the Government of the Republic of Lithuania and the the Comprehensive Plan of the Territory of the Republic of Lithuania was supplemented with an Annex on Responsible Use of the Sea and Coast.[111]

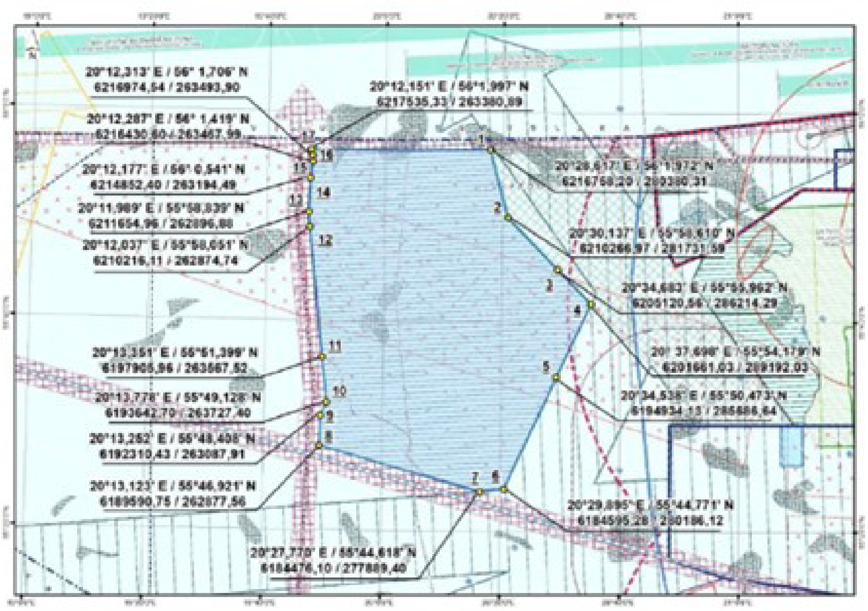

Figure 9: Annex on the Responsible Use of the Sea and Coast indicating the territory allocated to the development of renewable energy.[112]

110 Parliament of Lithuania, 'Dėl Nacionalinės energetinės nepriklausomybės strategijos patvirtinimo'.

111 Lietuva 2030, 'Atsakingai Naudojama. Jura Ir Pakrantė'.

112 Lithuanian Energy Ministry, 'Inžinerinės Infrastruktūros Uždaviniai Ir Vystymo Planas'.

The total marine territory in the country's exclusive economic zone dedicated to the development of renewables (i.e. not only offshore parks, but also floating solar, wave-energy converters, etc.) equals 644 km2, with the closest distance to shore being 29.5 km. The calculated potential of the territory adds up to 4.5 GW of offshore wind.

To determine specific, detailed areas where offshore-wind farms can be developed and operated in phases, as well as reserve corridors for the related infrastructure and ship routes, an engineering infrastructure-development plan has been approved at the state level for the whole dedicated ma-rine territory. The Lithuanian Government approved of the first two regions (indicated by the col-ours green and orange in Figure 10) to be auctioned for future offshore-wind development in the Baltic Sea.

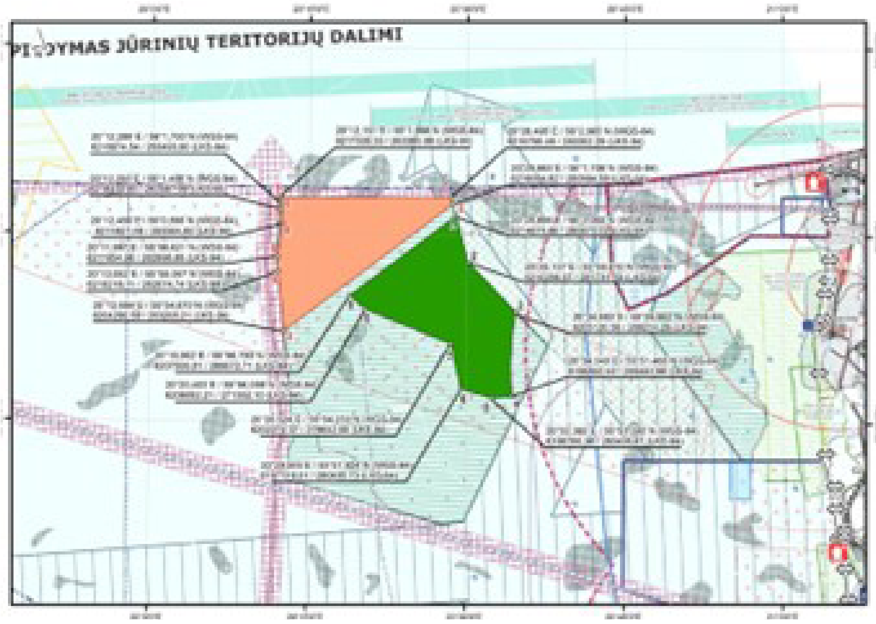

Figure 10: The first two territories indicated for offshore-wind development in Lithuania.

The area of the first territory planned for the offshore windpark (Phase I tender, represented by the orange area in Figure 10) development in the Baltic Sea covers approximately 120 km2 and will have a capacity of around 700 MW. The territory is located some 36 km from shore. The tender process included administrative screening of the participants and their bids. The tender, which ended in Autumn 2023, specifies that the winner must take care of all the preparatory work (geophysical/ geotechnical studies, metocean data collection, environmental impact assessments) themselves. The developer will also be responsible for connecting the offshore park to the land-side electricity-transmission grid and for addressing any grid imbalances resulting from the generated electricity.

The territory planned for the second offshore-wind park (Phase II tender, represented by the green area in Figure 10) in the Baltic Sea is approximately 136 km2, also with a capacity of some 700 MW. This territory is located 29.5 kilometres from shore. The tender process includes administrative screening of the participants and their bids; however, unlike in the first tender, the tender participants can choose to make use of state support in the form of a contract for difference or, if they decide against the support, they may offer a development fee. The tender is planned for late 2024. The developer will be responsible for connecting to the landside electricity-transmission grid and for addressing any imbalances. However, all necessary preparatory work will be carried out by the state before the tender.[113]

The two offshore-wind parks are planned to be commissioned by 2030. They are expected to generate up to 6 TWh of green electricity per year, meeting up to half of Lithuania's total electricity demand today. They are also expected to attract around €3 billion in investments and create at least 1,300 new jobs.

According to Lithuania's National Energy Independence Strategy, which is pending approval in late 2024, offshore-wind parks will continue to be developed. Installed capacity should be increased from 1.4 to 2.8 GW by 2040 and up to 4.5 GW by 2050. The development of these parks will allow Lithuania to secure national needs for renewable electricity and establish itself in the regional market as an exporter of energy resources.

113 Lithuanian Energy Ministry, 'Inžinerinės Infrastruktūros Uždaviniai Ir Vystymo Planas'.

4.6.4 Green hydrogen in Lithuania

Lithuania currently predominantly uses grey hydrogen, primarily within the fertiliser industry and in the refining processes of petroleum products. Only a small fraction is allocated to other industrial sectors.[114] From 2015 to 2021, the volume of hydrogen produced from fossil fuels and used in Lithuanian industry grew from 260,000 to 320,000 tonnes per year. Approximately 75-80% of the hydrogen was used for ammonia production, 20-25% were used for refining petroleum products, and about 1% was deployed for other purposes (see Figure 11). The guidelines for the development of green hydrogen in 2024-2050 were approved in April 2024, setting the stage for continued integration of green hydrogen into Lithuania's industrial, transport and electricity sectors.[115] An implementation plan for these guidelines must be approved by the end of 2024 to ensure the smooth and efficient achievement of the outlined goals.

An environmental impact assessment has already been carried out at the Port of Klaipeda, where production of green hydrogen should start in 2026. This green hydrogen will be used for municipal public transport and seagoing vessels.

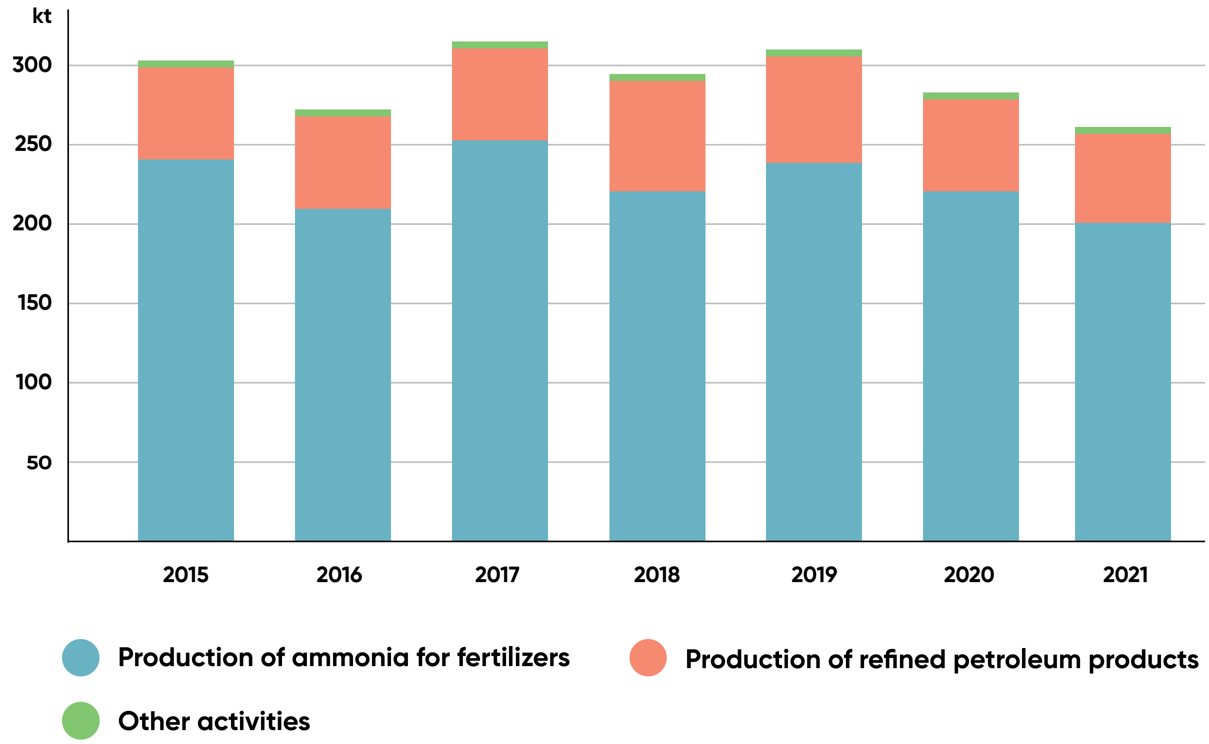

Figure 11: Production and use of hydrogen from fossil fuels in industry in Lithuania in 2015-2021.

Lithuania's strategic initiatives include the "Lithuania 100% Renewable Energy" project, launched in collaboration with the U.S. National Renewable Energy Laboratory in 2024. This project aims to evaluate future scenarios and provide critical insights for decisionmakers to facilitate the country's energy transition. A key focus is on identifying cost-effective options for decarbonising local indus-tries such as oil refining and ammonia production and exploring the integration of green hydrogen with the planned European Hydrogen Backbone. Legislative and investment efforts are also crucial to Lithuania's green-hydrogen plans. The Alternative Fuels Law, debated in early 2023, anticipates that, by 2030, at least 5% of the final energy consumption in the transport sector will come from biomethane and green hydrogen. Amendments to the Natural Gas Quality Requirements have been prepared to allow hydrogen inclusion in the natural gas-transmission and distribution system.

The primary demand for green hydrogen in Lithuania is expected to come from SAF production, fertiliser producers and transport sector. The main centres for green-hydrogen development and production are anticipated to be the port of Klaipeda, as well as northwestern and central parts of Lithuania where green-hydrogen valleys are planned.

114 Innovation Agency, 'Vandenilio Iš Atsinaujinančiųjų Išteklių Energijos Gamybos Ir Naudojimo Pramonėje Lietuvoje Galimybių Studija'.

115 Parliament of Lithuania, 'Dėl Vandenilio Plėtros Lietuvoje 2024–2050 m. Gairių Patvirtinimo'.

By 2030, Lithuania has set several ambitious targets for green hydrogen production and utilisation. The country plans to install at least 1.3 GW of electrolysis equipment, which should produce no less than 129,000 tonnes of green hydrogen annually. Additionally, there is a goal to establish ten hy-drogen-fuelling stations nationwide to cater to trucks, buses, vans and cars. It is projected that 6.51 TWh of electricity will be required for green hydrogen production by 2030, a figure expected to rise to 36.36 TWh by 2050.

Lithuania is working to establish hydrogen clusters, expand hydrogen infrastructure, and enhance storage capacity. By 2030, these initiatives are expected to generate approximately 7,000 new jobs.

4.7 Poland

4.7.1 Today's electricity market in Poland

In 2023, the gross domestic-electricity consumption in Poland amounted to 170.2 TWh, a decrease of 3% compared to 2022. Industrial consumption accounted for 42.1% of the total, and consumption by small consumers made up 44.5%[116] Economic growth and electricity demand have recently be-come decoupled: despite Poland's large cumulative GDP growth (37.7% at constant prices), demand for electricity grew by only 5.5% during the last decade.[117]

In Poland, electricity is produced primarily in utility thermal-power plants. In 2023, the volume of production at these facilities amounted to 112.67 TWh, which accounted for around 68% of total gross production. Industrial power plants produced 14.5 TWh, or 9.7% of the total, in 2023. The remainder of the electricity was produced by independent power plants, mainly wind power.[118]

2023 brought significant changes to the Polish generation mix, with the share of coal in electricity generation falling to 60.5% (from 69% in 2022).[119] Coal-fired generation was replaced mainly by renewable power, which accounted for a record 27% of generation. Due to the return of lower natural-gas prices and higher flexibilities, electricity generated by burning gas increased by as much as 41%.[120]

4.7.2 Energy-transition goal

Poland has not adopted climate-neutrality targets, but still aims to increase the share of renewable energy in its mix. Poland's Energy Policy until 2040 (PEP2040) specifies that the share of renewable energy in gross final energy consumption is to be at least 23% by 2030, including no less than 32% in the electricity sector, and around 40% in 2040. This is to be achieved mainly through the expansion of wind and photovoltaic energy. Offshore-wind energy is to play a particularly important role in achieving these targets, with plans for 5.9 GW of installed capacity in 2030 and about 11 GW in 2040.[121]

In April 2022, the Ministry of Climate and the Environment presented its "Assumptions for the update of Poland's Energy Policy until 2040 – strengthening energy security and independence" in response to Russia's aggression against Ukraine. The Polish government now plans to aim for around half of its electricity generation to come from renewable sources by 2040, up from the current plans of 32% by 2040 (see Figure 13).[122]

116 Agencja Rynku Energii, 'Wydawnictwa opracowywane w ramach PBSSP'.

117 Forum Energii, 'Transformacja energetyczna w Polsce. Edycja 2024'.

118 Agencja Rynku Energii, 'Wydawnictwa opracowywane w ramach PBSSP'.

119 Statistics Poland (GUS), 'Gospodarka paliwowo-energetyczna w latach 2021 i 2022'.

120 Forum Energii, 'Transformacja energetyczna w Polsce. Edycja 2024'.

121 Polish Ministry of Climate and the Environment, 'Polityka energetyczna Polski do 2040 r.'

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

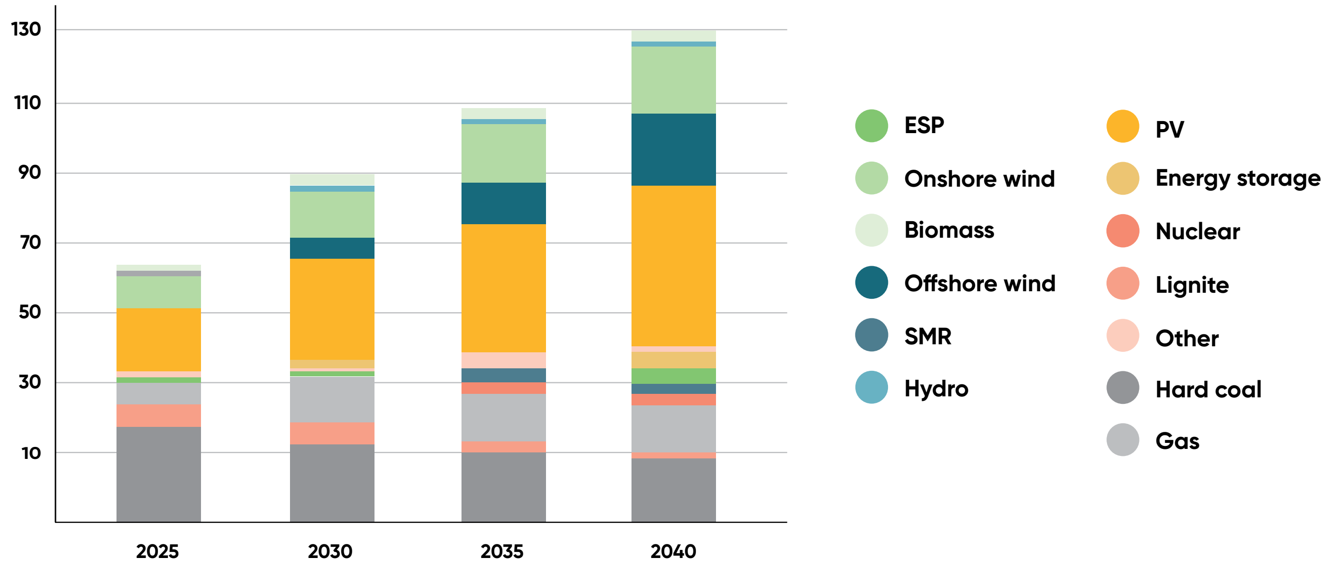

Figure 12: Planned Polish energy mix according to the Assumptions for the update of Poland's Energy Policy until 2040

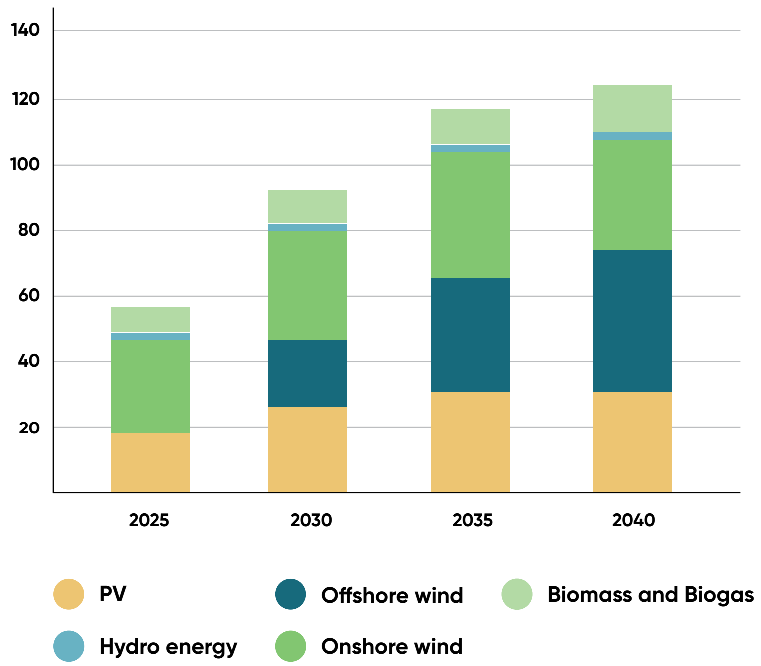

Figure 13: Planned renewable-electricity generation according to the Assumptions for the update of Poland's Energy Policy until 2040.[123]

4.7.3 Offshore-wind energy in Poland

No offshore-wind farm is yet operational in Poland. However, there are several projects in the pipeline and location permits for more have been granted. Several projects with a total capacity of approximately 8.4 GW are currently under construction and more are planned.

The European Commission estimates the potential of Poland's maritime zones to be approximately 12 GW. Under current regulations, offshore-wind farms in Poland can only be located in the exclusive economic zone, within some 2,340 km2 of areas that have been assigned the primary function of obtaining renewable energy.

123 Polish Ministry of Climate and the Environment.

According to a PWEA report, these areas have a potential of around 15 GW, while the technical potential of offshore-wind energy in all Polish maritime areas is 33 GW. The report calculates that offshore-wind energy can contribute as much as 57% of total electricity in Poland by 2040.[124]

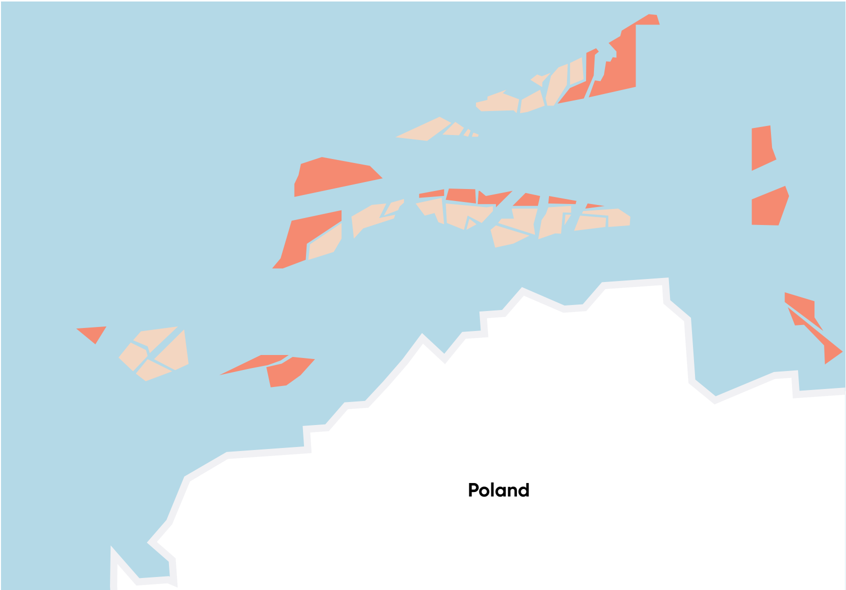

Figure 14: Potential areas for offshore wind-energy development in Poland (grey: areas designated in the Polish maritime spatial plan; blue and green: other areas considered in the PWEA report).

In Poland, projects are being implemented in two phases, defined based on the method of obtaining support. Phase I covers projects that have, in accordance with Polish law, been granted support through an administrative decision by the Director of the Energy Regulatory Office. There are seven such projects with a total capacity of 5.9 GW (see Table 6).

