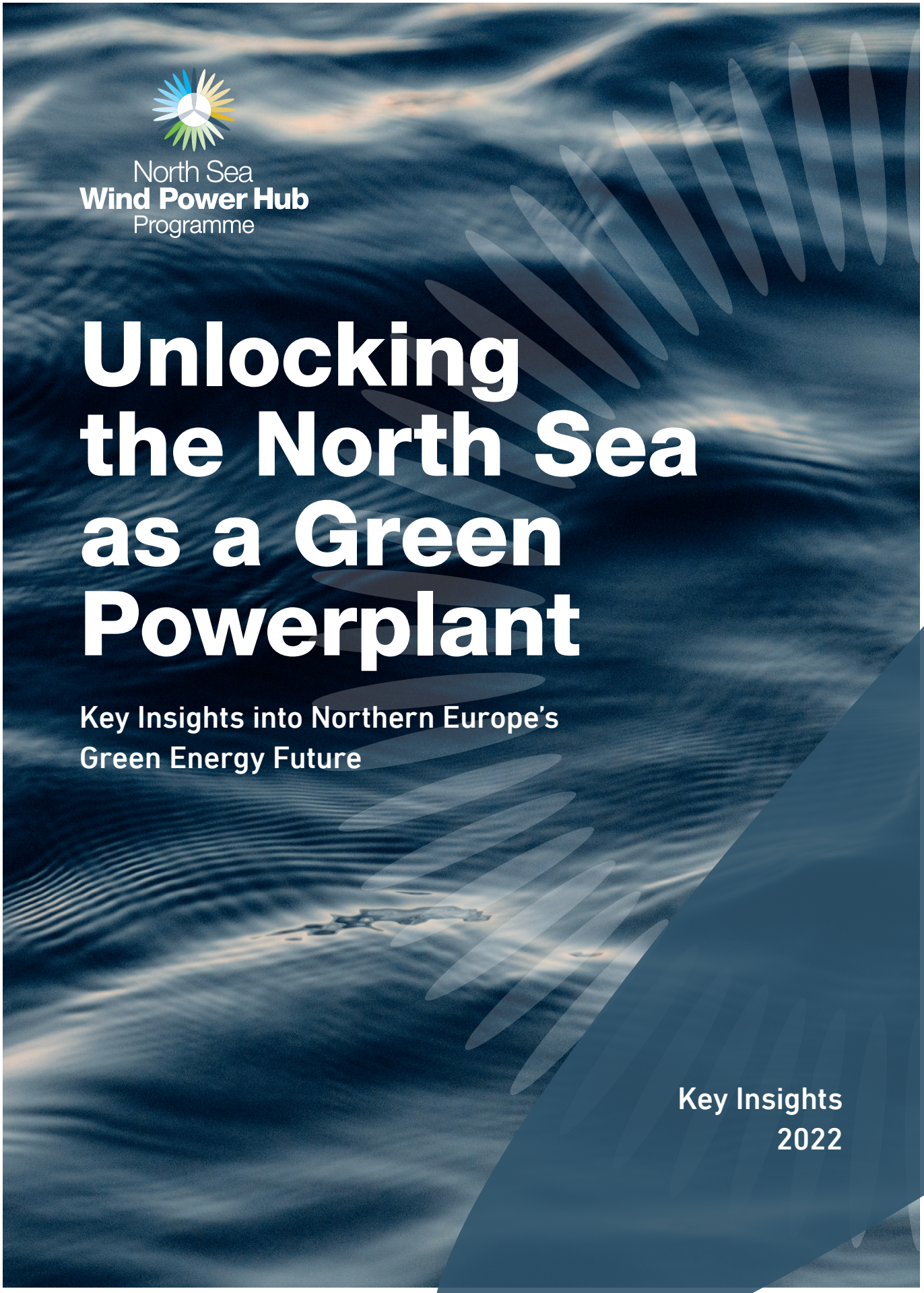


North Sea
Wind Power Hub
Programme

Unlocking the North Sea as a Green Powerplant

Key Insights into Northern Europe's Green Energy Future

Key Insights
2022

Co-financed by the Connecting Europe Facility of the European Union

An ambitious next step for the North Sea

The North Sea is a massive, shared resource. A powerhouse of wind energy with enormous potential to benefit the whole of Europe. That can help drive energy independence in light of a challenging supply situation and war, and help us rely more on sustainable sources.

Right now, key decisions are being made. They will determine the offshore energy capacity for the next 25 years and define our response to climate change.

No one country around the North Sea can deliver the comprehensive and integrated solution we need. We are facing a 180 GW offshore wind integration in the European energy system – renewable energy at a scale never seen before. To succeed, we need to go beyond. Beyond what works for smaller quantities, and beyond borders, to create a novel approach.