Nr	Investor	Project	Capacity [MW]
1	Polenergia/Equinor	Bałtyk II	720
2	Polenergia/Equinor	Bałtyk III	720
3	PGE / Ørsted	Baltica 2	1,498
4	PGE / Ørsted	Baltica 3	1,045
5	RWE Renewables Polska	FEW Baltic II	350
6	RWE Renewables Polska	Baltic Power	1,200
7	Ocean Winds	B&C Wind	400
Total			**5,900**

Table 6: Phase I projects in Poland.

124 Polish Wind Energy Association, 'New Potential of the Baltic Sea'.

In Phase II, projects will apply for support through auctions. Two projects are being developed under this procedure in Poland, but this is only the initial stage of implementation. The investors have obtained location decisions and connection conditions for them. The total capacity of these projects is expected to amount to approximately 2.5 GW (see Table 7).

Nr	Investor	Project	Capacity [MW]
1	Polenergia/Equinor	Bałtyk I	1,560
2	PGE	Bałtyk 1	896
Total			**2,456**

Table 7: Phase II projects in Poland.

The administrative procedure for the granting of a location permit has also been completed for a further 11 areas identified in the maritime spatial-development plan. For one of these, no winner was selected, while the remaining 10 were awarded to two companies: PGE and ORLEN.

4.7.4 Green hydrogen in Poland

Poland is the third-largest producer of grey hydrogen in Europe, but its green-hydrogen production is negligible. The country currently lacks any of the technology necessary for green-hydrogen production (in particular electrolysers), except for those installed for demonstration or research purposes.[125] Even so, Poland is planning to build on existing infrastructures to gain an edge in renewable hydrogen.

The most advanced commercial project is the 5 MW installation at the Konin power plant developed by ZE PAK, which will be powered by a biomass unit. It is expected to become operational in the second half of 2024. ZE PAK intends to use the green hydrogen produced to fuel a hydrogen-bus station in Konin.[126]

Orlen has unveiled an ambitious plan to spearhead green and zero-emission hydrogen production. The company aims to construct electrolysers with a capacity of at least 1 GW by 2030, alongside ventures into waste-to-hydrogen projects, targeting an annual production of 130,000 tonnes of hydrogen. These facilities will be geared towards generating both renewable and low-carbon hydrogen, and will require the implementation of carbon capture and utilisation facilities. Orlen's overarching goal is to achieve a CO2 absorption capacity of three million tonnes by the year 2030.[127]

Polenergia is advancing the H2Silesia Project, which involves the establishment of a large-scale facility for green hydrogen production with a capacity of roughly 105 MW. It is expected to enable an annual output of approximately 13,000 tonnes of hydrogen. Situated in Upper Silesia, the project is geared towards supplying renewable hydrogen to heavy industry and enabling emissions-free transportation.[128]

The demand for green and blue hydrogen in Poland is projected to surge from its current level of zero to approximately 450,000-510,000 tonnes by the year 2030.[129] According to some estimates, Poland could ultimately have an electrolysis capacity of more than 20 GW by that year.[130]

125 Tomaszewski, 'Hydrogen Alliance - How Poland and the Netherlands Can Strengthen Cooperation in Green Hydrogen Development'.

126 ZEPAK, 'Produkcja Wodoru w ZE PAK SA.'

127 Czyżewski et al., 'Transformacja energetyczna'.

128 Polenergia, 'Fabryka zielonego wodoru na Górnym Śląsku z dofinansowaniem do 142,77 mln euro. To projekt H2Silesia, rozwijany przez Polenergię'.

129 Tomaszewski, 'Hydrogen Alliance - How Poland and the Netherlands Can Strengthen Cooperation in Green Hydrogen Development'.

130 Czyżak, Sikorski, and Wrona, 'Co po węglu? Potencjał OZE w Polsce'.

4.8 Germany

4.8.1 Today's electricity market in Germany

Current data on the German energy market reveals a decline of 5.3% in electricity consumption from 482.6 TWh in 2022 to 456.8 TWh in 2023, as reported by the German Bundesnetzagentur.[131] These numbers follow the trend of the energy transition in Germany, where electricity consumption has been steadily decreasing since 1990.[132] In 2023, Germany imported a total of 54.1 TWh of electricity, 63% more than in 2022, and exported 42.4 TWh, 24% less than in 2022.[133]

Primary Energy Type	Consumption 2022	Consumption 2023
Mineral Oil	1140	1078
Natural Gas	767	734
Renewable Energies	575	588
Hard Coal	313	260
Lignite	324	253
Other	29	62
Nuclear Energy	105	22

Table 8: Consumption of primary energy in TWh in Germany in 2023.[134]

Most significantly, 55% of Germany's electricity demand in 2023 was covered by renewable sources. This phenomenon can be ascribed to the considerable expansion of onshore wind-energy sources, as well as to a reduction in electricity demand.[135] Onshorewind turbines supplied 118.7 TWh of electricity, a record in terms of annual feed-in. Offshore-wind power declined by 4.9% over the previous year, partly due to lack of power links between wind farms and mainland Germany. Hydropower experienced a remarkable increase, surpassing the previous years' output by 16.5%. Biomass production decreased by 3.1%.

The consumption of primary energy from renewable sources grew to almost 18% of the total from 17.5% in 2022[136] The share of mineral oil decreased by 5% to 33%. The consumption of natural gas also dropped to 22% in 2023 from 23% in 2022, while hard coal decreased from 8% to 9.5% and lignite from 10% to 8%. Nuclear power accounted for 1%, with the last plants in Germany shut down on 15 April 2023.

131 Bundesnetzagentur, 'Presse - Bundesnetzagentur veröffentlicht Daten zum Strommarkt 2023'.

132 Agora Energiewende, 'Die Energiewende in Deutschland: Stand der Dinge 2023. Rückblick auf die Wesentlichen Entwicklungen sowie Ausblick auf 2024.'

133 Bundesnetzagentur, 'Presse - Bundesnetzagentur veröffentlicht Daten zum Strommarkt 2023'.

134 Agora Energiewende, 'Die Energiewende in Deutschland: Stand der Dinge 2023. Rückblick auf die Wesentlichen Entwicklungen sowie Ausblick auf 2024.'

135 Bundesnetzagentur, 'SMARD | Der Strommarkt im Jahr 2023'.

136 Agora Energiewende, 'Die Energiewende in Deutschland: Stand der Dinge 2023. Rückblick auf die Wesentlichen Entwicklungen sowie Ausblick auf 2024.'

4.8.2 Energy-transition goal

Updates to the Federal Climate Change Act made the government's climate-action targets more ambitious. Germany now aims to achieve climate neutrality by 2045 and to reduce greenhouse-gas emissions by 65% over their 1990 levels by 2030.[137]

4.8.3 Offshore-wind energy in Germany

At the end of 2023, there were 1,566 offshore-wind turbines in operation in Germany, with a total capacity of 8.5 GW.[138] Twenty-seven of these wind turbines, with a capacity of 257 MW, were connected to the energy grid in 2023 for the first time. Furthermore, 222 wind turbines were modified during 2023, and 74 new foundations were built in German waters.

Germany's goals for expanding offshore-wind energy are outlined in the Wind Energy Act (Wind-SeeG) and call for 30 GW of capacity installed and connected to the power grid in 2030, 40 GW by 2035 and 70 GW by 2045 (see Figure 15).[139] Under current plans by the Maritime and Hydrographic Agency (Bundesamt für Seeschifffahrt und Hydrographie), Germany may surpass the 40 GW and achieve 50 GW in 2035.[140]

By the end of 2023, Germany had 7.1 GW of capacity installed and in operation in the North Sea, and 1.4 GW in the Baltic. Most new turbines installed in 2023 were in the Baltic Sea, but Deutsche Windguard expects future growth to continue to be concentrated in the North Sea. [141]

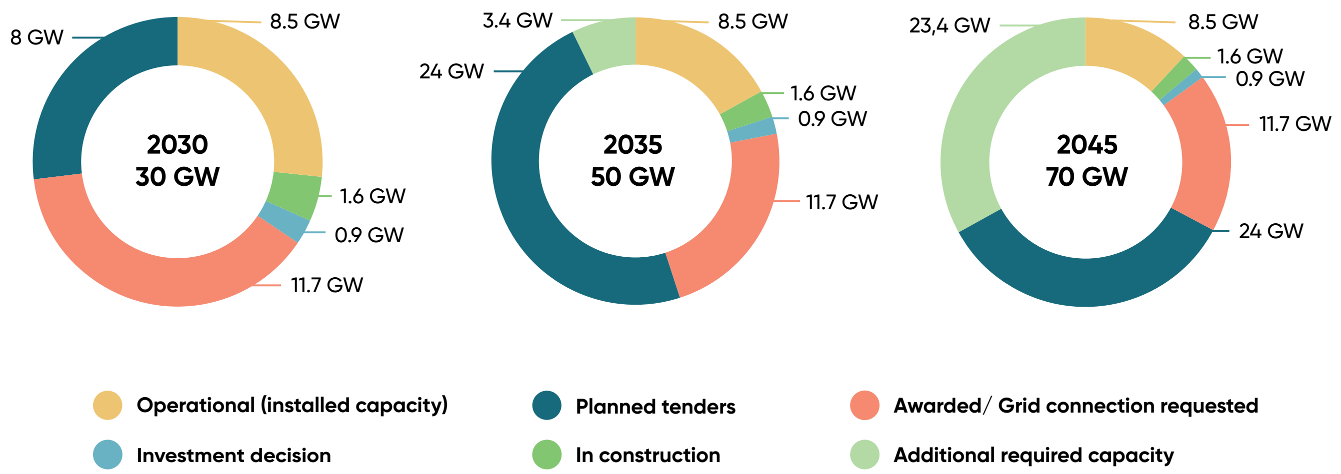

Figure 15: Expansion of offshore power in Germany in 2030, 2035 and 2045. [142]

4.8.4 Green hydrogen in Germany

Targets for the expansion of hydrogen production and deployment in Germany are defined in the European, German and North German Hydrogen Strategies, and are set to significantly increase the demand for renewable energy. The National Hydrogen Strategy (NHS) and its updates in particular promises investment contracts worth billions of euros before 2030, intended to come from the German federal government as well as the federal states.

The National Hydrogen Strategy was last updated in July 2023 by the Federal Ministry for Economic Affairs and Climate Action (BMWK). It calls for an increase of hydrogen-generation capacity from 5 GW to 10 GW before 2030.[143] An import strategy is also being elaborated. Moreover, two councils made up of secretaries of state and 26 independent scientistic experts, respectively, continuously work on innovations for the National Hydrogen Strategy, covering everything from hydrogen infrastructure and transport to the production of hydrogen throughout Germany.

137 German Federal Government, ‘Klimaschutzgesetz: Generationenvertrag für das Klima’.

138 Deutsche WindGuard, ‘Status des Offshore-Windenergieausbaus in Deutschland’.

139 Deutsche WindGuard.

140 Wasserstoff Wirtschaft SH, ‘Offshore BSH legt Flächenplan für 30 GW bis 2030 vor - WTSH Wasserstoff’.

141 Deutsche WindGuard, ‘Status des Offshore-Windenergieausbaus in Deutschland’

142 Deutsche WindGuard.

143 German Federal Ministry for Economic Affairs and Climate Action, ‘Fortschreibung der Nationalen Wasserstoffstra-tegie’.

On 15 February 2024, the European Commission approved 24 German projects within the Hy2Infra wave of the IPCEI Programme (for Projects of Common European Interest).[144] The government and relevant federal states have allocated around €4.6 billion in funding for these projects, with German companies planning to invest around €3.4 billion. Seventy per cent of the funds will be provided by the central government and 30% by the federal states. The projects, located in seven Member States (Germany, France, Italy, the Netherlands, Poland, Portugal and Slovakia) aim to construct a hydrogen grid comprising over 2,700 km of pipelines as well as production capacity of 3.2 GW and some 370 GWh of storage capacity.

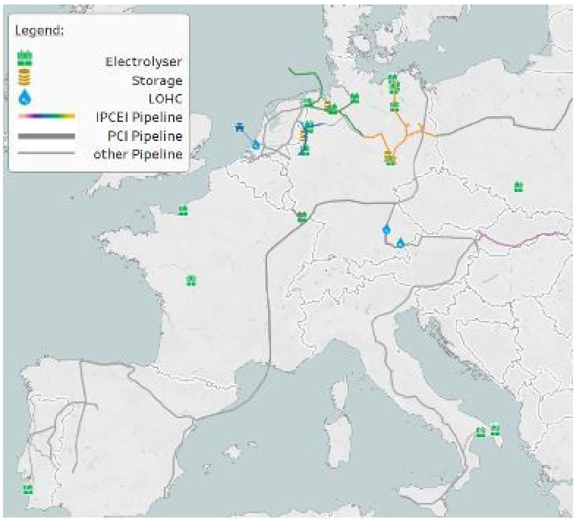

Figure 16: IPCEI Hy2Infra map of projects in seven member countries. [145]

There is currently one section of the draft German maritime spatial plan 2024 (SEN-1) – located in the North Sea – which is designated for "other renewable-energy projects". No hydrogen projects have been established in German waters to date, and it is not clear when a tender may be drafted for SEN-1 or any other area. Major energy businesses in Germany seem to already be competing and advertising initiatives and projects for SEN-1. One example is RWE's AquaVentus, which aims to operate electrolysers at sea with energy from offshore-wind farms. RWE is planning for a total capacity of 10 GW and annual production of one million tonnes of green hydrogen.[146]

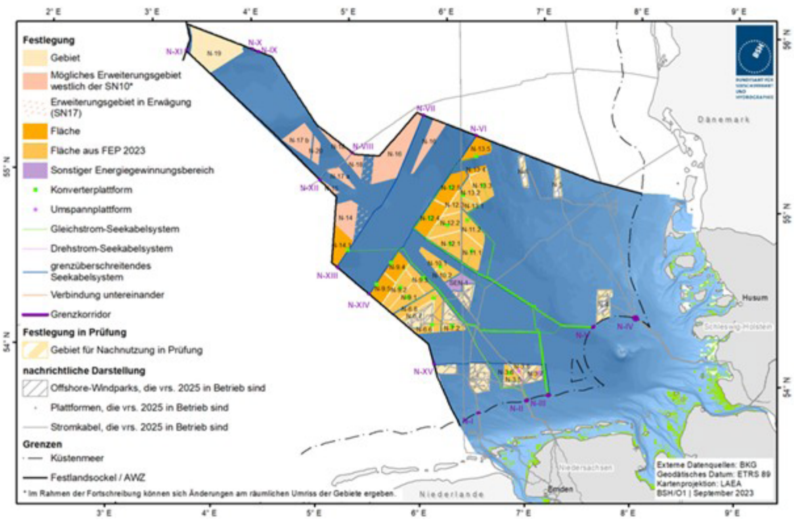

Figure 17: Draft of German maritime spatial plan with location of SEN-1 in the North Sea.[147]

144 German Federal Ministry of Education and Research, 'Update der Nationalen Wasserstoffstrategie: Turbo für die H2-Wirtschaft'.

145 IPCEI Hydrogen, 'Commission Approves up to €6.9 Billion of State Aid for "IPCEI Hy2Infra"'.

146 RWE, 'AquaVentus – Wasserstoffproduktion in der Nordsee'.

147 Bundesamt für Seeschifffahrt und Hydrographie, 'Vorentwurf Flächenentwicklungsplan'.

5. Vision for the Baltic Sea region

Most countries in the Baltic Sea Region explicitly plan to be climate-neutral by 2035 (Finland)[148], 2045 (Estonia,[149] Sweden[150] and Germany[151]) or 2050 (Denmark,[152] Latvia and Lithuania). Moreover, the EU has an overall target of climate neutrality by 2050. The need for such ambitious targets is underlined by the accelerating climate emergency.

A range of strategies exist on the national and EU levels that are meant to enable and foster the necessary transformations. However, national strategies often don't make the most of cross-border opportunities and initiatives, while overarching EU strategies (having a continental scope and being designed for ultimate implementation by the member states) can lack precision and detail. Moreover, there can be a lack of explicit support for useful links and synergies between large-scale strategies such as offshore-wind power expansion and the rollout of green-hydrogen infrastructure.

Innovative green technologies like offshore-wind energy and power-to-hydrogen can best be optimised on a regional level.

This is the best way to ensure that:

- best practices and lessons learnt are widely shared,
- supply chains can match the planned project pipeline,
- power production can meet demand (both within member states and across borders, and
- sufficient green electricity is planned for power-to-hydrogen projects.

An efficient energy transition to green alternatives, especially with complex high-capacity sources like offshore wind, requires regional coordination. but no regional or transnational platform exists yet to unite stakeholders in this vision. BOWE2H aims to make a modest contribution to bridging these gaps by providing a concrete and consistent vision which covers the entire Baltic Sea Region while bringing together offshore-wind power and green-hydrogen production.

This section briefly discusses the promise of offshore wind and green hydrogen in the Baltic Sea Region separately, and then formulates a realistic and concrete transnational vision that brings the two together in a way that symbiotically boosts them both across the entire region.

5.1 Offshore wind-energy potential

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.[153]

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.

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.[154]

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.[155]

148 Finnish Ministry of the Environment, 'Finland's National Climate Change Policy'.

149 Klementi, 'Estonia Setting Increasingly Ambitious Climate Targets'.

150 Swedish Environmental Protection Agency, 'Sveriges klimatmål och klimatpolitiska ramverk'.

151 German Federal Government, 'Klimaschutzgesetz: Generationenvertrag für das Klima'.

152 Danish Energy Agency, 'Dansk klimapolitik'.

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

154 European Commission.

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

5.1.1 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.[156]

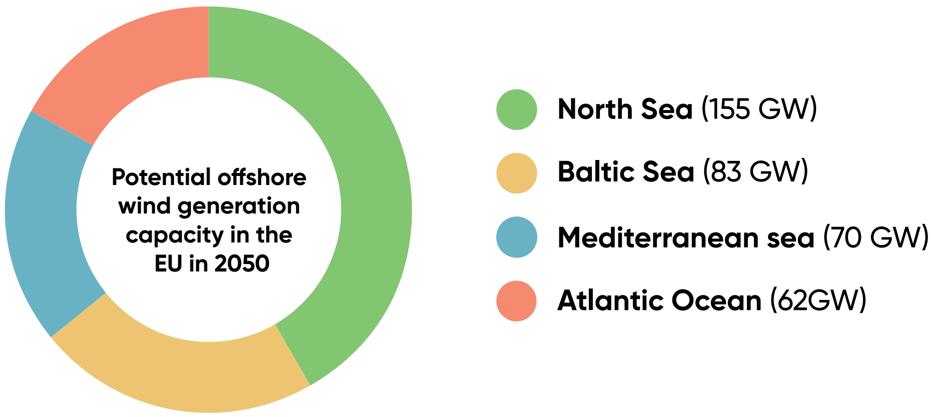

Figure 18: Possible distribution of the 370 GW offshore wind power generation capacity in the EU and candidate states in 2050.

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.[157]

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.[158]

The technology required to make ample use of the Baltic Sea's potential in offshore wind is quickly maturing. Aurora, located in between the Swedish islands Öland and Gotland, is planned to be the largest offshore-wind farm in the Baltic Sea with 5.5 GW of power capacity. Owned by developers OX2 and Ignka Investmet, the wind farm is currently under development and set to be commissioned in 2030.[159] This project alone would double the current offshore wind levels in the Baltic Sea Region and thus contribute greatly to the targets set by the BEMIP member states.

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

157 Freeman et al.

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

159 OX2, 'Aurora'.

5.1.2 Transnational offshore-wind energy plans

There is already some offshore wind power-generation and transmission infrastructure that is planned, owned or operated by more than one country in the Baltic Sea. 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.[160]

The Baltic Energy Market Interconnection Plan (BEMIP), which aims to achieve an open and integrated regional electricity and gas market between EU countries in the Baltic Sea Region, has identified four "advanced offshore hubs" which are especially worthy of development. They consist of Kriegers Flak, the ELWIND offshore-wind farm between Estonia and Latvia and the Bornholm Energy Island, each of which is either complete or in advanced planning stages, as well as the island of Åland between Sweden and Finland.[161]

These projects are explored below, along with other relevant plans and concepts that are being built or under serious consideration

Figure 19: The four BEMIP advanced offshore hubs.

5.1.3 Kriegers Flak

Kriegers Flak is a reef located in the western Baltic Sea north of Rügen, south of Scania and east of Møn, roughly equidistant from Denmark, Sweden and Germany. The area spans the exclusive economic zones (EEZs) of all three countries, and there are existing or planned wind farms in each of them.

The EnBW Baltic 2 wind farm in the German EEZ covers 27 km2 and consists of 80 Siemens SWT-3.6-120 wind turbines. It entered operation on 21 September 2015 and has a capacity of 288 MW, providing 1.2 TWh of power annually – enough to power 340,000 households.[162] The offshore-wind farm in Danish waters, called simply Kriegers Flak, is the largest wind farm in Scandinavia and alone increased Danish wind power production by 16% when it was commissioned in 2021. It consists of 72 offshore-wind turbines and a capacity of 604 MW, equivalent to the annual consumption of some 600,000 households.[163]

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

161 European Commission, Study on Baltic Offshore Wind Energy Cooperation under BEMIP: Final Report.

162 EnBW, 'Ostsee Windpark EnBW Baltic 2'.

163 Vattenfall, 'Skandinaviens största havsbaserade vindkraftspark invigd'.

5.1.4 Kriegers Flak Combined Grid Solution

The Danish and German wind farms are connected via the Kriegers Flak Combined Grid Solution (KF CGS), a hybrid power transmission system that combines the functions of international interconnector (i.e., electricity link between two countries) and of export cables (i.e., power links connecting offshore-wind farms to onshore grids). Completed by the Danish and German transmission system operators Energinet and 50Hertz in late 2021, the KF CGS links the Danish region of Sjælland with Mecklenburg-Vorpommern via the two offshore-wind farms on Kriegers Flak as well as the German Baltic 1 wind farm further south. It makes available an additional 400 MW of transfer capacity in each direction for electricity transport between the electricity bidding zones Denmark East and Germany.[164]

KF CGS is the first (and, so far, only) hybrid power transmission system in the world. This makes it a fascinating case and experimental subject for future such solutions planned in the Baltic Sea and beyond. For one thing, interconnectors and export cables fall under different legal frame-works – the primary purpose of interconnectors is to trade power between the grids of different electricity bidding zones, a process which is strongly regulated by the EU, while export cables simply transfer power from where it is produced to the grid where it can be distributed.

In theory, the two activities can be in conflict if the combined amount of the electricity produced by the offshore farms and the electricity being traded between the two bidding zones exceed the capacity of the cable. In recognition of this fact, KF CGS has received a temporary exemption by the European Commission from some of the regulations affecting interconnectors and as such can function primarily as a series of export cables.[165]

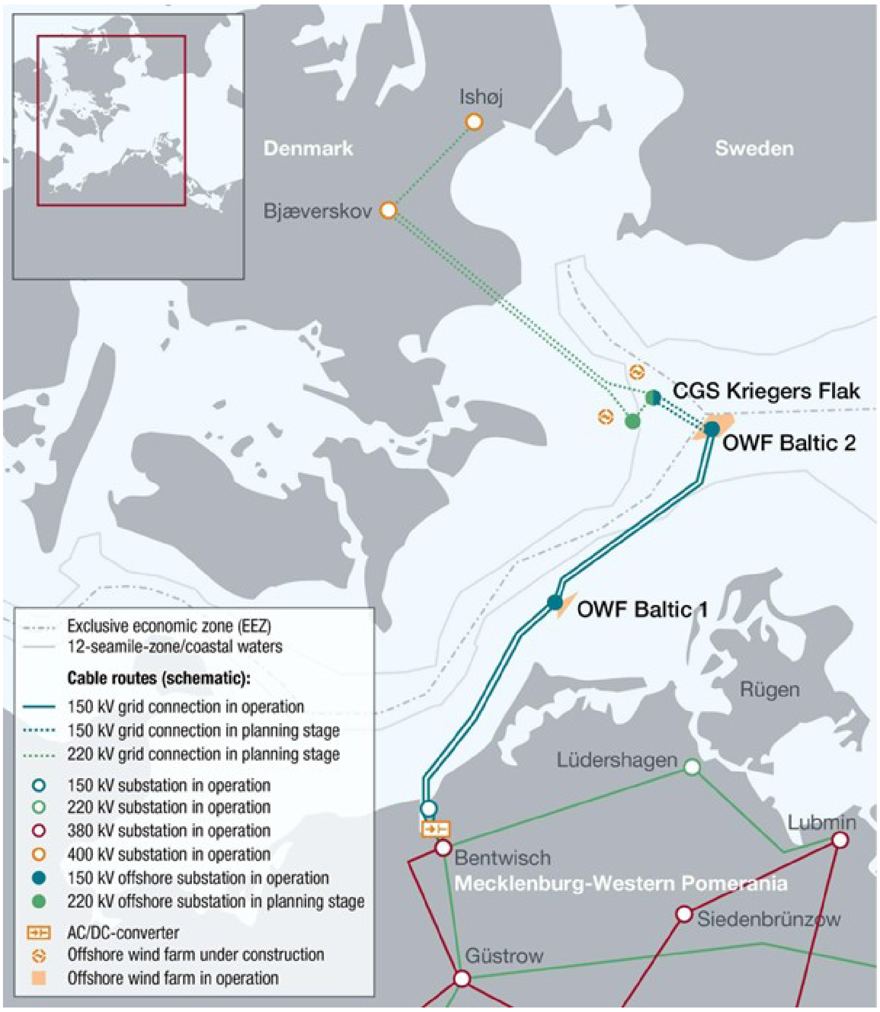

Figure 20: Kriegers Flak Combined Grid Solution offshore-wind farms and cables.[166]

A 640 MW wind farm in the Swedish part of the reef has been planned for a long time and received final approval by the Swedish government in May 2022. The owner Vattenfall has not yet (June 2024) taken an investment decision. The wind farm

164 50Hertz, 'Combined Grid Solution - Kriegers Flak (CGS)'.

165 Durakovic, 'Kriegers Flak CGS Exempt From 70 Per Cent Rule'.

166 50Hertz, 'Combined Grid Solution - Kriegers Flak (CGS)'.

is expected to comprise 35-50 wind turbines and be operational around 2028, when it will produce around 2.7 TWh per year, or enough to supply 500,000 homes or charge a million electric cars.[167]

The different experiences of the German, Danish and Swedish projects demonstrate the wide variety of national conditions and regulations that affect offshore wind development around the Baltic Sea. The possibility to explore the construction of an offshore-wind farm in the Swedish part of Kriegers Flag started in 2002. The Swedish government originally approved a plan to build 128 wind turbines in 2006, but the permits for the grid connection were appealed and the market conditions were ultimately found to be insufficient, leading to the permit to lapse before it could be used.[168]
The process was restarted some years later, with a licence for an onshore grid connection granted in 2016, and a new application for a permit for around 35-50 much larger wind turbines submitted in 2018. Parts of the zone were classified as protected Natura 2000 areas, requiring extensive environmental studies of reefs, birds, fish and porpoises, which were finalised in March 2021. In February 2023, the project received authorisation from the government to lay cables along the seabed to connect the farm to the national grid.[169]

The detailed design still needs to be completed, and a number of permits, mainly onshore, must be acquired. Assuming that the project is found to be profitable by the developer, an investment decision should be made in 2025 and the offshore-wind farm may be commissioned in 2028.[170] There are no plans to link it to the Kriegers Flak Combined Grid Solution or create a comparable interconnector through it (although there is already a small interconnector linking the island to the Swedish mainland).

5.1.5 Energy Island Bornholm

Among many ambitious goals and targets, the Danish Climate Agreement – signed by the country's main parties in June 2020 – foresees the creation of two so-called energy islands in the Baltic and North Sea. The Baltic Sea complex will be centred on the existing island of Bornholm, which is strategically located in the southwestern Baltic Sea with the German, Swedish and Polish coasts in close proximity. Originally slated to host 2 GW of offshore wind capacity, the project was expanded to 3 GW by the Danish government in the summer of 2022.[171] Each of the two energy islands will substantially exceed Denmark's entire current offshore wind power generation capacity of 2.3 GW. Plans for potential expansion further down the line could mean that the islands alone multiply Denmark's offshore wind capacity by a factor of seven.[172]

Denmark's transmission system operator (TSO) Energinet is building the technical facilities and cables which will transfer electricity from Bornholm to the Danish and German mainland. Energinet will commission the 209 km cable to Denmark and is working together with the German TSO 50Hertz to prepare the 130 km hybrid connection (combined interconnector and export cable) to Germany. Energinet's business case shows that, while establishing just 2 GW of capacity and linking Bornholm to Denmark alone would have been profitable, expanding the capacity to 3 GW and creating a hybrid connection to Germany provides some DKK 20 billion (€2.7 billion) more in benefits. For one thing, Energinet's investment costs will be reduced from DKK 17 billion to 14 billion, the difference being taken over by 50Hertz. The wind farm complex is expected to be commissioned by the end of 2030,[173] and tenders for the wind farms opened by mid 2024.

Bornholm is a fascinating test case in more ways than one, as the partnership between Denmark and Germany will not be limited to energy trade. It will also be reflected in cooperation on science and research, with a number of partners joining forces to form a dedicated foundation for this purpose and turning Bornholm into an international innovation centre for green technologies and energy islands. Moreover, both partners have stated that they wish other Baltic Sea countries to potentially join the project.[174]

Following the revised EU renewable energy directive (RED), the German and Danish governments were the first to sign a legally binding cooperation agreement for a transnational offshore project in September 2023.[175] Thereby, the outcomes of the Energy Island Bornholm can be attributed equally to both countries in fulfilling their respective contributions to the EU target of 300 GW of offshore energy across the EU's sea-basins by 2050 specified in the RED.[176]

167 Vattenfall, 'Vindkraftsprojekt Kriegers flak'.

168 Vattenfall.

169 Vattenfall.

170 Vattenfall.

171 Energinet, 'Bornholm Energy Island Is Blazing the Trail for Offshore Expansion in the Baltic Sea'.

172 Danish Ministry of Climate, Energy and Utilities, 'Danmark bliver en ø rigere: Verdens første energiø etableres 80 km ude i Nordsøen'.

173 Energinet, 'Energiø Bornholm'.

174 en:former, 'Energieinsel Bornholm'.

175 German Federal Ministry for Economic Affairs and Climate Action, 'Bundesminister Habeck unterzeichnet deutsch-dänisches Offshore-Projekt „Bornholm Energy Island" mit seinem dänischen Amtskollegen'.

176 Dumortier, Regulation (EU) No 910/2014 on Electronic Identification and Trust Services for Electronic Transactions in the Internal

5.1.6 ELWIND

The joint Estonian-Latvian ELWIND project is a partnership between the Environmental Investment Centre from Estonia and the Investment and Development Agency of Latvia. By 2030, the project is meant to comprise two offshore-wind parks, one in Estonian and one in Latvian waters.[177] Construction will be carried out by private companies chosen through a competitive bidding process, with the costs and benefits of the cross-border project split evenly between the two countries. The project will create a hybrid grid connection with interconnector and transmission lines which connect the power systems of both countries.[178]

ELWIND is planned west of the Sõrve peninsula at the southwest extremity of the Estonian island of Saaremaa, which has highly advantageous wind and ice conditions. The project foresees a total installed offshore wind capacity of 700-1000 MW, with Estonia and Latvia expected to install up to 500 MW each. ELWIND may ultimately produce enough electricity to save on the use of fossil fuels that would otherwise cause emissions of three million tonnes of carbon dioxide equivalents per year. This corresponds to the total emissions of the entire transport sector in Estonia and Latvia each year.[179]

The implementation of the cross-border offshore project was initiated in 2020. A preliminary feasibility study selected the site location in 2022, and the developers issued a successful application to the Connecting Europe Facility (CEF) programme in 2023. The CEF promotes projects which contribute to renewable energy goals under the European Green Deal and the European Union´s RE-PowerEU strategy. Once the building permit is issued, detailed theoretical and geotechnical studies of offshore-wind farms in both countries will be carried out.[180]

Expected to exceed 30 million euros, these studies have proven to be quite costly – but over half of the cost will be covered by the CEF.[181] All of the necessary studies are expected to be completed and construction permits issued by 2026, clearing the way to holding an auction. The wind farms and interconnectors should be commissioned by 2030.[182]

Examples of the benefits of this hybrid project include lower electricity prices in what is a deficit bidding zone. Moreover, ELWIND will significantly contribute towards the Estonian and Latvian National Energy and Climate Plans and may stimulate the development of further regional projects. It can also come to represent an important element in future wind energy partnerships and cooperation between Sweden, Estonia and Latvia. [183]

There are some doubts about the grid connections for ELWIND on both sides of the border, notably in terms of future offshore wind-farm plans. It is not entirely clear that the grid expansion plans are proceeding in a timely manner. Ensuring a level playing field will be important to reduce the impact of grid tariffs, especially given the high costs of the grid rollout.[184]

Market (EIDAS Regulation).

177 CEEEnergy News, 'AST and Elering to Survey Potential Routes for Connecting the Offshore Network to the Onshore Power Grid'.

178 Buljan, 'Elering Unveils Major Baltic Sea Offshore Grid Connection Plans'.

179 Environmental Investment Centre; Investment and Development Agency of Latvia, 'Bring Baltic's Wind Together'.

180 CEEEnergy News, 'Latvia and Estonia to Apply for EU Funding for the ELWIND Offshore Wind Farm'.

181 European Climate, Infrastructure and Environment Executive Agency, 'CEF Energy'.

182 CEEEnergy News, 'Latvia and Estonia to Apply for EU Funding for the ELWIND Offshore Wind Farm'.

183 Bite, 'GIPL & ELWIND PROJECT: Discussion on Coordinated Onshore and Offshore Infrastructure Planning'.

184 Rapacka, 'Konkurentsiamet: Elering Must Ensure a Level Playing Field for Offshore Wind Farm Developers'.

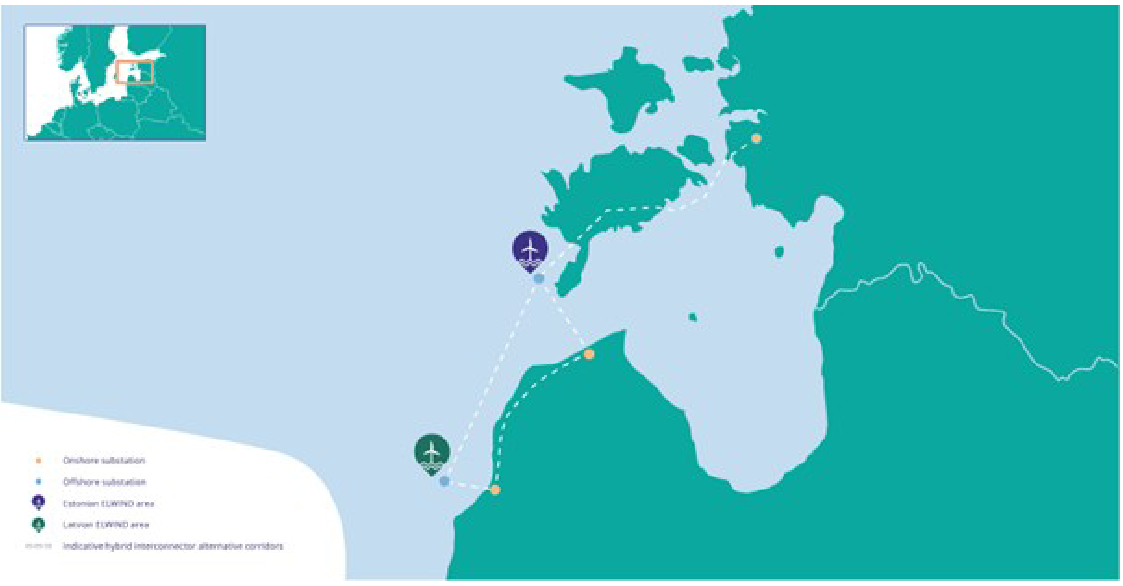

Figure 22: ELWIND project.[185]

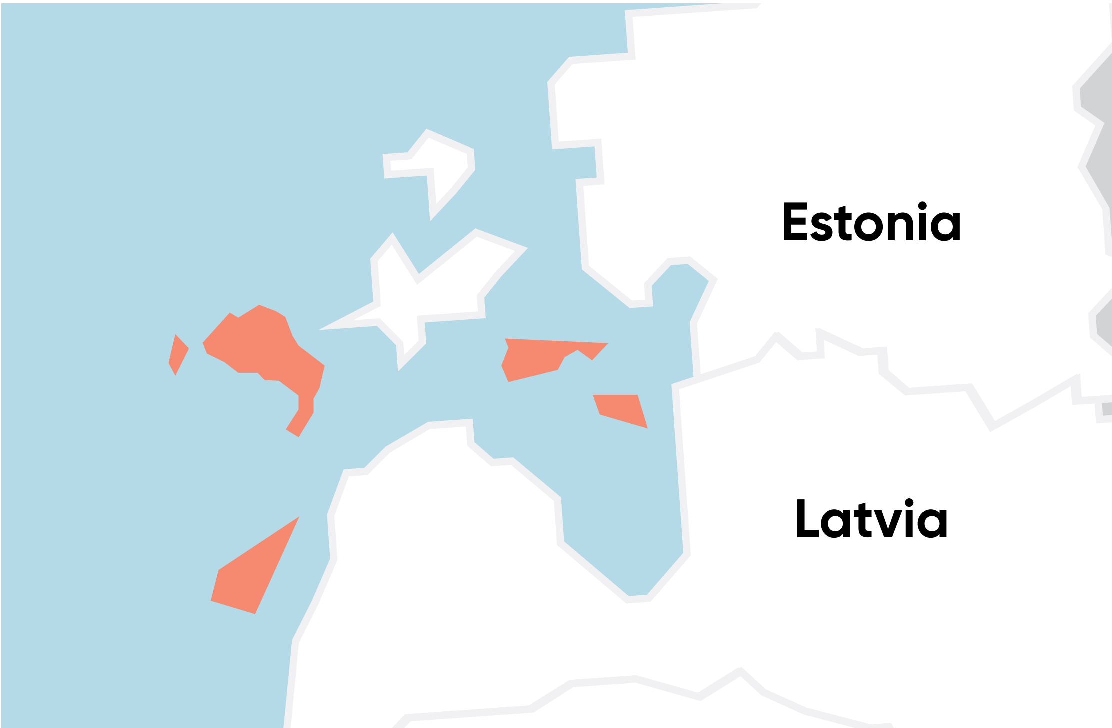

Figure 23: Overview of the ELWIND project sites.

185 ELWIND, 'Bringing the Baltic's Wind Together'.

Figure 24: Scenarios for offshore wind development in the Baltic Sea region.

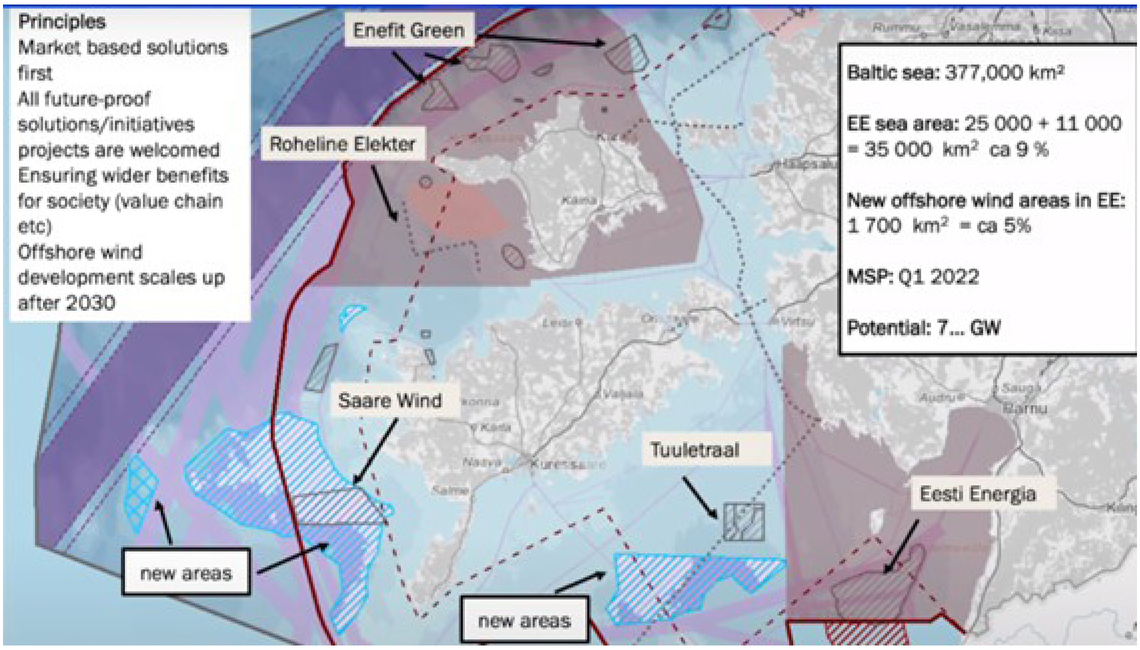

Figure 25: Overview of planned offshore-wind park sites in the maritime spatial plans of Latvia and Estonia and possible supply corridors.[186]

186 Baltic Wind, 'Estonian-Latvian Offshore Wind Farm Joint Project Location Revealed'.

5.1.7 Åland

The islands of Åland, located at the centre of the Baltic Sea, constitute a self-governing autonomous region of Finland. Åland has also been a demilitarised zone since 1856. The Åland parliament possesses the right to pass legislation on topics such as the environment as well as the promotion of industry.[187] The archipelago has taken a pioneering role in onshore wind energy with 20% of the region's electricity being generated by locally produced onshore wind power in 2015.[188] Wind conditions around Åland are well suited for large-scale wind energy production both on and offshore; the potential is calculated to be some 500 turbines at sea and up to 31 GWh offshore wind energy per year.[189]

In November 2021, a joint venture between the Swedish renewables developer OX2 and investor Alandsbanken Fondbolag was founded to develop two offshore wind projects around Åland, Noatun Syd and Noatun Nord. The former is intended to consist of 250 wind turbines with a total capacity of 3 GW which will generate 20 TWh of electricity per year, enough to supply the annual electricity consumption of four million households.[190] Noatun Nord was announced as an extension of the initial project, included in May 2022, with an expected total capacity of 5 GW. The project is planned to encompass 360 wind turbines and generate an additional 20 TWh electricity per year.[191]

While both Noatun projects are still in the announcement phase, the Government of Åland issued a permit in September 2022 to carry out site investigations for environmental impact assessment work for the projects.[192] Fully realised, the Noatun projects have a potential of being the largest offshore-wind farm worldwide covering the energy supply of 8 million households (19,5 TWh electricity/year).

In February 2023, the same joint ventures, OX2 and the Bank of Åland's fund management subsidiary Ålandsbanken Fondbolag, initiated a feasibility study for the project of a Mega Green Port located by the port of Långnäs in Åland. This port is aimed to be the region's leading green hub for realisation of both Noatun projects. The twelve-month study will give insights into the role the port of Långnäs could play in the construction and electrical connections of wind power projects as well as the production and transportation of hydrogen e-fuel.[193]

5.2 Green-hydrogen potential

The Baltic Sea Region countries all recognise the importance of hydrogen as an energy carrier of the future, and all have plans and strategies to promote and harness it. In most cases, this will require massive increases in electricity consumption, which is expected to double, triple or quadruple in most countries largely due to the production of hydrogen and its derivatives.

The national strategies specify various degrees of detail in terms of legal frameworks (including certification programmes), financial support, partial targets and strategies, and the deployment of hydrogen in different sectors like industry and transport. Hydrogen clusters and other initiatives to guarantee vital supply chains and trained labour also often feature. In many cases, some degree of hydrogen blending with natural gas or repurposing of gas pipelines is envisaged.