A solution is at hand. With a hub-and-spoke-model, we believe we have the best way to link together the power systems of Northern Europe in one well-planned network. The hub-and-spoke-model allows for an internationally coordinated and modular build-out that achieves three vital tasks that the future green power plant in the North Sea must be able to perform:

- *Collect* vast amounts of offshore wind power generated at wind farms and energy islands in the North Sea at a few decentralised hubs.
- *Connect* these hubs in a flexible network that spans the North Sea and can supply power deep into the European mainland to supply millions of consumers with green energy.
- *Convert* surplus electricity to hydrogen to expand the uses of the green power and reduce CO_2 emissions from heavy industry, transport and more.

We don't have all the answers for how to do this yet, but we are making important progress. In this publication, we share five key insights that we believe will be crucial to building this future hub-and-spoke system. For instance, we are moving closer to identifying the most efficient pathways to bring the vast energy resources of the North Sea onshore through a coordinated roll-out with multiple energy connections between North Sea countries.

We are also developing a much clearer picture of how to build a modular system, where different functionalities can be fit together like LEGO bricks and allow us to start building today without losing the option to include new and improved technologies in the future.

The key choices that shape our response to the climate challenge are being made right now. There is no scope for short-sighted or haphazard decisions. We need a long-term view, a common blueprint based on thorough analysis, and clear common goals to guide us to 2030 and beyond.

The five insights in this publication are part of a much wider work. For more, please see our Feasibility Study Report published in the fall of 2022. We also continuously provide new research and publications. All this is available free of charge on our website: www.northseawindpowerhub.eu.

Powered by: ENERGINET gasunie TenneT

How we work

At the North Sea Wind Power Hub consortium, we want to be a part of building the long-term energy solution for Northern Europe. Our contribution is to produce and disseminate knowledge about future solutions. We also support national and European stakeholders through consultations and by sharing insights. We aim to guide decisions that offer the best, easiest, and quickest way towards the Paris climate goals and European energy independence.

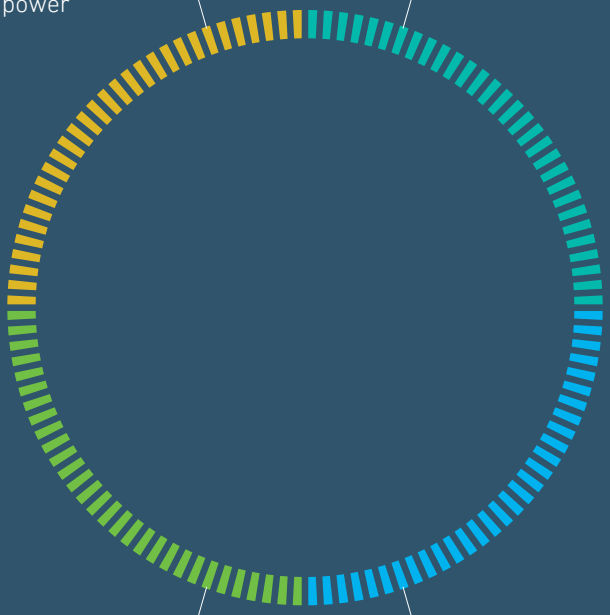
To achieve this, we focus on four specific areas that are crucial for the build-out of offshore energy.

System integration

How can a hub-and-spoke concept help to reduce mismatches between supply and demand, improve security of supply and support decarbonizing non-power demand sectors?

Technical feasibility

What is the range of feasible hub-and-spoke configurations and how do they compare?



Costs & benefits

How can we develop a new internationally accepted perspective for a suitable cost and benefit analysis (CBA) framework for hub-and-spoke projects?

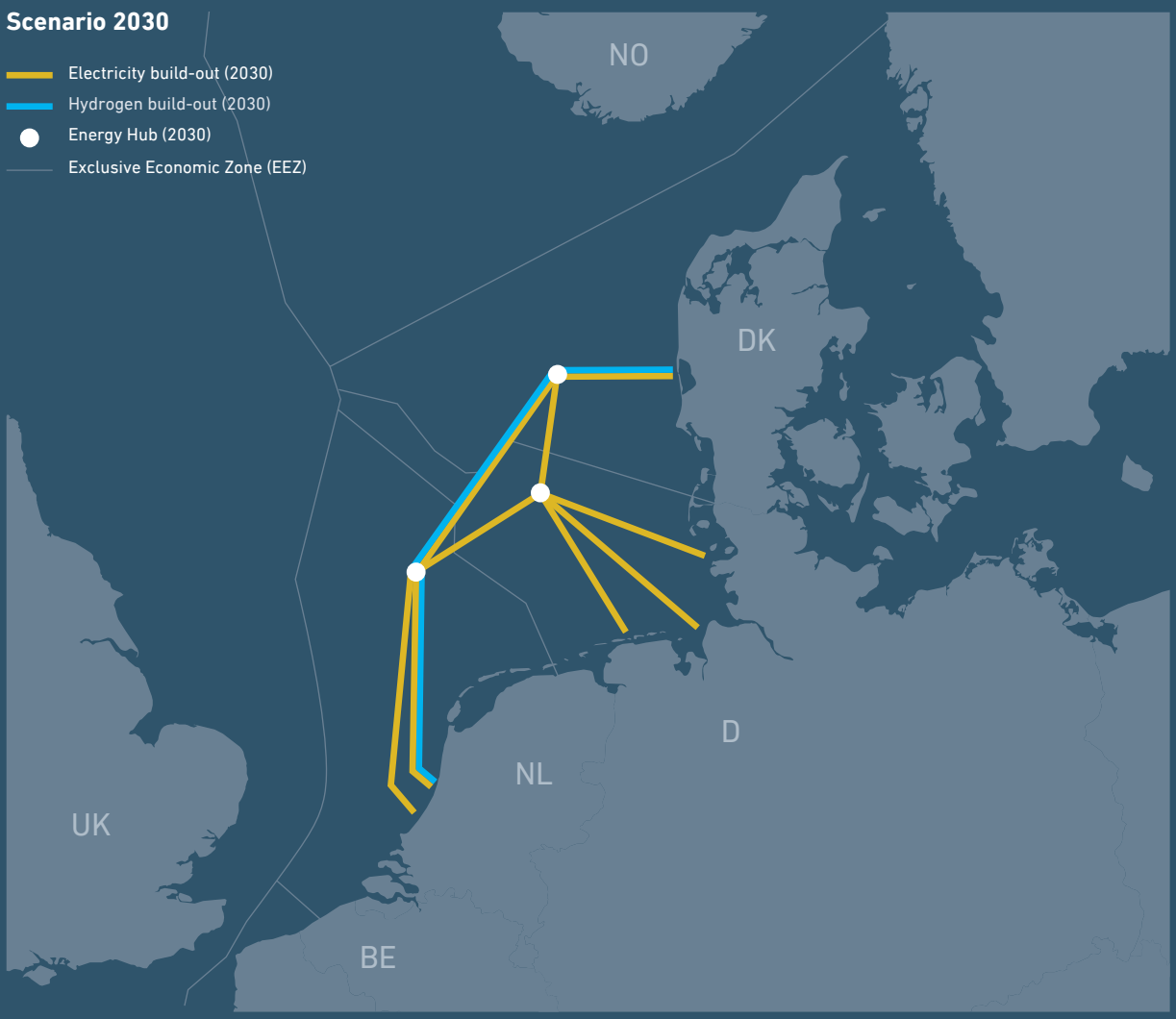
Regulation & Market design

How can we ensure that governments make the necessary decisions at the right time?

Our future North Sea – how might it look?