Denmark's power-to-X strategy proposes 4-6 GW of electrolyser capacity in 2030 corresponding to yearly electricity consumption of 130 TWh and leading to a carbon-dioxide reduction of 2.5-4.0 million tonnes.[194] In Sweden, which has a relatively large process industry and existing use of (grey) hydrogen of some 6 TWh per year in 2022,[195] the proposed national strategy for hydrogen, e-fuels and ammonia specifies a target for annual green-hydrogen production of 22-42 TWh by 2030, and 44-84 TWh by 2045, with a corresponding electrolyser capacity of 5 GW and 15 GW.[196] Up to 120 TWh of electricity would be used every year by 2050 for hydrogen production, resulting in 2-3 million tonnes of hydrogen and reducing carbon-dioxide emissions by 7-15 million tonnes.[197]

Finland aims to produce 10% of the EU's green hydrogen by 2030, positioning itself as a key player in the emerging hydrogen economy. Around 35-50 TWh of clean hydrogen should be

187 Finnish Foreign Ministry, 'The Special Status of the Åland Islands'.
188 Landmesser, 'Das Ökostrom-Archipel'.
189 Pyrhönen et al., 'Carbon Negative Åland: Strategic Roadmap'.
190 Durakovic, 'Nordic Partners Team Up on 250-Turbine Offshore Wind Farm Project'.
191 Power Technology, 'Power Plant Profile'.
192 Memija, 'Underwater Life Surveys Completed for Two Multi-Gigawatt Baltic Sea Offshore Wind Projects'.
193 Ålandsbanken, 'OX2 and the Bank of Åland Plan a Mega Green Port Project in Åland'.
194 Danish Ministry of Climate, Energy and Utilities, 'The Government's Strategy for Power-to-X'.
195 Vätgas Sverige, 'Hydrogen in the Industry'.
196 Swedish Energy Agency, 'Sveriges nationella strategi för vätgas, elektrobränslen och ammoniak'.
197 Thema Consulting Group, 'Offshore Wind Development Key to Meet Sweden's Climate and Growth Targets'.

generated by 2030 (requiring 10-15 GW of electrolyser capacity and consuming 50-70 TWh of power), increasing to 80-135 TWh (25-40 GW capacity, 110-190 TWh of power) by 2040. Much of the produced hydrogen is expected to be exported to industrial centres in northern Sweden and Central Europe.[198] As elsewhere in the Baltic Sea Region, most of the green electricity required for the production of hydrogen for export would come from onshore and offshore-wind power.[199]

Lithuania aims to have at least 1.3 GW of electrolysis capacity and production of 120,000 tonnes of green hydrogen by 2030, which is projected to consume 6.5 TWh of power and reduce annual carbon-dioxide emissions by one million tonnes. This is expected to rise to 732,000 tonnes of hydrogen, 36.4 TWh of electricity and six million tonnes of carbon dioxide in 2050.[200]

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 too. The Polish Hydrogen Strategy for 2030 calls for 50 MW of installed capacity for low-emissions hydrogen by 2025 and 2 GW by 2030. In Germany, annual demand for hydrogen in 2022 was 55 TWh. This is expected to rise to 90-110 TWh in 2030, with the National Hydrogen Strategy calling for 10 GW of electrolyser capacity and 14 TWh of national production by then. Germany expects its annual hydrogen demand by 2050 to be 170-450 TWh.[201]

A 2024 study by DNV on the export of green hydrogen is less optimistic than many of the national hydrogen strategies with regard to the green electricity that will be available to power electrolysers for export. It expects that the eight countries in the Baltic Sea Region can collectively hope to have 16 TWh of renewable electricity surplus in 2030, 90 TW in 2040 and 119 TWh in 2050. Finland is expected to be by far the largest contributor, accounting for well over half the surplus electricity, Sweden a distant second, and the Baltic states and Poland providing small contributions. Germany is expected to remain an importer.[202]

5.3 Comprehensive vision and cross-border benefits

There are clear and substantial benefits to fostering offshore wind-energy generation and hydrogen deployment in tandem, and in a coordinated transnational manner. Setting out the vision for how that might best look and which courses of action could be followed to fulfil that vision is the main thrust of the BOWE2H project.

5.3.1 Setting the stage

Optimal joint expansion of offshore-wind power and hydrogen deployment must take into account three dimensions; going from highest to lowest level of abstraction, they are geopolitics, demography and physics.

5.3.1.1 Geopolitical considerations

The first dimension – and most fundamental motivation – largely revolves around military and energy security, and in a transferred sense the capacity of Baltic Sea Region states to continue to determine their own economic and political fate. The Baltic Sea has the potential to produce and perhaps export huge quantities of energy in the form of electricity or hydrogen and its derivatives, or embedded in manufactured products such as steel. To unlock this potential would mean more value added and more clean manufacturing being produced in the Baltic Sea Region, and less energy and fewer carbon-intensive products being imported. In addition to slowing down climate change and boosting the wealth of the region, this would lower its exposure to the whims of unreliable or aggressive regimes, and reduce financial transfers to such regimes, diminishing their influence over the Baltic Sea Region and the wider world.

198 Finnish Ministry of Economic Affairs and Employment, 'Government Adopts Resolution on Hydrogen – Finland Could Produce 10% of EU's Green Hydrogen in 2030'.

199 Fingrid and Gasgrid, 'Energy Transmission Infrastructures as Enablers of Hydrogen Economy and Clean Energy System - Scenarios'.

200 Parliament of Lithuania, 'Dėl Vandenilio Sektoriaus Plėtros Lietuvoje 2023–2030 Metais Gairių Patvirtinimo'.

201 Borrmann, Kruse, and Wallasch, 'Erzeugung von Wasserstoff durch Windenergie auf See'; Wang et al., 'Analysing Future Demand, Supply, and Transport of Hydrogen'.

202 Hülsen et al., 'Potential for a Baltic Hydrogen Offshore Backbone'.

5.3.1.2 Demography and economy

The second dimension, which broadly orients the concrete actions that need to be taken to make the most of available opportunities, concerns the distribution of population centres and hubs of economic activity (between which there is a great deal of overlap). Table 9 shows population and total GDP by market prices among the eight Baltic Sea Region states.

Country	Population (million)	GDP (billion €)
Germany	83.24	3,876.81
Poland	37.65	656.15
Sweden	10.55	561.79
Denmark	5.87	380.62
Finland	5.55	267.69
Lithuania	2.81	67.47
Latvia	1.88	38.39
Estonia	1.33	36.01

Table 9: Baltic Sea Region population and GDP.[203]

More specifically, if we look at offshore wind-energy potential in the Baltic Sea for each country and compare it to current consumption (in 2022), we can see how much the Baltic Sea Region countries can potentially export (see Table 10). The comparison is, of course, largely speculative, as it contrasts future energy potential with presentday consumption. Future consumption is expected to rise due to the emergence of new industries such as data centres, green heavy industry, and conversion inefficiencies as sectors transition to green hydrogen, among other factors. The exact extent of this increase will vary between countries and is difficult to forecast, though it will likely be constrained by efficiency improvements and stagnating or declining population growth. Electricity demand is expected to rise substantially in the coming decades, which is why it was not used as the primary variable in this comparison.

Even so, this clearly shows that optimising the buildout of offshore-wind power and hydrogen infrastructure across the Baltic Sea Region will entail very different policies in each of the individual countries. Certain nations are clearly destined to be either exporters or importers of offshore-wind power. For example, while Latvia possesses enough potential offshore wind energy to meet nearly all of its 2022 energy demands, Germany, even with full exploitation of its offshore wind resources in the Baltic, would only meet less than 1% of its energy needs (see Table X). In fact, the total potential energy output from offshore wind in the entire Baltic Sea, around 326 TWh annually, would only cover just over 10% of Germany's energy consumption in 2022.

It is important to recognise that the countries with the highest surplus potential in offshore-wind energy also have the most renewable-energy capacity in onshore wind, hydroelectric and, in many cases, nuclear sources (this is the case of the three Nordic and three Baltic nations), highlighting their greater potential as energy exporters beyond what offshore wind-power capacity alone suggests. Conversely, Poland, and, to an even greater degree, Germany, cannot hope to cover their own consumption purely with domestic renewable-energy sources, offshore or otherwise.

203 Eurostat, 'GDP and Main Components (Output, Expenditure and Income)'.

Country	Offshore wind-energy potential (TWh)	Energy consumption (TWh)	Potential/ consumption
Latvia	49.2	50.1	98.2%
Estonia	24.0	54.9	43.7%
Denmark	70.7	186.0	38.0%
Lithuania	15.5	73.4	21.1%
Sweden	68.2	493.9	13.8%
Finland	26.0	351.2	7.4%
Poland	43.2	1,146.7	3.8%
Germany	29.1	3,030.6	1.0%

Table 10: Comparison of offshore wind-energy production and energy consumption (2022) in the Baltic Sea Region.[204]

5.3.1.3 Physical constraints

A map of population density (see Figure 26) shows that many of the major consumers of energy (in Germany and Poland in particular) are far inland south of the shores of the Baltic Sea, while the coastline where much offshore wind-power potential can be found is sparsely populated. Looking beyond the Baltic Sea Region, there are further potential markets in the landlocked countries of Central Europe or even farther afield.

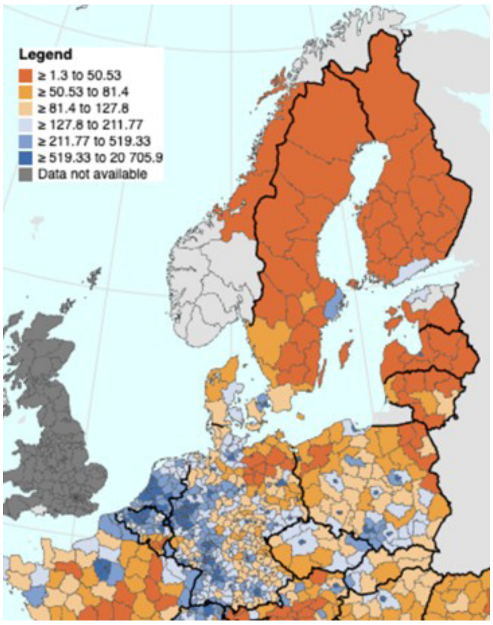

Figure 26: Population density in the Baltic Sea Region.[205]

204 Eurostat, 'Simplified Energy Balances'; European Commission, Study on Baltic Offshore Wind Energy Cooperation under BEMIP: Final Report.

205 Eurostat, 'Population Density by NUTS 3 Region'.

The large distances involved in getting energy from surplus-generation areas to major consumption centres mean that pure electricity is not the most convenient vector. Embedding energy in physical mediums such as manufactured products (steel being the prime example) or versatile green hydrogen (and/or its derivatives such as ammonia or methanol) makes more sense in most cases. Moreover, hydrogen pipelines allow for much more efficient transmission of energy across long distances than power lines.[206]

Of course, using hydrogen for the storage and transport of energy poses its own problems that must be resolved in turn. As mentioned in the first section of this report, the major issues are the flammability and low density of pure hydrogen gas, which must be greatly cooled down and/or compressed to be handled. It can be converted to other green fuels such as ammonia or methanol, which have benefits as well as drawbacks of their own, not least the fact that more energy is required to produce them from hydrogen. Pure hydrogen can most easily be moved through pipelines, as natural gas is today; however, existing natural-gas grids cannot be used for this purpose without adaptation, and new ones would need to be built across long distances.

5.3.2 Solving the equation

A comprehensive vision for the optimal buildout of offshore wind-energy combined with hydrogen deployment must take into account the different starting points and resulting motivations for the countries in the Baltic Sea Region. The fact that each individual country has either substantial surplus green energy or is a major potential importer means that the costs and risks of building infrastructure may fall upon countries that will not directly reap the benefits in terms of energy security. The benefits are more abstract: local value creation and attendant profit and employment possibilities, gains to pan-European security – directly thanks to reduced fossil imports from Russia and indirectly through lower fossil imports from other sources.

European and national strategies already explicitly call for a massive expansion of production and transmission infrastructure for both offshore-wind energy and green hydrogen. What is relatively scarce, however, is clear plans on how to implement these two developments in tandem. For the time being, Baltic Sea Region countries seem to be prioritising the expansion of offshore (and on-shore) wind-power facilities first, which is perhaps logical given the state of the art in hydrogen technology. Moreover, plans are first and foremost national, again perhaps logically so since strategies change and evolve, and countries have no control over what goes on beyond their borders.

To take just one extreme example, the Swedish Wind Energy Association (SWEA) considers 106 GW of offshore wind-power capacity plausible in Swedish waters.[207] This is a far cry from Sweden's 20 GW share of the often-cited 93 GW of total possible capacity in the Baltic Sea by 2050 presented in the latest European Commission study which quantified national potentials,[208] or from the Swedish TSO Svenska kraftnät's expectation that offshore wind-energy will account for up to 67 TWh per year in the country's production in 2045 (while the generation of hydrogen consumes 87 TWh).[209] As such, the 106 GW figure eloquently shows that endless theoretical possibilities are not accompanied by clear vision or realistic strategy.

The answer to this conundrum is more ambitious planning and investment, which necessarily must be coordinated across borders. For instance, it makes no sense for Sweden to install over 100 GW of offshore wind-power capacity to produce massive amounts of hydrogen for export if it is not clear that there is corresponding import demand abroad. The clear vision and realistic strategy must therefore be accompanied by stable and reliable transnational decision-making on networks of production and consumption. This in turn requires continuous discussion and coordination through more or less permanent forums. The main obstacles to this vision are described in the next section of this report, followed by concrete recommendations on how to overcome them.

206 Miao, Giordano, and Chan, 'Long-Distance Renewable Hydrogen Transmission via Cables and Pipelines'.

207 Swedish Wind Energy Association, 'Utbyggnaden fortsätter, men bristande politisk handlingskraft oroar'.

208 European Commission, Study on Baltic Offshore Wind Energy Cooperation under BEMIP: Final Report.

209 Svenska kraftnät, 'Svenska kraftnät skruvar upp elförbrukningen i nya analyser'

6. Key obstacles to overcome

This section of the report describes the main obstacles to the adoption of the vision described above, divided by technology (offshore-wind energy and hydrogen) and by country. Most of this information comes from a series of interviews carried out with stakeholders in each of the five target groups in Denmark, Sweden, Latvia, Lithuania, Poland and Germany.

6.1 Obstacles to the expansion of offshore-wind energy

6.1.1 Denmark

Denmark has a strong national commitment to developing offshore wind energy, with tenders for 6 GW of capacity open until 2030 and an additional 3 GW expected soon, particularly around Bornholm. The tender conditions are somewhat unique, presenting a clear challenge in striking a balance between attracting bidders and keeping costs low for society. By 2050, Danish electricity production is projected to increase fivefold, largely driven by power-to-X production to replace fossil fuels.

Many participants in the offshore wind market are global, meaning Danish projects must compete internationally. To succeed, developers need to "de-risk" projects, addressing a variety of risks – whether political, technical, or financial. Experience from the North Sea highlights additional hurdles for transnational projects, such as cost-sharing, regulatory differences, and varying support schemes across countries.

Denmark also faces a unique challenge among Baltic Sea Region states in that it has a substantial offshore natural-gas industry. While this provides significant expertise and experience, it is predominantly a fossil fuel-based industry, which brings considerable revenue and will be difficult to phase out.

6.1.2 Sweden

Currently, Sweden has no support scheme for offshore-wind energy. Green certificates have been phased out, and a previous decision for the state to build a transmission grid at sea, with dedicated connection points for offshore-wind energy, has been revoked by the current government. The regulations surrounding offshore wind-energy permitting are complex, and the process is slow. There is also significant uncertainty about whether a permit will be granted when an application is submitted.

The government's focus on new nuclear-power plants, including financial guarantees for their construction, has created further uncertainty about the future market balance. Additionally, there is no mandatory compensation scheme or incentives for those affected by wind farms, such as fishermen or people living near the shore who can see the wind farms on the horizon. As a result, appeals processes are common.

There is a substantial need for investment in the Swedish grid, both to replace outdated equipment and to increase capacity. Connecting new wind farms is one of the driving factors behind this demand. Offshore-wind energy projects today are very large, and the amount of electricity each wind farm produces is significant. However, only a small portion of planned projects can currently connect to the existing onshore grid. From the perspective of the transmission system operator, there is uncertainty about which projects will receive permits and be constructed, making future grid planning difficult.

The business case for new offshore-wind farms in Sweden is challenging and may explain why no recent investment decisions have been made, even for permitted projects. Rising costs for components, financing, and logistics have increased project expenses, while future electricity prices are more unpredictable than ever. Price cannibalisation, where high production leads to lower electricity prices and vice versa, will become more prominent as offshore-wind capacity expands. Furthermore, onshore wind power remains a competitor as long as new permits are granted for onshore projects.

Many developers are competing for offshore-wind farm permits in Swedish waters, with some even applying for overlapping areas. The criteria for obtaining permits are unclear, and the parameters on which the government evaluates applications are unknown. This competitive situation limits the possibility for developers to collaborate until it is determined which projects will be approved. The uncertainty also impacts necessary port investments to handle offshore-wind farm components.

Most offshore-wind farms, and many onshore projects, face opposition from the Swedish Armed Forces. Considerable research and testing are required to mitigate these conflicts and facilitate co-existence. There is also concern about a potential shortage of expertise, workforce, and resources when the offshore-wind energy buildout begins in Sweden, particularly as other Baltic Sea Region countries will be developing their own projects simultaneously. Few areas are prioritised for offshore-wind energy without also involving military interests. Sweden's changing view of Russia and recent NATO membership has increased army activities, reinforcing their negative stance on wind power as an obstacle. At present, initiating a dialogue with the army to resolve these conflicts is extremely difficult.

6.1.3 Latvia

From a general policy perspective, the main obstacles to the further development of offshore wind energy are: 1) insufficient financing, both for research and continued development, and 2) inadequate grid capacity. From the viewpoint of local governments, public opinion among local residents presents a significant challenge. Attitudes range from cautious to actively negative, with some communities protesting against offshore wind farms.

The most common argument from local residents is that offshore-wind farms will ruin the traditional natural landscape, with wind turbines altering the picturesque views. Additionally, concerns are often raised about the potential negative impact of wind turbines on human health, with claims that the health risks have not been adequately researched. In most cases, negative public opinion stems from fear of the unknown or a lack of clear communication from experts in the field.

In light of recent geopolitical developments, the public often associates wind farms with potential security threats, making this a particularly sensitive issue. Furthermore, extremely high and potentially unprofitable investments are also cited as barriers to the more active development of wind energy. Local governments additionally face obstacles in the form of a slow and complex process for attracting investors.

6.1.4 Lithuania

Offshore-wind energy is recognised as a key element in the transition to green energy, but its development is hindered by a range of challenges. Stakeholders generally demonstrate a high level of awareness regarding national offshore wind goals, though their opinions on the adequacy of policies and regulations are mixed. While many believe the current framework is sufficient, only just over half of those surveyed share this view.

Environmentalimpact measures related to offshore-wind projects are largely seen in a positive light, with many believing that appropriate steps are being taken to mitigate environmental harm. However, there is significant division over the permitting process. Some stakeholders, particularly in Lithuania, consider it clear, but many others, especially those in infrastructure and national government, find it overly complex and unclear, suggesting a need for regulatory simplification.

Financial-support mechanisms for offshore wind receive favourable feedback, but the state of infrastructure – particularly in ports and transmission lines – is a major concern. A majority of stake-holders believe that the necessary infrastructure is not yet ready to support the full development of offshore wind farms.
Opinions on knowledge exchange within the sector are divided, with some stakeholders, particularly from scientific institutions, viewing it positively, while others, such as those in industry and local authorities, see room for improvement. There is also uncertainty regarding the economic benefits offshore wind projects will bring to local communities. While some stakeholders, including certain authorities and companies, believe that economic benefits are assured, others, such as scientific institutions and associations, remain sceptical.

Key obstacles identified by stakeholders include:

1. Lack of international cooperation
2. Shortage of specialists
3. Supply chain issues
4. Inadequate infrastructure
5. Lengthy administrative procedures
6. Limited funding opportunities
7. Legislative shortcomings
8. Export capacity issues
9. Security concerns
10. Low demand for Power Purchase Agreements (PPA)

Addressing these barriers will require coordinated efforts, including enhanced international collaboration, improved infrastructure, streamlined regulatory processes, and more robust financial incentives.

6.1.5 Poland

Poland's energy sector is nearing a pivotal shift, with the offshore wind sector expected to play a major role in bridging the capacity gap left by the gradual phasing out of large coalfired plants. This makes the smooth and timely development of offshore wind in Poland essential. However, one of the main hurdles is the complex and lengthy permitting process. In Poland, it can take 12 to 14 years to develop an offshore wind farm, largely due to the need to secure dozens of permits before construction can begin.

A key challenge lies in strengthening the administration responsible for handling these procedures at both national and regional levels. Currently, there is a shortage of staff with the necessary expertise and authority to effectively manage offshore projects.

Poland also faces issues with its aging transmission networks, which are not wellequipped to handle the changes brought by the growing reliance on renewable energy sources.

Another crucial factor is the development of ports. Adequate port infrastructure is essential for the construction, operation, and eventual decommissioning of offshore wind farms, as well as for ensuring the safety of these investments. While Poland has ambitious plans for port development, it is unclear whether these projects will be completed in time to support the country's first offshore wind farms.

Additionally, the COVID-19 pandemic has disrupted global supply chains, causing investors in Poland to face shortages of offshore wind-farm components, delivery delays, and significant cost increases. Inflation has further exacerbated the situation by driving up the prices of many components, making it harder for investors to manage and optimise development costs effectively.

6.1.6 Germany

The development of offshore wind energy in the Baltic Sea faces several challenges, as highlighted by public authorities, large enterprises, and research institutions in Germany. These challenges include issues with communication, coordination, regulations, public acceptance, transnational cooperation, educational gaps, labour shortages, and the role of small and mediumsized enterprises (SMEs) in the sector.

One of the main obstacles is communication. Large companies and universities have called for improved dialogue with local authorities, noting that stakeholder communication was better in the past and should be revived to support the energy transition.

Coordination of wind farms is another major issue. Both public authorities and enterprises have struggled to align construction and grid connection timelines, leading to inefficiencies and delays. Despite the implementation of the German maritime spatial plan as a central instrument, stakeholders feel it is still insufficient.

The regulatory framework also poses significant challenges, with complex rules slowing down both planning and implementation. Navigating these regulations, especially in the early stages of project development, requires considerable time and resources.

Public acceptance is crucial yet remains difficult to secure. Resistance from local communities, particularly in border regions and concerning cooperation with other Baltic Sea countries, continues to hinder progress. Overcoming this resistance is essential for moving forward.

Transnational cooperation is another weak point. While collaboration between Baltic Sea countries is critical for efficient project development, it is currently lacking. Stakeholders stress the need for better regional coordination and sharing of best practices across national borders.

Research institutions point to public scepticism and educational shortcomings as critical barriers. Public trust in offshore wind energy is low, worsened by unmet promises from various stakeholders. Educational programs in relevant fields like wind energy and maritime technology are not meeting sector needs, with fewer students entering these programs, exacerbating labour shortages.

Supply chain issues and a shortage of skilled workers further complicate offshore wind development. Finding qualified professionals is increasingly difficult, and apprenticeship programs are undersubscribed. SMEs also face financial barriers, limiting their ability to contribute to research and development in offshore wind energy.

Addressing these challenges requires coordinated efforts from all stakeholders. Streamlining regulatory processes, improving public engagement, enhancing education and training programs, and fostering transnational cooperation are essential steps to advance offshore wind energy in the Baltic Sea region. With the right strategies, the region can overcome these barriers and realise its offshore wind potential.

6.2 Obstacles to the expansion of green hydrogen

6.2.1 Denmark

Denmark has a very ambitious strategy for hydrogen and aims to scale up production and use of green hydrogen in fossil-fuel-reliant industries like shipping, aviation and heavy transport.

The scale and timeline of the ambitions are the main challenges for their green hydrogen goals.

6.2.2 Sweden

Sweden lacks a clear definition of green, renewable, or sustainable hydrogen. There are concerns that the EU's definitions of renewable fuels of non-biological origins (RFNBOs) will be difficult to interpret and implement. The government's push for nuclear power adds uncertainty about whether hydrogen from nuclear sources will qualify for future support.

Sweden's conditions for low-carbon electricity production are favourable, but renewable sources like wind and solar are weather-dependent, leading to fluctuations in hydrogen production. This requires large-scale storage or flexible users. Despite many industrial hydrogen initiatives, only two projects in Sweden have qualified as Projects of Common Interest (PCI), which offer faster permits and EU funding.

Transporting energy as hydrogen is more cost and space-efficient than electricity, but the energy system, including conversion losses between hydrogen and electricity, is complex. Calculating and realising an optimal mix of electrical and gas grids is challenging due to varying project timelines and dependencies. There are plans for a hydrogen pipeline in Sweden, though it's unclear whether it's best to build onshore or offshore, especially given concerns about sabotage, as with the North Stream incident. Building a gas grid on land may face challenges, similar to the difficulties in permitting electrical grids.

Hydrogen is rarely included in local policies, although some municipalities like Trelleborg and Sjöbo are working to integrate it into their energy systems. Sweden's gas grid is small, serving mainly industries in the southwest. It would need upgrading to handle hydrogen, and the country has limited experience with gas grids.

Hydrogen storage is being tested at medium scale in the Hybrit green-steel project, but large-scale storage remains costly and unproven. Hybrit recently decided not to build large storage in its next phase, meaning hydrogen production will have to be nearly continuous.

Sweden lacks a designated transmission system operator (TSO) for hydrogen, unlike its electrical grid managed by Svenska Kraftnät (SvK). Additionally, regulations for hydrogen are underdeveloped.

Several hydrogen companies have grown quickly in Sweden, supported by risk capital, but since the invasion of Ukraine, securing funding has become more difficult for startups and green tech firms. While the government has launched support for hydrogen infrastructure in industry and transport, progress on filling stations has been slow.

Permitting processes for hydrogen infrastructure remain complicated and costly, as many permits are required, and the legislation is not harmonised. Research, education, and expertise are crucial for developing this new industry. The Swedish Government has initiated programmes, such as the Centre for Hydrogen Energy Systems Sweden at Luleå Technical University, to support this.

6.2.3 Latvia

Under current conditions and infrastructure, the primary obstacle to the rapid development of green hydrogen in Latvia is the high cost, making its use economically unviable. The key priority is to develop sufficient solar and wind farms, which can provide the energy needed for green hydrogen production in the future.

6.2.4 Lithuania

Green hydrogen is recognised as a key element in the transition to sustainable energy, but several significant challenges hinder its development. A recent survey highlighted obstacles from the perspectives of various stakeholders.

There is broad awareness of the national strategy for green hydrogen, but many feel that support from national authorities is lacking. Over half of respondents expressed concerns, with most believing stronger political instruments are needed to drive the sector's growth. Investment levels are also seen as insufficient, particularly among industrial companies and scientific institutions.

International cooperation and knowledge exchange are vital for the sector's success, yet many stakeholders feel there is not enough engagement in these areas. This lack of global collaboration limits innovation and the sharing of expertise. Additionally, stakeholders identified a deficiency in national initiatives promoting green hydrogen use across sectors like transport and industry, and believe innovation is not sufficiently encouraged.

Public awareness is another key barrier, with many respondents citing a lack of initiatives to educate the general populace about the benefits of green hydrogen, hindering public acceptance and support.

Key obstacles identified in Lithuania:

1. Shortage of specialists
2. Lack of funding opportunities
3. Inadequate legislation
4. Infrastructure deficiencies
5. Supply chain problems
6. Limited international cooperation
7. Lengthy administrative procedures
8. Lack of renewable energy sources
9. Perceived low enduser demand
10. High costs
11. Uncertainty about the future of green hydrogen

Addressing these barriers will require stronger governmental backing, increased funding, international collaboration, and efforts to raise public awareness about the benefits of green hydrogen.

6.2.5 Poland

Poland's green hydrogen market is in its early stages, facing similar challenges as those at the European and global levels. Green hydrogen production currently costs at least twice as much as hydrogen from natural gas, making it hard to compete in cost-focused industries. Infrastructure for production, storage, and transport is underdeveloped, limiting scalability and adoption.

Polish law lacks clear regulation for green hydrogen, creating investment uncertainty and hindering market growth. Poland also invests less in hydrogen innovation compared to leading EU countries, with most projects relying on foreign technologies. Educational offerings on hydrogen are scarce, with energy programmes focusing more on heating and renewables.

The Polish Hydrogen Strategy of 2021 needs updating due to geopolitical changes, rising gas prices, and the energy crisis, but the government lacks a clear vision or timeline for revising the strategy.

6.2.6 Germany

Advancing hydrogen technologies in the Baltic Sea region faces various challenges, with differing views from local authorities and large enterprises. A key issue is the lack of government-set targets for green hydrogen production, causing uncertainty and hindering long-term planning. Regulatory delays, including the pending SoEnergieV regulation and postponed tenders like SEN-1, also slow progress.

Infrastructure development, particularly cross-border hydrogen pipelines, must align with national energy strategies. Large enterprises face complexities navigating multiple legal frameworks across different countries' exclusive economic zones and transnational offshore wind projects, requiring regulatory adjustments.

Technical challenges include grid integration, as seen with the Krieger's Flak interconnector, and the need for more efficient electrolyser technology for offshore conditions. Pipelines, preferred for hydrogen transport, present technical hurdles, while public resistance, especially over concerns like electricity prices, further impedes progress.

Investment risks are significant, with high costs requiring shared responsibility among European nations. Limited space in the Baltic Sea for hydrogen projects, as indicated by the German Maritime Spatial Plan draft for 2024, complicates development. Supply-chain pressures and soaring commodity prices also strain efforts to meet hydrogen targets.

In summary, advancing hydrogen technologies in the Baltic Sea requires coordinated efforts, clearer regulations, strategic planning, and better infrastructure to ensure sustainable growth.

7. Recommendations

This section builds on the vision outlined above and the national obstacles to formulate recommendations for the five target groups of the BOWE2H project, namely: national & European policymakers and regulators; local and regional government; the private sector; grid operators; and research institutes.

7.1 Policy and regulation (National and EU)

To accelerate the green energy transition in the Baltic Sea Region, it is essential for governments to demonstrate clear leadership and commitment to offshore wind energy and green hydrogen. National coordinators, similar to those employed in other sectors, can streamline these efforts. The pace of permitting and project development must be improved by providing clearer guidelines on handling conflicting interests in offshore wind-energy projects, possibly through centralised or auction-based systems. Regulatory frameworks should prioritise the simplification of bureaucratic processes to reduce administrative barriers, expediting both offshore wind-energy and hydrogen project approvals.

Governments should develop integrated green-transition strategies, covering offshore wind, hydrogen, and other forms of renewable energy, instead of pursuing separate plans. These strategies should include specific targets for offshore-wind energy and hydrogen, establishing clear goals and fostering a shared understanding among stakeholders. National policies should ensure regulatory stability and create market incentives, such as Contracts for Difference (CfD) and Power Purchase Agreements (PPA), to attract investment in renewable energy sectors. Support should also be extended for additional costs, such as grid connections for hydrogen projects.

Infrastructure development is key. Investments should be prioritised in expanding grid capacity, building hydrogen storage facilities, and developing transportation networks and refuelling stations. Public awareness and acceptance of the green energy transition are also crucial. Governments must launch nationwide information campaigns, highlighting the climate, health, and economic benefits of renewable energy, including offshore wind and green hydrogen technologies. Collaboration with local authorities will be essential for effective communication, ensuring community support and engagement in these projects.

Workforce development is a significant priority. Governments should invest in national education programmes and specialist training to address the shortage of skilled professionals in both offshore wind and green hydrogen sectors. Research and development should also be supported, with funding allocated to innovation hubs and centres of excellence that foster collaboration between academia, industry, and government, helping to advance new technologies and solutions for the green energy transition.

Coordination mechanisms, such as maritime spatial plans, should be strengthened to synchronise offshore wind-energy development with grid connections and streamline project timelines. Regulatory harmonisation and innovation across the region will help reduce bureaucratic hurdles, supporting faster and more efficient project implementation. Regional and transnational cooperation must be enhanced to ensure the effective development of cross-border energy infrastructure, including a comprehensive hydrogen pipeline network. Governments should engage in regular dialogues and joint initiatives to foster strong partnerships across the region, promoting efficient production and distribution of green hydrogen.

Clear communication regarding green energy possibilities is essential, including information about support mechanisms, electrolyser locations, and local conditions. Governments should ensure that stakeholders and the public are well-informed about the opportunities available and how they can contribute to the energy transition. By implementing these measures, countries in the Baltic Sea Region can effectively drive the transition to renewable energy, enhancing both offshore wind-energy and green hydrogen production for a sustainable future.

7.2 Local and regional government

Local and regional governments in the Baltic Sea Region play a crucial role in advancing offshore wind-energy and green-hydrogen projects. To effectively support these initiatives, they should focus on increasing awareness and education, particularly within municipal authorities, local communities, and the general public. Municipal representatives should launch educational campaigns, work-shops, and seminars to raise awareness about the benefits and safety of green hydrogen and offshore wind technologies. These efforts will foster understanding and acceptance at the local level.

Infrastructure development is another key priority. Local governments should begin by initiating small-scale pilot projects to demonstrate the feasibility of hydrogen and offshore wind projects, thereby building local confidence and gaining support. Collaboration with private investors and securing funding from national and EU sources will be essential in developing the necessary infrastructure. Partnerships should also be established with universities and technical institutions to develop training programmes that build local expertise in hydrogen technology and offshore wind, attracting specialists through competitive incentives and career development opportunities.

Municipalities must work to strengthen regulatory frameworks by advocating for policies that facilitate the adoption of hydrogen and offshore wind technologies. Standardising safety procedures and regulatory protocols will streamline project implementation. Additionally, promoting intermunicipal and international cooperation is vital. Local governments should share best practices and lessons learned from projects and establish partnerships with international organisations to access advanced expertise.

Public engagement is a critical component of successful project development. Early involvement of local communities and transparent communication about the specifics of projects, including potential risks and benefits, can build trust and mitigate opposition. Local governments should also facilitate dialogues between project developers and civil society to encourage constructive participation. In regions affected by offshore wind-energy projects, economic incentives for local communities and municipalities can further boost support.

Addressing funding challenges is another priority. Local governments should explore financial incentives such as grants, subsidies, and public-private partnerships to reduce the initial costs and share the financial burden of hydrogen and offshore wind projects. Centralised information hubs or online platforms should be created to provide municipalities with uptodate resources and success stories that highlight the benefits of these technologies.

Local and regional energy planning must integrate offshore wind-energy, hydrogen, and power-to-X technologies. Cross-border cooperation is also critical, as international collaboration allows for the exchange of experiences, insights, and best practices. Continuous engagement with stakeholders – including industry sectors, environmental authorities, and national public authorities – will align interests and help expedite project approvals, ensuring a smooth and coordinated approach to the energy transition.

7.3 Industry

For the private sector across the Baltic Sea Region, several strategic recommendations are crucial to drive the successful development of offshore wind-energy and green-hydrogen projects.

Reducing regulatory burdens is a key priority. Streamlining the number of permits required for hydrogen infrastructure will accelerate development. Governments should work towards harmonising regulatory frameworks across the region to make transnational projects more feasible, especially for offshore wind-energy and hydrogen initiatives. Additionally, the private sector would benefit from clearer, consistent market designs and tender rules that address risks associated with these projects, particularly for cross-border offshore wind farms.

Infrastructure development is essential. The private sector should collaborate with governments to identify key ports for handling offshore wind-energy logistics, and ensure investments in facilities capable of managing offshore wind-energy components. A focus on optimising infrastructure for green hydrogen, such as building pipelines and transportation systems to efficiently handle hydrogen transport, is also critical. Improvements in electrolysis technology are necessary to make these systems more efficient and compact, particularly in offshore environments. Developing adequate storage and balancing supply and demand will ensure stability and efficiency in green hydrogen production and distribution.

Financial incentives and risk mitigation are important for stimulating private investment in these sectors. Governments should offer financial support, guarantees, or Contracts for Difference (CfD) to reduce risks and make projects more attractive. Support mechanisms to offset the high costs of producing green hydrogen and renewable energy infrastructure, such as favourable tariffs and public-private partnerships, will further encourage investment. Ensuring an equitable distribution of investment costs through cross-EU funding mechanisms will also help balance the financial burden among countries and developers.

Collaboration and innovation will play a vital role in advancing technological solutions and market integration. Private sector companies should partner with research institutions to enhance technological innovations, particularly during periods of low energy demand. Strengthening supply chains is also critical, ensuring that the increased demand for materials and components necessary for offshore wind-energy and hydrogen projects is met. Companies should actively engage in international cooperation and transboundary agreements to create a decentralised and integrated electrical grid across the Baltic Sea Region.

Public engagement is essential for project success. Companies should initiate early dialogues with local communities, addressing concerns and building support for offshore wind-energy and hydrogen projects. Effective public education campaigns highlighting the benefits and safety of green hydrogen technologies will foster trust and acceptance, reducing resistance to new technologies.

Strategic project planning and coordination must focus on selecting sites that align with existing and future electricity and hydrogen transmission systems. Projects should be integrated with regional energy independence goals, supporting EU and national renewable energy targets. The private sector should advocate for the inclusion of designated areas for hydrogen projects within national maritime spatial plans, and collaborate with governments to implement consistent and clear regulatory policies that provide financial stability.

Finally, maintaining continuous dialogue with stakeholders – including the offshore wind energy sector, shipping industry, and environmental authorities – will ensure alignment of interests, helping to expedite project approvals. Transparent trading mechanisms for green hydrogen certificates and clear market valuation systems are also needed to facilitate cross-border trading and enhance market integration.

By addressing these recommendations, the private sector can effectively contribute to the growth of offshore wind energy and green hydrogen, supporting the Baltic Sea Region's energy transition.

7.4 Grid

Grid operators across the Baltic Sea Region must take proactive steps to facilitate the energy transition, particularly in the integration of offshore-wind energy and green hydrogen into national grids. Key to this effort is ensuring that the electrical and hydrogen transmission networks are developed in tandem, with clear responsibilities and regulations established to support a future hydrogen grid.

A proactive approach is essential, particularly for transmission system operators (TSOs), who must anticipate offshore wind-energy developments and provide suitable connection points. In Sweden, for example, this involves creating a dedicated national hydrogen TSO. Across the region, the focus should be on adapting existing infrastructure to accommodate hydrogen transport and increasing the capacity of the electrical grid to handle largescale renewable energy sources such as offshore wind and solar power. Grid operators must work to integrate these renewable sources while also developing solutions for seasonal energy storage to balance supply and demand effectively, especially during periods of fluctuating production.

Smart grid technologies can play a pivotal role in ensuring the stability of the grid while enhancing efficiency in both electricity and hydrogen transport. Grid operators should embrace modernisation and expansion efforts, supported by consistent regulatory frameworks and government incentives. Streamlining administrative procedures is necessary to reduce delays in grid development, making the permitting process more efficient and less complex.

Cross-border cooperation is another vital component of the Baltic Sea Region's energy future. Increased integration between Baltic Sea states through additional electricity interconnectors and a common hydrogen transport infrastructure will be crucial to achieving shared energy goals. This collaborative effort can be strengthened by promoting transnational projects, sharing best practices, and ensuring that technical challenges in interconnector projects are addressed.

Public-private partnerships should be encouraged to attract investments, helping to fund the grid modernisation necessary for integrating renewable energy and hydrogen technologies. Governments, industry, and academic institutions must collaborate on innovative solutions to drive the efficient development of grid infrastructure. Investments in research, education, and workforce development are also essential. Establishing scholarships, internships, and career development opportunities will help attract and retain skilled engineers and specialists capable of managing advanced grid technologies and hydrogen infrastructure.

Grid operators must also engage with local communities throughout the planning and development process to build support, address concerns, and ensure that projects are aligned with local needs and expectations. Transparent communication will help foster trust and cooperation.

Establishing clear expansion targets and timelines is crucial for grid operators, with designated zones for offshore wind and coastal electrolysis projects. This includes prioritising offshore and coastal green hydrogen initiatives and supporting research in these areas. By focusing on these strategies, grid operators in the Baltic Sea Region will ensure the successful integration of renewable energy technologies, strengthening the region's energy resilience and supporting the transition to a greener future.

7.5 Research

Research institutes across the Baltic Sea Region play a pivotal role in driving innovation and supporting the transition to renewable energy sources like offshore wind and green hydrogen. Key recommendations for these institutes focus on fostering collaboration, promoting education, and addressing sector-specific challenges.

A major area of focus should be the development of solutions that enable the coexistence of offshore wind-energy projects with other national interests, such as military operations. This challenge is particularly relevant in Sweden, where transnational cooperation could help develop strategies that allow the armed forces and offshore wind-energy projects to share maritime space effectively.

Holistic research on energy systems is also essential. Research institutes should investigate current and future bottlenecks in the energy transition, particularly in sector coupling – understanding the intersections between electricity, heat, and hydrogen systems to optimise the use of resources.

To build a strong pipeline of talent, research institutes should promote renewable energy studies through scholarships and active outreach, ensuring that more students are attracted to the field. Comprehensive public education campaigns will also be key to raising awareness about the benefits of offshore wind energy and clean hydrogen. These campaigns should include public lectures, seminars, and collaborations with media outlets to reduce public scepticism and foster greater acceptance of new technologies.

Collaboration is crucial to innovation. Research institutes should establish partnerships with international counterparts to share knowledge, best practices, and technological advancements in off-shore wind energy and hydrogen. Cooperation between scientists, businesses, and academic institutions should be actively encouraged to foster research and development, focusing on solutions that drive the energy transition forward.

There is also a need for indepth research on the socio-economic impacts of offshore wind-energy and hydrogen hubs on local communities. This research can help inform policymakers and ensure that communities benefit from the energy transition. Institutes should also consider establishing industrial-scale training centres, such as a hydrogen technology valley, to provide handson experience and facilitate practical learning.

Global participation in hydrogen research initiatives and forums is essential for remaining at the cutting edge of technological developments. Research institutes should also focus on analysing legislative frameworks to propose improvements that support the development of green hydrogen. Innovative financing models should be explored to attract investments in hydrogen projects, while providing clear, data-driven insights to policymakers can reduce uncertainty and build investor confidence.

Educational programmes need to be strengthened to align more closely with the demands of the renewable energy sector. By enhancing curricula, promoting renewable energy careers through marketing campaigns, and establishing clear pathways for job placements, research institutes can ensure a well-trained workforce for the future. Partnerships between educational institutions and industry players should be fostered to provide students with practical training, internships, and apprenticeships. Specialised curricula focusing on the latest offshore wind and hydrogen technologies will better equip students for the challenges ahead.

Involving companies in the research and education process is vital to ensuring that research out-puts are relevant and directly applicable. Educational efforts should begin as early as primary school to raise awareness of renewable energy sectors and build a more energy-literate population.

Finally, institutes should work on marketing renewable energy technologies effectively. Strategic communication campaigns can help explain the benefits of renewable energy and the role of hydrogen in the future energy landscape, increasing public trust and understanding of the green energy transition.

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9. Annex: Interviews

During the BOWE2H project, extensive interviews were held by the project partners among stakeholders belonging to the five target groups of the project (local public authorities, national public authorities, infrastructure operators, private companies and research institutions) in Sweden, Lithuania, Poland and Germany. These interviews provided invaluable insight into the concrete obstacles to the expansion of offshore wind-energy and hydrogen facilities in the Baltic Sea Region, and supplied key contributions to the recommendations of the BOWE2H project.

9.1 Sweden

9.1.1 Local public authorities

In Sweden, local authorities, that is municipalities, have strong influence on renewable energy projects, especially when it comes to planning and building permits. They can and actually often choose to veto wind power projects on land and in territorial waters, which normally have to be 22 km from shore. Regional authorities are mainly Regions and County Administrative Boards (CABs). Regions are elected and have responsibilities in regional development and sustainable growth. A CAB is the government's extended arm in the regions and handles environmental permits for offshore wind energy and other infrastructure with potential environmental impact. Their mission is to support the energy transition, environmental protection, civil defence and much more. Regions and CABs are working side by side to support the energy transition. While the Regions have taken a coordinating role supporting developers and connecting stakeholders to strengthen regional development and growth, the CAB has a governmental assignment to support the energy transition and specifically electrification.

The absence of goals for offshore wind energy and an unclear permitting process from local authorities gives room for actors in opposition to offshore wind projects and leaves the developers alone rather than assisting them in offshore wind endeavours.

Since the coastal areas of southeast Sweden have long hosted military and defence activities, a coexistence with the Swedish Armed Forces (SAF) is imperative for offshore-wind farms to be built both on and offshore. The last years of increased Russian aggression put even stronger focus on this. Dialogue, however, is very difficult and most projects are rejected by SAF, appealed, and eventually go to the Swedish Government for approval.

Another conflict which local authorities have to take into consideration when approving projects in this field is one with nature, as wind turbines often are developed on banks with less depth but high natural values. One current example is south Victoria, an RWE project that has been denied permit due to a population of the rare porpoise.

Compared to many other countries, the cost for grid connection is to be covered solely by the developer and the project. Since the connection point to the transmission grid often includes both the sea cable and some land cable, it is very expensive, requires many permits and takes a long time to finalise, which poses another hurdle to offshore wind and hydrogen projects. As does the lack of skilled workforce, which is feared to be a challenge when many projects are to be realised in a short time.

Regarding acceptance, an early and committed dialogue is the preferred strategy, the lack of which is the cause of many of the protest movements that have emerged. The dialogue should take place jointly by municipalities and their rural developers, county administration and regions if resources and ability exist, together with civil society in the affected areas. Incentives for the local community, nearby residents and municipalities are also an important factor. Regarding hydrogen, acceptance problems have so far not been as big of an issue, but political forces acting against the green transition may possibly endanger that.

Transnational exchange is seen positively by local authorities to meet common challenges, for example establishing working methods for citizen dialogues, solutions for coexistence between defence interests and renewable energy, as well as planning and support for further interconnection between countries' electricity grids.

Since the current users of hydrogen are mainly within industrial processes in the south of Sweden, small scale local initiatives are probably facing challenges to be profitable more so than big companies. Thus, municipal planning including access to suitable locations with grid connections, logistics and so on is especially important for smaller initiatives. Furthermore, it has been noted that there are interesting possibilities for symbiosis with the forest and pulp industry which has a long tradition in Sweden. Green fuels and chemicals can be made from hydrogen and CO^2-capture.

Key recommendations:

- Public authorities should provide clearer leadership and commitment to establish and expand offshore wind power.
- Clearer guidance is especially needed to assess how to value conflicting interests in development and permitting processes.
- The Swedish transmission system operator should meet the planned offshore wind energy projects with suitable connection points.
- Economic incentives for the local community, nearby residents, and municipalities should be implemented if they are affected by offshore wind energy.

9.1.2 National public authorities

Important national authorities in Sweden are the government, parliament but also authorities such as the National Energy Agency, the Swedish Agency for Marine and Water Management, and Svenska kraftnät, the Swedish transmission system operator. They are the main policy makers that can influence the green transition.

Early offshore wind energy projects in Sweden had a difficult permit process. The process is different today but still very difficult. Conflicting interest with the Swedish Armed Forces has increased over the years. Offshore wind energy was also very expensive at the beginning and projects realised without subsidies have not been profitable. Technology used to not be developed for sea conditions. Meanwhile today, there is new technology such as floating turbines. Sweden's green certificates were successful in promoting renewable energy resource power production.

Today's turbines are larger and more suitable for sea conditions. The size does however create challenges with transport, storage, and assembly. There is a need for special ships that exist in a limited number. Larger wind farms as built today are more difficult to integrate in the electrical grid system.

Public opinion on wind power is more negative today, boosted by social media campaigns. This has an influence on the political agenda at the local but also national level. At an EU level, goals for renewable energy are ambitious but increased nature protection targets create conflict of interests for many projects.

Furthermore, Sweden's (lack of) targets for offshore wind energy can be a disadvantage when weighing conflicts of interests. Technology-specific targets can on the other side be counterproductive and steer to non-optimal solutions. Planning targets can enable different scenarios and create opportunities for different technologies. New maritime plans will identify areas for offshore wind energy capable of producing more than 120 TWh yearly. Political will to subsidise certain production sources may also play an important role as the uncertainty within the pursued energy policy makes investment decisions difficult. Production goals may not be needed but removing regulatory barriers would be more effective. It is unclear why processes for permits are not in place when the need for them is certainly known.

Today, there is a mutual understanding that a lot of electricity is needed to replace fossil fuels. The need for nuclear to reach scenarios of double usage of electricity in 2045 is currently being debated. Since the electricity market is sensitive and hard to capture in models, it is difficult to come up with objective models even if neutral input is provided.

As outlined previously, the potential for offshore-wind energy in Swedish waters is very high. Scenarios for electricity use in 2045 are envisioning double of today's use, a large portion of which will be produced by offshore wind energy. The coming development of costs of offshore wind energy production relative to other power sources as well as possibilities for permits will both affect the pace of the transition and the share of offshore wind energy.

At the moment, there is some cooperation with neighbouring countries on the electricity market through Nordenergi and Nord Pool and to some extent for grid planning. However, last year's energy crisis has also shown tendencies for a degree of protectionism and putting national interests first. Moreover, having different national models for permits is a barrier for international cooperation. Sweden and Finland entering NATO may give unforeseen possibilities to solve common problems such as conflicts between offshore wind energy and armed forces. Especially in maritime planning, transnational cooperation is very important to optimise offshore wind energy and at the same time minimise environmental impact.

Offshore wind and hydrogen production are technologies that are important for each other. Systems including both will thus be more efficient. They will compete with Solar-PV and hydrogen systems in south Europe. Hydrogen produced in Sweden will probably also be used in Sweden in an initial phase, as the national need for hydrogen in industry is high. The location of electrolysers will have to be a balance between proximity to the user and access to electricity and grid connections. Examples of early projects are Fertiberia in Boden and Ovako Steel in Hofors. One main challenge to produce the large volumes of hydrogen needed is the access of green electricity at a low cost. Many decarbonisation projects such as non-fossil steel assumes an excess of electricity from renewable-energy sources available at a low cost. There is a risk for acceptance issues with hydrogen, although less than for wind power.

Key recommendations:

A holistic strategy for the green transition should be implemented instead of separate strategies for offshore wind, hydrogen and other renewable resources. A national coordinator should be part of this strategy to ensure clear leadership and commitment, similar to the one for nuclear power.

Potential measures within such a strategy are:

- a changed (centralised) permitting process,
- prioritising the energy interest over other interests,
- considering incentives such as Contracts for difference.
- introducing local incentives for near shore projects in territorial waters.
- making Svenska kraftnät (TSO) plan and build grid connections for OWE,
- developing collaborative solutions with the Ministry of Defence.

9.1.3 Infrastructure operators

The electrical transmission grid in Sweden is owned and operated by the state transmission system operator Svensk kraftnät, SvK. They operate most, but not all interconnectors to neighbouring countries. Medium level (region) grids are mainly owned by the companies Vattenfall, E.ON, and Ellevio. Local (distribution) grids are owned by various different companies. Gas grids in Sweden are limited to the southwest and distribute methane of fossil and biogas origin. The main grid is operated by Weum – a part of Nordion Energi.

Only a small part of all planned offshore wind energy projects can be connected to the transmission grid today. The electricity must also reach customers in other parts of Sweden and Europe and there are limits in grid capacity. Moreover, cost for offshore wind energy is still high and there needs to be a market for the electricity produced. If investors are uncertain of the future market and prices, states must derisk and potentially give subsidies. It is important to take a leading position before the market is saturated.

As producing hydrogen at sea is not a mature technology, onshore production remains more efficient. Generally, gas pipelines are often cheaper than the electrical grid. A first hydrogen pipeline may be built outside Luleå in the north. Furthermore, the strongest focus is on the west coast where there is experience from natural gas use and a large industrial demand. Efforts must be invested in helping the Baltic states in their energy transition – away from Russian dependencies. A planned Baltic hydrogen connector is in the first stage of connecting countries at sea. Interconnectors for hydrogen pipelines give a better possibility to balance different markets in their supply and demand.

The four following challenges arise for stakeholders in infrastructure regarding offshore wind and hydrogen. First, there is a challenge in dimensioning electrolysers in relation to the size of the offshore-wind farms. Second, the many different permits and processes that are needed pose a challenge. Third, there is not enough cooperation between gas and electricity actors. Lastly, there is no clear picture of how the energy system will look once everything is ready. New nuclear plants for example would not hamper the hydrogen development.

In this context, ports are an important part of infrastructure providers. While they can vary in size and type of activities, a commonality is that ports are hubs for different types of energy logistics and usage. One point high on the agenda is shore power. New EU requirements regarding this will be implemented soon. Battery as well as electrical ships are being used more and more, which requires very high grid capacity.

Some ports produce electricity from wind turbines in the harbour area. Hydrogen has been discussed as a fuel for ships, but e-fuels or ammonia are mainly seen as a better option. In ports with many truck transports (so-called ro-ro ships), fuel for trucks is discussed. Hydrogen here is an op-tion for long and heavy transports.

Ports defined as "Core" ports, located along prioritised routes, can apply for dedicated funding for sustainable projects. Some ports have specialised in handling offshore wind energy components. Since the wind turbines are getting larger over time, the requirements on ports are also increasing. It is a challenge to finance these upgrades unless several offshore wind energy projects are foreseen to use the port. Furthermore, several hydrogen and Power to X factories are planned close to ports due to synergies between ports and logistics infrastructure.

Key recommendations:

- The Swedish Energy Agency should have responsibility for the strategic design of the energy system.
- Hydrogen should be regulated the same way as methane.
- Responsibilities and roles need to be clarified. For example, there needs to be a designated transmission system operator in Sweden for hydrogen.

9.1.4 Private companies

In Sweden, several offshore wind energy developers are also active in hydrogen projects, sometimes with inhouse competence, but often through cooperation with specialised hydrogen companies. Many are looking at hybrid projects in which electricity produces hydrogen and other Power to X products. The main reason is that hydrogen can increase the value of electricity production. It will also be easier to connect the wind farm if hydrogen production lowers the maximum grid capacity needed. A third reason is to avoid “price cannibalisation” through energy storage when electricity spot price is low.

In the short run hydrogen will be produced on shore, but cost benefits will probably drive production out at sea when technology is tested and mature. The Swedish development in offshore wind energy and hydrogen is more industry-driven than politically driven compared to other countries. New EU rules for renewable fuels of non-biological origin (RFNBO) will be favourable for Sweden due to its low share of fossil origin in the electricity mix. Assuming there is a need for hydrogen corresponding to 100 TWh electricity in 2050, a large portion of this electricity will come from OWE. In other words, a large share of electricity from OWE will be used to produce hydrogen.

A challenge for the current electricity market is the need for more electricity while at the same time, too much production will lower the price too much. It is thus likely that there will be Contract for Difference systems in offshore wind in Sweden. Regarding hydrogen, a volatile hydrogen production from wind and solar might also lead to volatile hydrogen markets. Therefore, there is a need for technical development of electrolysers optimised for this flexible production. To create profitable business, smart systems to optimise side currents from Power to X need to be created.

Key recommendations:

- Politicians should give permits to more projects to keep up the pace in the energy transition.
- The state should guarantee profitability and share the risk of electricity prices dropping with high production. In order to do so, hassle should be reduced and lower financial thresholds created.
- Enterprises should choose what they want to build and where on a national level, for example, nuclear power in designated locations.

9.1.5 Research institutions

Swedish research institutions have found several challenges to the development of offshore wind energy and hydrogen. For example, political uncertainty with different views on subsidies for nuclear energy creates an uncertain market. Further uncertainty persists about connection costs for offshore wind energy. As mentioned above, forecasts for future usage of electricity assume low electricity, yet there is uncertainty as to what would happen if those costs turn out to be high. For instance, the cost for building offshore wind energy has gone up in recent years, which poses a further challenge. Generally, research institutions have also stated that the industry is more active in the energy transition than politicians and policy makers which can also be seen as a significant problem.

Within research, there is a lack of focus on the cost and rational use of resources. Further research is also needed in the field of sector coupling, including more systems thinking. Although there is a shortage of competence in some areas, more seats in universities are not necessarily required as too many may reduce attractiveness and the quality of education. Most importantly, the industry itself needs to be able to identify which knowledge and competences will be needed and have an active dialogue with the universities so that this is met.

Attracting students through marketing is a complex issue. One idea is to approach parents to of recent high school graduates in order to present the possibility of studying within the energy field to their children. Although some Swedish universities are successful in attracting students from outside the EU, they may leave the EU after completing their studies.

Future research is required into questions such as how a fossil-free Sweden can be managed as efficiently as possible and how the energy market should look like to support the green transition. Moreover, scale-up projects maintaining a sustainability focus, research into bottlenecks such as lack of resources as well as potential cooperation between sectors are needed. Transnational research should focus on solutions for common challenges such as the conflict of interest between offshore wind energy and defence or how to set up an optimal permitting system.

9.2 Lithuania

9.2.1 Local public authorities

There are varying levels of engagement and interest in hydrogen markets and projects across different municipalities in Lithuania. Vilnius is leading the way with active development, while other municipalities show potential interest, dependent on future perspectives. Despite the potential and interest in hydrogen projects, municipalities face various challenges, including a lack of engagement, infrastructure, funding, and technical hurdles. Common challenges across municipalities include a lack of awareness and knowledge, which makes an increase of awareness and an understanding of hydrogen technology and its benefits among municipal authorities and the public crucial. Without prior experience or groundwork in hydrogen projects, initiating and developing new projects can be challenging. Further, the development of infrastructure including establishing the necessary infrastructure for hydrogen production, storage, and distribution is a significant undertaking that is yet to be done. However, securing sufficient funding and investment for such hydrogen projects, particularly in municipalities with no prior experience, can be difficult. What’s more, the building of technical expertise and capacity to manage hydrogen projects effectively is lacking although evermore important. Lastly, ensuring that supportive regulatory frameworks and policies are in place to facilitate the development and adoption of hydrogen technologies is crucial but not yet prevalent.

In addition to such general difficulties, different municipalities face different problems and their level of progress also varies. A few key insights can be distinguished for each of them. While the Vilnius municipality plays an active role in planning and implementing hydrogen projects, facing challenges related to infrastructure, funding, regulatory development, and interinstitutional collaboration, the local authorities in Klaipeda currently have limited involvement. They do however highlight the importance of community engagement and effective dialogue for future projects. In Kaunas, the municipalities emphasise the need for detailed planning and costbenefit analysis, with infrastructure development being a key challenge. Various other municipalities highlight the need for better information dissemination and public engagement to overcome local challenges, as well as familiarisation with successfully implemented hydrogen projects.

Involving and educating local communities has proven to be a very pressing issue. A common obstacle is the public's lack of information about hydrogen technology. Educating the public about hydrogen's benefits and uses is essential. It is also very important to engage the public and local government representatives early in the project planning and design stages, which helps build trust and mitigate opposition. Holding detailed and transparent discussions with residents about project specifics, including risks and benefits, can help resolve public concerns. Overall, addressing public opposition to hydrogen production requires proactive education, early engagement, and transparent communication to build understanding and support among residents and stakeholders.

Municipalities also indicated the benefits of implementing green hydrogen projects at the local level based on their knowledge. Hydrogen projects, especially in public transport, for example, can reduce air pollution and improve public health by emitting only water vapour and heat. Additionally, with increased fuel accessibility comes an enhanced availability of hydrogen filling stations for hydrogen-powered vehicles. Economically, stakeholders could benefit from potentially lower transportation costs and reduced emissions.

However, municipalities see the disadvantages that the ongoing hydrogen projects can bring as well. While hydrogen projects offer significant environmental and economic advantages for municipalities, addressing public resistance through education and information dissemination is crucial for successful implementation. First of all, due to a lack of information and understanding about hydrogen technology, there can be natural resistance and misconceptions about its safety and benefits. From this arises a need for education. Effective informational and educational campaigns are essential to inform residents about the benefits and safety of hydrogen, thereby reducing resistance and fostering acceptance. However, this also requires additional knowledge and additional specialists at the local level.

Considering the pros and cons of hydrogen projects, all respondents expressed interest in cooperating with other municipalities and foreign institutions on green hydrogen projects. There is a strong interest in collaborative efforts to develop green hydrogen projects, focusing on exchanging knowledge, increasing capacity, and enhancing public understanding and support. Benefits of cooperation include sharing best practices and experiences, increasing planned capacity and expanding the hydrogen network, raising awareness about hydrogen technology and its benefits and learning from existing operational hydrogen facilities.

Another problem related to the success of green hydrogen implementation is the lack of specialists. All respondents agree that there is a significant lack of specialists in the field of green hydrogen at the local level. Addressing the lack of specialists in the field of green hydrogen requires focused training and educational programmes, with local authorities and relevant institutions playing a key role in organising these initiatives.

Key recommendations:

- The public should be proactively educated about hydrogen's benefits and involved in the early stages of project planning to mitigate opposition and misconceptions as well as build understanding and support among residents.
- Green hydrogen projects should also be implemented at the local level, especially in public transport.
- Municipalities benefit from cooperation with other local authorities as well as foreign institutions through sharing best practices, increasing planned capacity and raising awareness.
- Focused training and educational programs for local authorities and relevant institutions are required to address the lack of specialists.

9.2.2 National public authorities

For this target group, two ministries, EPSO-G, which is a state-run group of energy transmission and exchange companies, and the Environmental Protection Agency were interviewed. The interviews found that Lithuania's ambitious energy transition towards green hydrogen and renewable energy faces several key challenges that need to be addressed to achieve a sustainable future.

One of the primary obstacles is the high production cost of green hydrogen. This is due to the significant energy input required, primarily from renewable sources, and the efficiency losses in the electrolysis process, making green hydrogen less competitive compared to traditional methods.

Infrastructure development also poses a major challenge. Developing the necessary infrastructure for hydrogen storage, transportation, and filling stations is critical. This includes adapting the natural gas network for hydrogen transport and constructing new facilities to meet demand. Longterm storage solutions for green hydrogen are essential to ensure a stable supply, but they are complex and challenging to develop.

Regulatory stability and market incentives are crucial for the energy transition. Regulatory reforms are needed to streamline processes, prioritise green hydrogen projects, and establish funding mechanisms. Achieving regulatory stability is difficult due to the evolving energy market. Financial incentives, such as Contracts for Difference (CfD) and Power Purchase Agreements (PPA), are vital for attracting investment but require careful planning and implementation.

Creating sufficient market demand for green hydrogen across various sectors, especially in transportation and heavy industries, is vital. The market is not yet fully formed, and consumers are often reluctant to pay higher prices for green energy. Decarbonising sectors like heavy industry, aviation, and heating is particularly challenging due to their high energy demands and reliance on fossil fuels.

Supply chain disruptions are another critical challenge. Potential delays in permitting and supply chain issues for renewable energy technologies can hinder the progress of offshore wind and other renewable projects. Offshore wind energy development, crucial for green hydrogen production, faces high costs and permitting delays, affecting project timelines and cost-effectiveness.

There is also a shortage of skilled engineers and specialists who are needed to develop and maintain new green technologies. Reliance on foreign technologies and services exacerbates this bottleneck. Investing in national education programs and specialist training is necessary to build a skilled workforce for the energy transition.

Moreover, effective international cooperation, particularly in the Baltic Sea region, is essential for sharing best practices and accelerating green hydrogen adoption. Collaboration in projects like Interreg "HyTruck" and the Baltic Offshore Grid Initiative is crucial for regional integration and development. Continuous progress in system flexibility and the electrification of fossil fuelconsuming sectors is necessary for success.

Furthermore, rigorous Environmental Impact Assessments (EIA) are important for renewable energy projects, including hydrogen production. Ensuring that these projects align with environmental protection goals and safety standards is crucial for sustainable development. Addressing land use and habitat impacts through careful planning and stakeholder engagement is necessary to mitigate potential negative effects of renewable energy infrastructure.

In summary, Lithuania's ministries and EPSO-G are proactive in promoting renewable energy and green hydrogen, focusing on creating a supportive regulatory environment, addressing challenges through state support and international cooperation, and emphasising the importance of ambitious yet achievable targets, robust infrastructure, and technological advancements to drive sustainable development in the energy sector.

Key recommendations:

Regulatory reforms towards market incentives and regulatory stability are needed to streamline processes, prioritise green hydrogen projects, create sufficient market demand and establish funding mechanisms.

- The state should invest in national education programs and specialist training to build a workforce skilled for green technologies.
- Effective international cooperation should be pursued to share best practices and accelerate green hydrogen adoption.
- Careful planning and stakeholder engagement through Environmental Impact Assessments (EIA) are necessary for safe sustainable development.

9.2.3 Infrastructure operators

For this target group, the infrastructure companies Amber Grid, LitGrid, ESO as well as Klaipeda port were interviewed. As a result, several key challenges that Lithuania faces in advancing hydrogen and renewable energy infrastructure have been identified.

First of all, developing hydrogen infrastructure requires advanced technologies and significant research to overcome engineering obstacles and ensure operational efficiency. Substantial investments are needed to fund the development and implementation of new technologies and infrastructure. Additionally, there is insufficient infrastructure for hydrogen production, storage, and transportation. Adapting existing natural gas pipelines for hydrogen transport is cost-effective but not planned until around 2050.

Second, the involvement of national authorities is crucial in creating a supportive regulatory environment, promoting investments and setting strategic priorities for the energy transition. Establishing clear policies and regulations can provide a framework that encourages investment and innovation in green energy projects. Regulatory complexities and a lack of expertise further hinder progress.

Third, a critical challenge faced by energy infrastructure organisations is the shortage of specialists in green energy. This scarcity complicates infrastructure development efforts, particularly in specialised areas such as hydrogen production equipment. Moreover, a shortage of highly qualified electrical engineers complicates development efforts, emphasising the importance of investing in education and capacity-building initiatives.

Furthermore, the fourth challenge is public resistance and a lack of municipal support, which also hinder the achievement of renewable energy targets and pose significant obstacles.

Fifth, limited grid capacities for mass electrification and ambitious climate goals also present significant hurdles. Moreover, increasing system flexibility, seasonal energy storage, and active system management remain ongoing challenges. Customer reluctance to fund reconstructions and limited network capacity further impede progress. Perhaps one of the most critical challenges is ensuring a balanced system that matches new generation with energy consumption. This requires strategic planning and coordination across various stakeholders to optimise energy distribution and usage effectively.

Sixth and more generally, unaddressed uncertainties in energy sector development and long planning horizons pose challenges to infrastructure projects. Sector integration and complex project implementation processes require careful navigation to ensure successful outcomes.

Finally, high production costs of green hydrogen, primarily due to electricity prices, pose a significant barrier.

In conclusion, navigating the challenges of the energy transition requires a collaborative effort from energy infrastructure organisations, national authorities, and other stakeholders. By addressing technological complexities, regulatory hurdles, and workforce shortages while embracing innovation and strategic planning, these organisations can overcome obstacles and pave the way towards a sustainable energy future.

One of the most cost-effective solutions is adapting existing natural gas pipelines for hydrogen transportation. This approach is economically advantageous, being 30-50% cheaper than building new infrastructure. Additionally, the European Northern hydrogen backbone project offers significant benefits by providing access to the broader European market, facilitating faster implementation with potential EU funding. Investing in infrastructure for hydrogen storage and transportation is also important.

Investing in infrastructure for offshore-wind farms is another strategic focus. The Klaipeda National Port has signed investment agreements to develop necessary infrastructure, such as reconstructing quays for wind power infrastructure. These efforts support the assembly, loading, and storage of wind power equipment and position the port as a centre for offshore wind-farm maintenance.

International cooperation also plays a crucial role in the energy transition. Collaborative efforts provide valuable knowledge exchange, facilitate joint regional projects, and enhance technological and organisational capabilities. Lithuania collaborates closely with countries in the BEMIP region to share best practices, technologies, and financing strategies, smoothing the implementation of RES and hydrogen infrastructure projects.

Generally, clear and stable strategic goals as well as political agreements with regional countries are necessary to attract investors and achieve renewable energy targets. Continuous monitoring of neighbouring countries' energy system plans and seeking approval from relevant institutions for anticipatory investments are also crucial.

As mentioned above, the shortage of specialists in green energy is a significant hurdle. To address this, initiatives such as promoting scientific research, expanding higher education programs, and creating specialised training courses are essential. Some companies are actively involved in developing these programs, collaborating with training institutions, and contributing to curriculum development. Additionally, attracting international experts and participating in specialised events can further alleviate the expertise gap. Addressing the shortage of highly qualified electrical engineers through collaboration with universities, offering scholarships, internships, and participating in student events can attract and develop the necessary talent for the energy sector.

Public education on green energy and active participation from society and businesses are also crucial for successful green energy development. Therefore, infrastructure companies encourage promoting public education and engagement to increase acceptance of new technologies.

To support green initiatives, simplifying regulations and fostering public-private partnerships are essential. By making the regulatory environment more conducive to innovation and investment, and encouraging collaboration between the public and private sectors, green energy projects can gain the necessary support and momentum. Energy infrastructure organisations thus propose active involvement from state institutions in creating longterm development strategies, promoting investments, fostering international cooperation, and enacting favourable legal regulations. The electricity and gas distribution company ESO emphasises utilising existing resources and optimising infrastructure to save costs and maximise efficiency. Implementing usercentric planning based on consumption scenarios ensures optimal network use. Reviewing strategies to attract skilled professionals and fostering international cooperation to share new technologies and practices can further enhance development efforts.

Further, green hydrogen is and should be considered for energy storage or grid balancing, depending on market demand. This flexible approach allows market participants to choose the most suitable technologies for their needs, ensuring that renewable energy development is economically justified and does not burden consumers.

Sector integration and cooperation across energy sectors are also vital for a cohesive and successful energy transition. Energy infrastructure organisations emphasise the importance of aligning electricity and gas network plans to assess hydrogen development opportunities and production centres. Enhanced international cooperation, particularly with Baltic Sea region transmission system operators, can synchronise systems and develop energy hubs, increasing bandwidth and expanding export opportunities.

For green energy to flourish in Lithuania by 2030, state institutions must thus actively create longterm development strategies, promote investments, foster international cooperation, and educate the public. Simplifying regulations, promoting public-private partnerships, and ensuring stakeholder engagement are crucial steps toward achieving Lithuania's ambitious renewable energy and hydrogen infrastructure goals. It is believed that active participation from society and businesses, alongside continuous technological advancements, and regulatory support, will pave the way for a sustainable and resilient energy future.

Key recommendations:

- Simplified longterm development strategies and policies fostering public-private partnerships should be implemented.
- Existing natural gas pipelines should be adapted for hydrogen transportation to create a cost-effective solution to transportation issues.
- Investments in infrastructure for hydrogen storage and offshore-wind farms should be promoted to achieve active participation from businesses and foster technological advancements.
- International cooperation and regional collaboration is highly beneficial to attracting investments and achieving renewable energy targets.
- Educating the public will help to achieve active participation from the society and increase acceptance of new technologies.

9.2.4 Private companies

For this target group, European Energy Lithuania (Danish renewable energy company), Ignitis Group (the largest electricity and gas supplier in Lithuania), Orlen Lietuva (Lithuanian oil refining company), the Lithuanian confederation of industrialists, and Klaip□da industrialists' association each highlight various challenges and solutions for renewable energy development in Lithuania, particularly focusing on green hydrogen.

Lithuanian institutions and companies have identified several key areas essential for advancing renewable energy, particularly green hydrogen and offshore wind. The potential benefits of initiatives like the European Northern Hydrogen Backbone, which aims to facilitate green hydrogen production and export from Lithuania to Western Europe, are significant. These include increased investment, job creation, and enhanced scientific knowledge and competitiveness for Lithuania. However, the following challenges must be addressed to realise these benefits.

One major challenge is the high production cost of green hydrogen, primarily due to electricity prices. This makes green hydrogen more expensive than traditional methods such as grey hydrogen. Additionally, insufficient infrastructure for the production, storage, and transportation of hydrogen poses a significant barrier. Dedicated pipelines and transport systems are essential but currently lacking. Moreover, there is a need for market reorganisation and integration, particularly for solar and wind energy, to create a more flexible and decentralised electrical grid.

Regulatory uncertainty and complex bureaucratic processes further hinder the development of renewable energy projects. Simplifying and streamlining bureaucratic processes to prioritise green hydrogen projects is necessary, along with clear and consistent regulatory policies to provide the stability needed for longterm investment and development.

Public resistance to new technologies, exemplified by incidents like the Darbenai case (intention to build a new emethanol factory in that region), underscores the need for effective communication and public engagement. Increasing public awareness and education about the benefits of renewable energy is crucial for gaining societal acceptance. In order to do so, a focus on scholarships and the active promotion of renewable energy studies is recommended to increase interest and participation. Comprehensive education and training programs should focus on technology performance, economic benefits, and the integration of renewable energy into existing curricula. Public information campaigns can help reduce scepticism and increase acceptance of new technologies.

As there is also a shortage of skilled specialists who are needed to develop large-scale energy projects, the local education system needs to be improved to train future professionals in the field of renewable energy. Furthermore, state subsidies, pollution taxes, and favourable tariffs for renewable-energy sources can help offset high production costs.

Overall, a coordinated strategy involving government, industry, and public participation is essential for achieving Lithuania's renewable energy targets. Addressing regulatory uncertainties, improving infrastructure, ensuring a skilled workforce, and fostering international cooperation are crucial steps towards a sustainable green energy future.

Key recommendations:

- Bureaucratic processes should be simplified and streamlined in combination with clear and consistent regulatory policies to prioritise green hydrogen projects.
- Public awareness and education should be increased through specialised training and public information campaigns to reduce public resistance to new technologies.
- Future professionals should be trained in the respective energy sectors to counteract the shortage of skilled specialists.

9.2.5 Research institutions

Research institutions in Lithuania (Vilnius university, Vilnius TECH, Lithuanian Energy institute and Kaunas Technology University) have identified several key challenges and opportunities in advancing renewable energy technologies, particularly offshore wind and hydrogen.

The first major obstacle is the need for increased public education and awareness about these technologies. Although renewable energy studies are available, their popularity is low. Institutions suggest that scholarships and active promotion could boost interest. International cooperation and public information dissemination are also crucial to overcoming barriers in developing large energy infrastructures. Public education also plays a significant role in reducing scepticism and opposition, thereby increasing acceptance of new technologies.

Another significant challenge is the certification and price competitiveness of green hydrogen. Current estimates for green hydrogen range from 6 to 12 EUR/kg , indicating the need for substantial capital and operational expenditure support. A stable electricity supply is critical for optimal electrolyzer operation, necessitating large amounts of green electricity. Additionally, the transportation of hydrogen from production sites to end-users requires dedicated pipelines or transport systems, which are currently lacking.

To address the problem of a shortage of skilled personnel, research institutions advocate for comprehensive educational programs and joint academia-business initiatives. Establishing a Hydrogen Technology Valley for industrialscale training could help develop the necessary workforce. An additional approach could be specialised training programs that encourage retraining from other sectors, and developing initiatives to attract young talent. There is also a call for more international cooperation to enhance technological exchange and collaborative research.

Moreover, economic competitiveness of green hydrogen with existing energy sources is essential. Creating a favourable legal environment and clear policies to attract investors and support infrastructure construction are thus important steps. Investing in scientific research and development, particularly in physical and technological sciences, is crucial to enhance economic competitiveness.

To integrate hydrogen into the mainstream energy system, a comprehensive approach is needed. This involves ensuring surplus or cheap green electricity, installed hydrogen capacities, transportation infrastructure, skilled personnel, and willing endusers. Overcoming challenges such as regulatory uncertainties, infrastructure development, and public education are essential steps toward a sustainable green energy future for Lithuania.

Key recommendations:

- Public education and awareness should be enhanced through the promotion of renewable energy studies and scholarships as well as comprehensive educational programs and joint initiatives between academia and the industry.
- A clear certification process for green hydrogen should be established to ensure its recognition and competitiveness in Europe.
- Investments in green electricity generation should be made to provide a stable supply for hydrogen production.
- Infrastructure such as dedicated pipelines and transport systems for efficient hydrogen distribution should be developed.
- International cooperation should be fostered by engaging in technological exchange and collaborative research with international partners.
- A favourable legal environment should be created to develop and implement comprehensive and clear strategies attracting investment and integrating hydrogen into the energy system.

9.3 Poland

9.3.1 Local public authorities

Local government administration in Poland is responsible for implementing local energy and climate policies – including the preparation of regional strategies to support the development and use of renewables and hydrogen, the creation of energy clusters, hydrogen valleys, transport policy or, in case of municipalities, the development of fuel and energy demand plans. The authorities often cooperate with investors by supporting the implementation of investment projects, also in terms of public perception. Furthermore, it is not uncommon for local authorities in Poland to organise various campaigns and events that raise public awareness of renewables and hydrogen and provide a platform for discussion of key issues for offshore wind and hydrogen industry. Interviews conducted with representatives of key local authorities, for example the West Pomeranian and Pomeranian Voivodeships, allowed the following conclusions to be drawn and recommendations to be defined.

Polish local governments possess reasonable knowledge about offshore wind and hydrogen economy in Poland. They are aware of their key role for the transformation of the energy sector in Poland. Nevertheless, they express the need for more detailed knowledge, especially regarding hydrogen. Training or study tours for representatives of the local administration are thus recommended. Recognising the important role of these sectors, local authorities are active towards the national government (the central administration), pointing out industry development issues visible from a local perspective.

Moreover, local governments in both provinces are actively involved in solving the industry's problems. Both the Pomeranian and West Pomeranian regional authorities take action primarily towards solutions to support the development of human resources for the offshore wind sector. The local authorities support the creation of new education and training courses and support the industry in its efforts. However, they also emphasise the need to focus on secondary vocational and technical education and to support business in, for example, organising apprenticeships or training in these sectors.

Offshore wind and hydrogen are seen by local authorities as a historic opportunity for many companies and institutions to develop their products and services in these sectors. The authorities see great potential for companies to become part of global supply chains in these sectors and also see significant potential for innovation projects. For local authorities, a key issue is the so-called local content, which is support for local companies to participate in the implementation of projects in Poland and Europe. They support infrastructure projects, which are welcomed in municipalities, but with a focus on supporting local business. In addition, they highlight the positive impact of investments made in the sector, especially offshore wind, on the labour market. Local authorities point to positive aspects, such as increased employment, better-paid jobs and employees gaining additional competences, as well as the negative like the cannibalisation of the labour market which induces a fear of attracting employees from other sectors to this sector or the remaining poor cooperation of new businesses with universities and secondary technical schools.

Furthermore, Polish local authorities support the preparation of installation and service ports. The development of port infrastructure will have an impact on the revitalisation of the region, which is indisputable for the local authorities. They also underline the expected economic development in the vicinity of small ports.

As local authorities do not have sufficient staff to serve the offshore wind and hydrogen sector, administrative procedures are often prolonged which is the responsibility of the local authorities. Additionally, due to the innovative nature of these industries, local authorities recognise the need for further education and training of staff. This would ensure that the tasks carried out by the municipality are performed on the relevant level of competence and that administrative procedures are streamlined.

Beyond internal challenges, international cooperation is very important for local authorities. They see an opportunity to learn about good practices and experiences from other regions or countries. The local governments in Poland are very active internationally and are keen to get involved in all sorts of projects. In this respect, support would be required for international cooperation of local authorities in the area of offshore wind and hydrogen. They also stress that such cooperation should be well targeted and prepared in order for it to be as effective as possible.

Similarly, cooperation between local government and business is generally seen as positive. Local governments willingly support investors and local entrepreneurs representing the supply chain. It is common practice to promote local entrepreneurship at national as well as international events and study tours.

Key recommendations:

- Support is needed to train and educate the staff of local institutions and local authorities.
- More emphasis should be placed on international cooperation, targeting local governments and exchange of experiences and good practices.
- There is a need to take measures aimed at developing a local human resources management system.
- Support for the secondary education system, including, in particular, vocational and technical education, is crucial. International cooperation in this area is also welcome.

9.3.2 National public authorities

The national government administration plays a key role in creating supply and demand for energy from offshore-wind farms and for green hydrogen. This is done by creating development policies and tools for the implementation of projects within this field. Therefore, the opinions of government representatives are highly valuable for such projects. Their input is crucial in defining recommendations that will maximise the economic and social benefits of developing the offshore wind sector and using electricity for green hydrogen production. For this purpose, a detailed survey as well as indepth interviews were conducted with representatives of the government administration who work on the legal framework for offshore wind and hydrogen to develop the following conclusions and recommendations.

Offshore wind is crucial for the transformation of the energy sector in Poland and to ensure an adequate supply of electricity for green hydrogen production. Responses collected show that offshore-wind farms, being single generation assets with large capacity, generating large volumes of energy, are an interesting source in the context of providing sufficient energy for green hydrogen production. An important feature of offshore wind in this respect is the stable operation with a high capacity factor, which in many cases can determine the profitability of investments in high-capacity electrolysers. Representatives of the administration also see an advantage in the limited possibility of power evacuation from offshore-wind farms, which allows electricity to go directly to hydrogen production facilities bypassing the public electricity grid. However, a perceived limitation to the development of the hydrogen economy in the coming years may be the high demand for renewable energy from the Polish economy and industry, which means that this is where green energy will go first. Only the saturation of this market and the emergence of surplus energy from renewables will result in a gradual development of the hydrogen market.

Moreover, further streamlining of administrative procedures and facilitating investments in offshore-wind farms is necessary. Offshore wind is a new component of Poland's electricity sector landscape and currently, there is not a single wind turbine in operation in the Polish exclusive economic zone (the first energy from the offshore wind sector is expected to flow at the end of 2025). This means that the existing legal framework needs to be adapted on an ongoing basis to meet emerging challenges. At this point, the activities of the Polish government administration, which analyses the current situation on a continuous basis and in cooperation with investors, and reacts proactively if necessary, should be welcomed. Nevertheless, the need to speed up the permitting process, which, due to the complexity of the investment projects and the environment in which they are carried out, is one of the longest for all renewables, is also recognised at the level of government administration. The need to accelerate the permitting process is also driven by the need to accelerate the energy transition in Poland and the desire to meet the industry's demand for energy from renewables to free up additional capacity for green hydrogen generation.

Ensuring adequate human resources will be key to the proper implementation of the objectives in the offshore wind and hydrogen sectors. The labour market is currently struggling with insufficient supply of employees, and Poland's current demographic situation means that there is a permanent shortage of workers on the labour market. That entails a major challenge (and risk) for growing segments of the economy including the renewable energy and hydrogen sectors, thus active measures are needed to ensure an adequate supply of workers in terms of quantity as well as quality. One of the main areas requiring adjustments is the education system that should follow the expectations of entrepreneurs and technological developments. Changes in the field of education should be holistic and take into account all levels of education, from primary to higher education. In addition, it is necessary to create conditions for acquisition of new knowledge and skills by employees leaving traditional sectors which are declining due to technological or legal changes such as energy transition. Such measures are not only part of a just transition policy, but also a market necessity – without these measures, it will not be possible to complete the projects planned.

A large-scale use of green hydrogen further requires enhanced development of relevant technologies and the creation of an adequate regulatory environment. At present, the lack of availability of suitable technology such as electrolysers or energy from renewables is defined as one of the major constraints to a widespread use of hydrogen technologies in the economy. A key role in this regard should be played by public institutions – at both national and community level – who should aim to address any imperfections in the emerging hydrogen market. It should be noted that legal regulations in Poland are still at the early development stage and, based on the example of offshore wind, preparing the relevant legal framework and adapting it to the dynamically changing innovative market takes several years.

Generally, cooperation between investors and administration is seen as positive. The government administration views cooperation with investors in offshore wind-farm projects as important. This is due to the openness of the administration at the stage of creating the legal framework for offshore wind, which means defining a new market that has not yet existed in Poland, and the professionalism on the part of the investors, who responded positively and with understanding to the expectations of the administration.

International cooperation on joint projects and the exchange of experience can have a positive impact on the development of both sectors as well. Offshore wind, due to the specific location of projects (international waters across various exclusive economic zones), is predisposed to see close cooperation between countries. In the case of farms developed in the Baltic Sea, this cooperation takes on particular importance due to the closed nature of the body of water and the possibility of integrating the electricity systems of the Baltic Sea states, especially taking into account security aspects. For the implementation of hydrogen projects, international cooperation is also expected, but its character should be different – the main focus should be on cooperation on pilot and research projects and exchange of experiences enabling the implementation of best practices contributing to the accelerated growth of this market.

Key recommendations:

- It is necessary to further facilitate investment for offshore-wind farms to accelerate the entire process.
- More emphasis should be placed on education and training of human resources to meet the adopted targets for offshore wind and hydrogen economy.
- There is a need for strong support for pilot and R&D projects in the green hydrogen sector.
- Cooperation in the Baltic Sea should be strengthened with regard to the implementation of wind and hydrogen projects.

9.3.3 Infrastructure operators

offshore-wind farms and green hydrogen facilities as components of the electricity system require adequate integration in the transmission grid. Transmission system operators play a key role in this regard, as they are responsible for the stability of grid operation and its balancing. Their opinion is therefore necessary to develop comprehensive recommendations for the development of the green hydrogen sector. Thus, a detailed survey complemented with indepth interviews were conducted with electricity grid operators in Poland leading to the following conclusions and recommendations.

First of all, there is a need for a clear, long-term vision for the development of hydrogen and offshore wind sectors. With the current geopolitical situation and new regulatory requirements at the EU level, the Polish Hydrogen Strategy until 2030 can already be considered outdated and failing to address the current challenges and needs of the economy. The lack of clear guidelines considering future demand, production and the infrastructure required makes long-term grid planning and development difficult. Without a clear strategy for green hydrogen development, operators are limited in making effective investment decisions regarding the development of hydrogen infrastructure. Only by defining clear objectives and setting a coherent development pathway can investment, research and regulatory action be guided in the right directions, ensuring optimal use of resources and reduced risk for all stakeholders.

Second, on a positive note, there is a strong synergy between green hydrogen production and offshore-wind farms. However, the adequate regulation to enable such solutions to be applied is currently lacking. According to responses collected, operators believe that the production of green hydrogen at offshore-wind farms can have a positive impact on the balancing of grid operation. With the ability to convert and store excess electricity from offshore-wind farms during periods of high generation, green hydrogen can become an effective tool for managing electricity supply and demand. This, in turn, can contribute to the reduction of grid congestion and transmission bottlenecks. Nevertheless, operators believe that there is currently no dedicated legal framework for such solutions. Changes in the law are not keeping up with current market challenges, making it very difficult to actually implement innovative projects.

Additionally, an appropriate funding strategy should be created for hydrogen infrastructure development. At the moment, there is a shortage of transport and storage infrastructure for hydrogen, hindering widespread deployment of renewable and low-carbon hydrogen across the energy system. Meanwhile, transmission system operators are limited in their capabilities to finance the necessary expansion of hydrogen infrastructure. Many operators argue that investment in hydrogen is beyond their current credit capacity. Thus, political decision-makers should develop a relevant strategy to support the expansion of the hydrogen grid with public funds.

Apart from financial resources, ensuring adequate human resources will also be key to proper implementation of the objectives for offshore wind and hydrogen economy. Operators agree that the offshore wind and green hydrogen sectors will generate an enormous number of jobs as they require significant development of infrastructure, technology and services. At the same time, little choice of educational programmes exists for hydrogen industry professionals in Poland. Therefore, there is a risk that with the current demographic problems the Polish labour market will have limited possibilities to meet the demand for specialists in green hydrogen and offshore wind. Addressing the skills shortage requires targeted efforts to develop specialised training programmes, improve technical skills and support interdisciplinary collaboration between grid operators and hydrogen industry specialists. As the energy transition progresses, current jobs in the fossil fuel sector will slowly disappear. Employees from that sector should receive adequate support from the state to help them acquire relevant skills in emerging energy sectors.

Finally, international cooperation on joint projects and the exchange of experience can have a positive impact on the development of infrastructure in both sectors. International cooperation between network operators is essential for the development of the European green hydrogen market. In this respect, the focus should be on expanding cross-border gas and electricity – and in the future hydrogen – interconnectors, particularly with countries around the Baltic Sea. The Baltic Sea region has significant potential for renewable energy, in particular offshore wind. Through cooperation on integrated hydrogen infrastructure development, the neighbouring states can increase resilience to supply chain disruptions and geopolitical tensions, providing a stable and secure source of energy for the region. Cooperation between international operators will also enable the exchange of best practice, technology and experience to facilitate accelerated innovation and technological progress in this sector.

Key recommendations:

- Poland needs an updated strategy for green hydrogen development that would take into account the current challenges and growing needs of the economy.
- A relevant regulatory framework should be created to enable development of hydrogen infrastructure.
- There is a need for an appropriate funding strategy for hydrogen transmission infrastructure.
- More emphasis should be placed on education and training of human resources to meet the adopted targets for offshore wind and hydrogen economy.
- The number of crossborder electricity interconnectors should be increased and the development of a common infrastructure for hydrogen transport should be pursued in the Baltic Sea Region.

9.3.4 Private companies

The point of view of entrepreneurs developing investment projects in the offshore wind or hydrogen sectors is essential to properly map the challenges and bottlenecks, whose elimination will allow for uninterrupted achievement of targets set for these sectors. Therefore, a detailed survey was conducted with representatives of stakeholders involved in offshore wind projects, both investors directly responsible for offshore windfarm projects and stakeholders from the broader supply chain. Moreover, a number of interviews, discussions and consultations with people familiar with and active in the Polish offshore market have been conducted.

As for relevant infrastructure, there is a similar need for a clear, longterm vision for the development of the hydrogen and offshore wind sector targeting the private market. The issue of proper design of development policies is not new in Poland. There are common claims about the opportunistic nature of such documents, their mismatch with the current situation and anticipated directions of development. This is also the case in the fields in question. Entrepreneurs report the need to ensure a longterm vision for both sectors and to define them at the level of key strategic documents. Although Poland has a development strategy for the energy sector (Poland's Energy Policy until 2040), it is widely regarded as inadequate and unsuited to Polish realities. Moreover, the word 'policy' properly reflects the document's content, where economic and social rationality are not always of key importance in determining the energy mix. However, it is worth noting that, for the offshore wind sector, long-term planning adopted at statutory level should be considered a positive example of planning compared to other energy sectors although still not to be considered optimal. The hydrogen sector also received its own separate development strategy (Polish Hydrogen Strategy until 2030 with an outlook until 2040), which should also be seen as an important signal from the government administration that this area is of particular importance that will continue to grow in the coming years.

What's more, further streamlining of administrative procedures and facilitating investments in offshore-wind farms is necessary. The entrepreneurs' assessment of currently applicable regulations governing the offshore wind sector is not conclusive. On the one hand, there are opinions that the legal framework in this area is well-structured, while on the other hand, arguments are raised that the provisions are ambiguous and leave too much room for interpretation at the administrative level. Such an assessment certainly comes from own business experience and is valuable information that calls for further optimisation measures to be introduced. This is also where the needs and expectations of businesses may clash with the needs and expectations of the state, represented by the central and local government administration, due to the government's need to protect the rights and interests of particular social groups, citizens. Nevertheless, the demands to speed up and facilitate administrative procedures accelerating the entire investment process, raised by entrepreneurs, are identical to the conclusions from the government administration, suggesting that this component is indeed a significant barrier to development today.

With regard to contacts with the administration, both national and local, entrepreneurs raise the need for more human resources on the part of the administration as well as a necessary improvement of its quality which suffers from insufficient competence and knowledge, also indicated as some of the barriers to the development of the offshore wind sector causing investment delays. This perspective from the business side may seem surprising in the light of the traditional view of administration as overstaffed.

Furthermore, ensuring adequate human resources within private companies will be key to the proper implementation of the objectives in the offshore wind and hydrogen sectors. The issue related to providing specific human resources necessary for development of investment projects is identified by most stakeholder groups. The demographic and structural challenges facing the Polish labour market require coordinated action by multiple stakeholders – both at the level of administration, central as well as local, and at the level of business, business environment institutions, educational facilities, etc. Entrepreneurs notice the risks related to the rapidly growing offshore wind market with the first projects moving from the design phase to construction, as well as in the context of the green hydrogen market expected to grow in the future. While the market is still in a very early stage of development, the main demand for human resources will only appear in a few years from now.
One of the main barriers to the development of offshore wind projects in the coming years will be the insufficient industrial base, which will contribute to bottlenecks at the supply chain level. Already, investors are competing with each other for access to adequate capacity at individual factories, taking on an increasing risk related to project delays. A similar situation also exists in services for offshore wind projects – this is particularly clear in services requiring access to a specialised fleet of vessels, where there is a strong shortage of suitable vessels, expected to further increase in the next few years. An important element for the future will be the need to better coordinate the planning of investment activities in Europe and in the Baltic Sea area, enabling the synergies of joint and coordinated implementation of individual projects to be utilised, which will significantly improve delivery and installation logistics, thus making it possible to meet the adopted schedules. In the context of supply chain expansion, it is essential to continue and strengthen the actions taken by the European Commission in the second half of 2023 focused on building a strong European supply chain for the offshore wind sector. There is a similar situation for the hydrogen sector, which is also facing delays in the delivery of key equipment, such as electrolysers. In this context, and given that this market is likely to develop as dynamically as offshore wind, identical problems can be expected.

Overall, hydrogen production is an opportunity for additional development of offshore wind. Entrepreneurs in the hydrogen and offshore wind sectors recognise the opportunity presented by the increased demand for electricity from hydrogen production to develop additional offshore wind projects. Hydrogen production is becoming an alternative to connecting offshore-wind farms to the electricity grid, which is getting increasingly complex, enabling more projects to be implemented. This is particularly important for the implementation of hydrogen projects, which need a direct connection to an RES generation asset. Poland is currently one of the largest producers of hydrogen in Europe and, if this position is to be maintained, future production should only involve green hydrogen. In this context, offshore wind energy is perceived as an opportunity to move from grey to green hydrogen production with access to large, stable volumes of electricity from renewables.

International cooperation between large enterprises on joint projects and the exchange of experience can further positively influence the development of both sectors. In the context of international cooperation, the issue of grid infrastructure – both for the transmission of electricity and for the transmission of hydrogen – is becoming a priority. This type of cooperation may be particularly interesting given the enclosed nature of the Baltic Sea and the historically well-established cooperation in other areas. Grid-related cooperation is also a matter of increasing integration between the countries of the region that are largely within the EU with implications for energy security issues in this part of Europe.

Key recommendations:

There is a need for long-term planning of development of the hydrogen and offshore wind sectors ensuring predictable conditions for investors.

Improvements in human resources at the administrative level are also needed. In this context, consideration should be given to creating a dedicated authority, grouping together the competences necessary for the development of the offshore wind sector.

- More emphasis should be placed on education and training of human resources to meet the planned targets in the area of offshore wind and the hydrogen economy.
- There is also an urgent need to strengthen the supply chain necessary to meet the ambitious targets in the offshore wind sector and for hydrogen projects.
- Greater integration between the Baltic Sea states should be pursued by increasing cross-border electricity interconnectors in the Baltic Sea and building a common hydrogen transport infrastructure.

9.3.5 Research institutions

In Poland, universities and research institutions are supporting the development of the offshore wind and hydrogen sectors. There is a very strong awareness among these institutions of the need to adapt their teaching and research offerings to the needs of these growing sectors. There is a clearly visible, rapidly developing offer from universities, as well as an increasing range of research projects carried out by research institutions in cooperation with businesses or in international partnerships. Interviews conducted with academic and research institutions from the West Pomeranian and Pomeranian regions allowed the following recommendations to be defined.

According to representatives from universities and research centres, the offshore wind sector, combined with green hydrogen, could be one of the cornerstones of energy transition. The role of green hydrogen is to store energy from wind turbines to be used in periods without wind. According to the majority of institutions who participated in the survey, offshore-wind farms can significantly support the production of green hydrogen. A small number of respondents indicated that the offshore wind sector would not play a significant role in powering electrolysis (concerns include high prices for electricity from offshore wind and the wording of Article 5 of the RFNBO regulation). Nevertheless, the vast majority of stakeholders indicate that offshore wind and hydrogen combined are a key condition for meeting the targets of EU's climate and energy package, even despite higher upfront costs.

This stakeholder group also indicates what is needed for offshore wind and hydrogen to become the mainstream of development in Poland. The need for clear strategic objectives and a coherent, consistent state policy to support these sectors was highlighted most frequently. Further, a demand for a clear and adequate legislative framework and targeted subsidies was pointed out. One of the more important issues is the need to build public awareness, to strengthen public acceptance of these sectors and to increase knowledge about them, for which the state should take on a major role. The need to make entrepreneurs aware of the potential of hydrogen technologies and business opportunities in the renewables industry was also highlighted. Necessary infrastructure investments including, above all, grids and port infrastructure were highlighted as other important issues. Public support for education from primary to university level is especially important here.

Moreover, according to representatives of universities and research centres, there are insufficient education, research and development programmes to produce and scale up the necessary offshore wind and hydrogen technologies in Poland. The need for an increase in appropriate research programmes, providing opportunities for laboratory expansion, is recognised. Some representatives of the scientific community declared that the programmes are there, but their number and scale may not be sufficient to meet the objectives. The role of universities should be to ensure the transfer of knowledge to companies and the general public, working together to find appropriate courses of action for the development of wind energy, which is an important aspect of energy security. Research and education programmes are developing all the time and it seems that the mutual involvement of universities and companies should yield greater results.

A key factor in increasing the effectiveness of the education and research programmes necessary for the development of technologies and technical and social solutions leading to climate neutrality in EU countries is the education of local governments, business environment institutions, secondary and higher education staff, to teach the teachers so to say.

In order to prevent staff shortages, it is necessary to adapt education programmes to market needs. In addition, measures are needed to improve the quality of technical education at secondary level and technical and economic-management education at university level. To achieve this, it is essential that employers in the offshore wind and hydrogen sectors identify what type of qualifications they need and expect. It is also necessary to review establishments and possibly develop specific training courses with the support of both the government and industry stakeholders. One of the solutions identified is also the creation of profiled university courses. The development of educational and research programmes should be supported by project funding. Training with state-of-the-art technologies used in the industries is essential.

The need to develop research infrastructure and laboratories is essential in order to attract high school graduates to study at university courses needed by the offshore wind and hydrogen sectors. Increasing staff capacity and competence is also an important factor here. Again support from the industry is of key importance here. It was pointed out that Poland lacks an institution that would be trusted by all stakeholders and be a platform for dialogue between industry (employers) and universities (education). Even before high school, knowledge about the offshore wind and hydrogen sectors and potential career paths from primary school onwards should be transferred to encourage young people to educate themselves in the directions needed for the further development of the sector.

Unfortunately, the teaching staff is not fully prepared to educate for offshore wind or hydrogen economy. Thus, public support is needed for the upskilling of this workforce by employees from the already established offshore wind and hydrogen sectors. A similar situation exists in secondary vocational education. There is a shortage of vocational education teachers. A hybrid education system has been proposed – with an Austrian system of technical vocational education wherever possible, and education programmes with public-funded employment of teachers from the offshore wind sector (including legal solutions to lift the requirement for teaching background).

Several potential research topics of interest were identified during the interviews. These include: digitalisation, O&M, floating support structures, grid integration, energy storage, possibility to use hydrogen as fuel for offshore wind vessels, project management.

In terms of international cooperation, there is a need for bidirectional activities between business and science. Universities in Poland need to develop the potential for research and implementation, including commercial implementation, which requires financial support from companies in the offshore wind and hydrogen sectors, often large multinational corporations. Only the right level of funding will allow research teams to be set up at universities, with academics carrying out research for business without the need to be involved in teaching activities. Exchange of experience between universities and integration of the research community can be of key importance to the development of those technologies.

Barriers perceived in terms of international cooperation and integration of international research communities include the lack of language skills, mental/cognitive block, generational barriers, lack of funding at Polish universities for implementation-oriented research and lack of talent which can be explained by qualified people preferring to work in business, due to low salaries in the academic sector and excessive bureaucracy. Additionally, excessive formalism, a fear of leakage of sensitive information as well as a lack of funds for international integration, for example for prestigious conferences, study tours, training, project programmes, impede international cooperation among universities.

Despite the above-mentioned challenges, the research potential of Polish universities in the field of offshore wind and hydrogen was assessed as fantastic although unfortunately squandered completely.

Key recommendations:

- Greater international integration of the scientific community is recommended, in order to obtain up-to-date knowledge on the development of the offshore wind and hydrogen sectors and on current research and teaching projects.
- Increased involvement of companies in the research and education process should be pursued. Only integration of the scientific and business community will have the greatest effect on the development of the offshore wind and hydrogen sectors.
- Teach the teachers – programmes are needed to enhance the skills of staff at secondary schools and universities. This will make the teaching and research processes more efficient.
- Adapting curricula to market needs, which requires the development of infrastructure with support for businesses and dedicated funding programmes, but also ongoing support from business.
- Financial and business support for development of research infrastructure and laboratories.
- Supporting educational activities from primary school onwards to increase public knowledge of the offshore wind and hydrogen sectors.
- Providing opportunities for practitioners to work as teachers, supported by public funding.
- More integration of the research community is needed – increased funding and streamlining of procedures at universities.

9.4 Germany

9.4.1 Local public authorities

No answers received

9.4.2 National public authorities

The German national public authorities refer to the EU maritime spatial plan as the central control element for offshore-wind farms and grid connections, which implements the expansion targets. However, there are no expansion targets set by the German government for the electrolysis of green hydrogen using offshore wind energy. The following results summarise the perspectives and status-quo of national public authorities in this field.

The construction and connection of offshore-wind farms have presented significant challenges at the national level. These include timely coordination of wind farm and grid connections, integrated expansion planning, and issues concerning public acceptance. The complexity of aligning these factors has been a major hurdle in the initial phases of offshore wind energy development.

In order to address these issues, the maritime spatial plan has been crucial in resolving the initial coordination problems, allowing for more streamlined and efficient development processes. Thanks to the robust strategy that is the maritime spatial plan, Germany is on its way to achieve the EU's goal of climate neutrality by 2050. The German strategy for offshore wind energy development has been in place for several years allowing for a systematic progress towards the targets. The aim that national public authorities pursue is 80% of the energy system to be made up of renewable energies in the near future. Towards the end of the project the German government released numbers that in the first quarter of 2024, nearly 60% of Germany's electricity was derived from renewable sources, with the precise figure standing at 58.4%. According to the Federal Statistical Office, this marks the highest proportion of renewable energy in a first quarter since the survey's inception in 2018. The expansion of solar energy is already evident, although wind power continues to be the predominant source. Wind turbines (on- and offshore) contributed 38.5% of the electricity generated in Germany

The development of renewable energies in the Baltic Sea Region, including solar, onshore, and offshore wind energy, is seen by German national public authorities as a collective effort. They engage in close, long-standing cooperation with neighbouring countries through various frameworks such as maritime spatial plan projects and the Baltic Energy Market Interconnection Plan (BEMIP).

Another important issue for public national authorities is the alignment of the timeline for integrating green hydrogen into the national energy goals and ongoing regulatory revisions. Transnational exchange with other national authorities has proven to be highly beneficial in sharing best practices and experiences, fostering mutual learning and improvement. That is why national public authorities intend to enhance their cooperation in the future focusing on initiatives such as cross-border connections of offshore-wind farms and hybrid interconnectors. This will not only strengthen regional energy networks but also contribute significantly to the collective renewable energy goals. Public national authorities emphasise the importance of transnational cooperation particularly in the field of hydrogen pipeline network planning. They recognise the importance of collaborative efforts and are already engaged in existing cooperation to facilitate this aspect of hydrogen infrastructure development. This cooperation is essential to ensure the efficient and effective integration of green hydrogen production and distribution across national borders, enhancing the overall energy network and contributing to broader environmental goals.

Key recommendations:

- The development processes of offshore-wind farms should be streamlined and designed efficiently as foreseen in the EU Maritime Spatial Plan.
- The integration of green hydrogen into the national energy goals should go hand in hand with ongoing regulatory revisions.
- Transnational exchange and cross-border cooperation should be enhanced to ensure the efficient integration of green hydrogen production and distribution across national borders.

9.4.3 Infrastructure operators

No answers received.

9.4.4 Private companies

From the perspective of large enterprises in Germany, the German energy sector has been undergoing a transformation towards sustainable and renewable sources in the recent years. The transition to offshore wind energy and hydrogen technologies in large-scale projects represents one step within this evolution. This report consolidates the insights gathered from interviews with several large enterprises in the renewable sector exploring their work, future projects, challenges they face, and the prospects for the development of offshore wind and especially hydrogen production in Germany. Coastal areas bordering the North Sea and the Baltic Sea are of particular interest due to their strategic positions for offshore wind energy and green hydrogen infrastructure development.

The interviews with large enterprises in Germany indicate the need for increased support for transnational energy projects with countries sharing the North Sea and Baltic Sea borders. However, these ambitions face numerous obstacles that require coordinated efforts to be overcome. Namely, the navigation of different legal frameworks of multiple countries can slow down the project implementation. Thus, harmonised regulations are crucial for smoother operations. Furthermore, offshore-wind farms that are connected to markets beyond their home country, that is their EEZ, systematically face higher risks compared to traditional radial offshore wind projects. These conditions are not adequately addressed in current market designs and tender rules which means that regulatory adjustments are required. Additionally, technical obstacles concerning, for example, the phase shifters, which are essential for stabilising the electricity flow between different grids, can occur. Public acceptance is another obstacle to be overcome. For example, projects such as the Norway-Germany energy exchange faced public resistance due to concerns over increased electricity prices in Norway.

Despite the push for renewable energies, there are doubts among large enterprises about the necessity of a hydrogen energy grid in the Baltic Sea because of the aforementioned obstacles. Other experts point out that the cooperation between countries sharing the North Sea and Baltic Sea borders is crucial for accelerating the development of a robust hydrogen pipeline infrastructure network. The European Hydrogen Backbone Implementation Roadmap from 2023 outlines key pipeline networks for these regions, emphasising the necessity of coordinated efforts to realise the full potential of offshore hydrogen. With the infrastructure in place, developers can achieve economies of scale, deploying significant hydrogen production capacities efficiently.

According to the interviewees in this target group, the primary consumers of green hydrogen will be the heavy industries that are difficult to decarbonise, such as refineries, steel and cement manufacturing. These have the capacity to integrate green hydrogen quickly into their processes. Looking ahead to the mid-2030s, the shipping industry is expected to demand substantial hydrogen feedstock for producing green methanol and ammonia, aligning with broader decarbonisation goals. Some interviewees also stated that hydrogen could become interesting for the market not as a pure product, but rather the derivatives of it such as ammonia. The following alternative or additional approaches have become focus of some enterprises to accelerate the hydrogen energy transition. Firstly, with the blue hydrogen approach enterprises have placed their attention mainly on blue hydrogen due to its potential to leverage existing natural gas infrastructure with carbon capture and storage (CCS). And secondly, integrating and utilising natural gas storage facilities for hydrogen is seen as a practical approach to scaling up hydrogen storage capacity.

Nevertheless, the transition to hydrogen technology is fraught with challenges, primarily related to investment risks. Projects in this field require significant investments to expand beyond current limitations but many lack such investments and thus remain on hold. The investment burden must be equitably distributed among European countries and developers benefiting from the grid. Therefore, cross-EU funding is essential to prevent early users from disproportionately high incurring transportation costs. Legislative clarity and support for infrastructure development will be crucial in overcoming these financial challenges.

Although the EU and the German government have set ambitious targets, experts from the private sector see a general lack of designated areas in the Baltic Sea for hydrogen projects. A need for tenders for hydrogen areas need to be released by the government.

Further technological obstacles such as electrolyser inefficiency due to the current early stages of development add to a difficult transition to hydrogen. As offshore hydrogen production additionally faces adverse weather conditions, electrolyser efficiency is even more challenged. The decision either for pipelines or cables for the transportation of hydrogen also poses a significant technical hurdle. Generally, pipelines are preferred over cables due to better efficiency and lower energy loss and should thus be expanded. Moreover, the ongoing energy crisis in the EU in 2024, marked by soaring commodity prices, is seen by enterprises to affect the overall feasibility and expansion of hydrogen projects.

Meeting the ambitious targets set by the EU and German government in spite of the abovementioned obstacles involves several critical steps. As achieving these targets will put immense pressure on supply chains, streamlined processes and robust infrastructure are crucial. In addition, substantial capital investments are required to develop the necessary technology and said infrastructure. In order to align interests and streamline project approvals, there is a need for ongoing dialogue with various stakeholders including the offshore wind energy sector, the shipping industry, and environmental authorities.

In conclusion, large enterprises are pioneering the transition to hydrogen as a core component to Europe's renewable energy strategy through ambitious projects and collaborative efforts. However, achieving the full potential of hydrogen energy requires overcoming technical, regulatory, and financial obstacles, necessitating greater support for transnational projects, improved cooperation between government and businesses, and sustained investment in new technologies. To address these challenges, it is imperative to establish clear ownership of infrastructure and market mechanisms for green hydrogen valuation. Transparent cross-border trading of green hydrogen certificates will enable investors to access a broad market and understand the value of their hydrogen products. The future of hydrogen energy in Europe hinges on these collective efforts and the ability to navigate the complexities of this evolving landscape. Achieving the hydrogen-related targets for 2030 will require significant effort and coordination among all stakeholders.

Key recommendations:

- Inter- and transnational cooperation between governments as well as businesses for example through harmonised regulations are necessary for a smooth development and operation of green hydrogen projects.
- Legislative clarity, capital investments and the establishment of clear ownership of infrastructure are crucial in overcoming financial challenges.
- An ongoing dialogue with all stakeholders involved is required to align interests and streamline project approvals.

9.4.5 Research institutions

From the perspective of higher education and research institutions in Germany, the energy transition, particularly in the realms of offshore wind and hydrogen technology, is a rapidly evolving sector with immense potential to transform Germany's energy landscape. However, for these technologies to become mainstream, several critical factors must be addressed. In this interview section, universities and research institutions share their insights on what needs to happen to achieve this transition, the sufficiency of educational programs, and the challenges within the supply chain and labour markets.

The path to making offshore wind and hydrogen technologies mainstream involves addressing several key issues. One of the most significant is the need for effective green energy marketing that explains the conscious use and application of renewable energy. There is great uncertainty among the public regarding the use of hydrogen with many promises made by researchers, politicians, associations, and the industry that cannot be kept. To combat this uncertainty, the No-Regret approach was explicitly mentioned by the interviewees. This involves clarifying that the future of energy lies in electrification with hydrogen being used only in selected applications where it is most beneficial. By doing so, the public can gain a clearer understanding of and trust in the role of hydrogen and other renewable energies in the future energy landscape. This strategic communication is vital to gain public trust and support for these technologies.

With the EU aiming to achieve climate neutrality by 2050, the role of educational and research programs is crucial. The interviewees agreed that while flagship projects like the various Important Projects of Common European Interest (IPCEI) are beneficial, they only represent a small part of the broader narrative. Research and Development efforts need to be particularly strengthened within small and medium-sized enterprises (SMEs) as they often produce targeted innovations. To foster widespread innovation, there needs to be a concerted effort to provide financial support, resources, and a structured framework that encourages SMEs to actively participate in the green revolution. This approach will ensure that technological advancements are not confined to large corporations but are disseminated across the industry.

Supply chain and labour shortages pose further significant challenges to the renewable energy sector, particularly in offshore wind energy and hydrogen technology. Declining students in relevant study programmes, such as Engineering and Maritime Technology Wind Energy, due to the size of the study programme exacerbates this issue. Furthermore, apprenticeship professions such as mechanics and technicians are lacking in applications. To address this, more robust support from industry associations is necessary. These associations should actively engage with educational institutions to promote relevant education and training from the school level onwards. Additionally, increasing the attractiveness of these fields through career guidance, scholarships, and clear job placement pathways could help draw more students into these crucial areas.

To address the educational bottleneck in renewable energy fields, a multi-faceted approach is necessary. Enhancing the visibility of career prospects in these sectors through targeted marketing campaigns can showcase the positive impact and innovative nature of these fields. Partnerships between educational institutions and industry players can provide practical training opportunities, internships, and apprenticeships that offer real-world experience. Furthermore, developing specialised curricula focusing on the latest technologies and practices in offshore wind and hydrogen can better prepare students for future challenges.

When asked about key research topics in offshore wind energy and green hydrogen, the importance of educating future energy users was highlighted. Companies frequently ask which energy carrier to rely on in the future; be it electrical energy, hydrogen, e-fuels, or synthetic natural gas (SNG). This indicates a substantial need for developmental and educational work in this area. Beyond education, regulation and policy frameworks around energy use and storage technologies present critical research areas. While many research and development topics are already well-covered, the integration and practical application of these technologies in daily life remain pivotal for the successful transition to renewable energy.

The development of large energy infrastructures, such as offshore wind and green hydrogen, can be more efficient through transnational cooperation. However, lengthy approval processes often hinder such collaboration. It is said that one of the main obstacles is the lengthy approval processes, especially when it comes to building infrastructure like a hydrogen pipeline in the North and Baltic Seas. To overcome these challenges, it is essential to streamline approval processes and establish a transnational regulatory body that can facilitate and expedite project approvals. Additionally, fostering a culture of collaboration and trust among countries, along with clear communication channels and shared objectives, can help harmonise efforts and resources.

To conclude, the transition to offshore wind and hydrogen technologies requires a concerted effort across various fronts, such as public awareness, robust educational frameworks, supportive research and development environments, and streamlined regulatory processes. By addressing these areas, Germany can position itself as a leader in the global energy transition, ensuring that these technologies become an integral part of its sustainable future. Through collaboration and innovation, the vision of a climate-neutral Europe by 2050 can become a reality.

Key recommendations:

- Strategic communication including clarification of the specific role of hydrogen in the future energy sector is necessary to gain public support and trust in new technologies.
- Small and medium-sized enterprises need to be supported through financial support and a structured framework in order to actively participate in the energy transition rather than just large enterprises.
- Industry associations should actively engage with educational institutions to promote relevant education and training in order to counteract labour shortages and promote public awareness.
- Streamlining approval processes and establishing a transnational regulatory body is necessary to facilitate transnational cooperation.