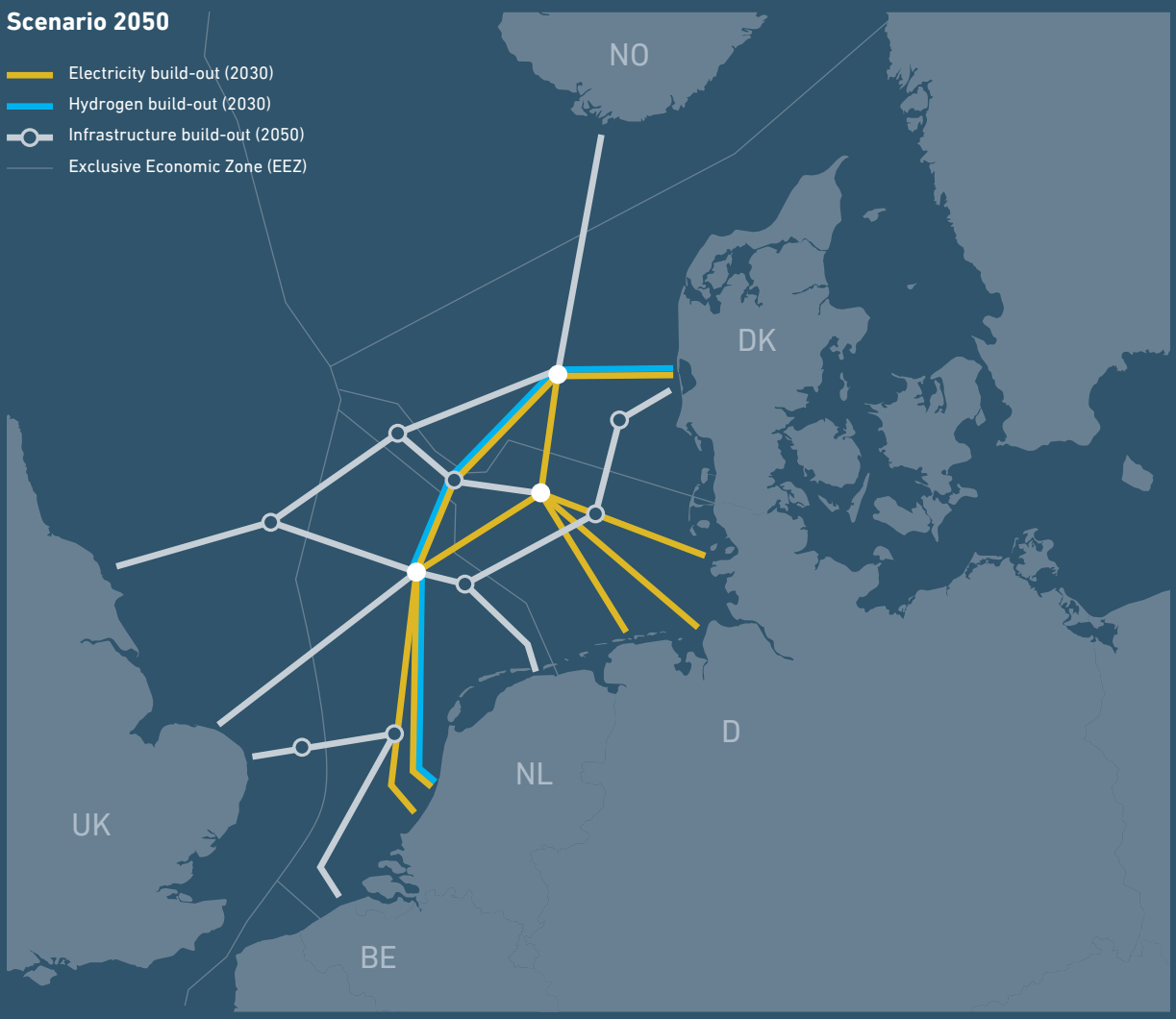
Development of energy capacity in the North Sea 2030

A North Sea wind power build-out may, on a shorter timeline, be realized between the nations of the participating TSOs, Germany and the Netherlands, where TenneT and Gasunie operate, and Denmark where Energinet is based. The simplest build-out connects three offshore energy hubs with interconnectors, with each hub having an on-shore connection to its corresponding country. The interconnection assures a constant European energy supply resistant to local absence of wind or other barriers to a robust energy system. This map illustrates how the build-out may be shaped. The specific landing sites of the on-shore connections have not been analysed and are only shown for illustrative purposes. The grey lines indicated as EEZ show where the sea is divided between the North Sea countries.



Development of energy capacity in the North Sea 2050

In the long run, the North Sea build-out may be scaled up and include other countries that wish to harness the energy of the North Sea. Three possible partner countries are Belgium, Norway, and the United Kingdom. This is exemplified below with new connected hubs and interconnector build-out. This can be expanded towards 2050 to support the building of more energy hubs and energy infrastructure. This map illustrates the full opportunities for expanding on the 2030-vision towards 2050.



Insight 1 | Cost-benefit analysis

Future-proof energy system in a cost-effective way

The challenge

When building the future green power plant in the North Sea, we need to choose the most promising design principle in order to avoid costly mistakes further down the road, and to allow us to move ahead with the build-out and reach the climate goals. Making the right choices requires a new approach to cost-benefit analysis.

The insight

The true heroes of the wind story will be the offshore hubs. They will make offshore wind at massive scale truly cost competitive towards 2050 and will enable us to harvest the full potential of the North Sea compared to an alternative tied to national borders. This new insight, based on a whole new methodology for cost-benefit analysis, allows us to move ahead with the build-out today.

Description

One exciting aspect of the build-out in the North Sea, aside from the ambitious scale, is all the new building bricks. New technologies and new physical structures will go into the design in a way we don't have anywhere in the world today.

It's important to pick the right approach with all the right bricks. The most intuitive approach is also the simplest: connect future offshore wind farms to shore with a direct connection to the specific windfarm's home country. But in this case, simplicity is not a virtue: efficiency is.

One very promising design principle, called hub-and-spoke, means introducing a whole new brick: the energy hub. A hub is where offshore wind energy is accumulated. From here, cables run to shore, and interconnectors run between hubs to distribute energy over multiple countries. The hubs will make sure the North Sea is one giant green power plant, able to supply many energy markets, rather than many smaller plants tied to specific countries. The hubs will make sure the energy goes where it is needed the most. This does not mean that everything will be connected to everything else. The right balance must be struck by making the optimal connections to tie countries together in a cost-effective way.

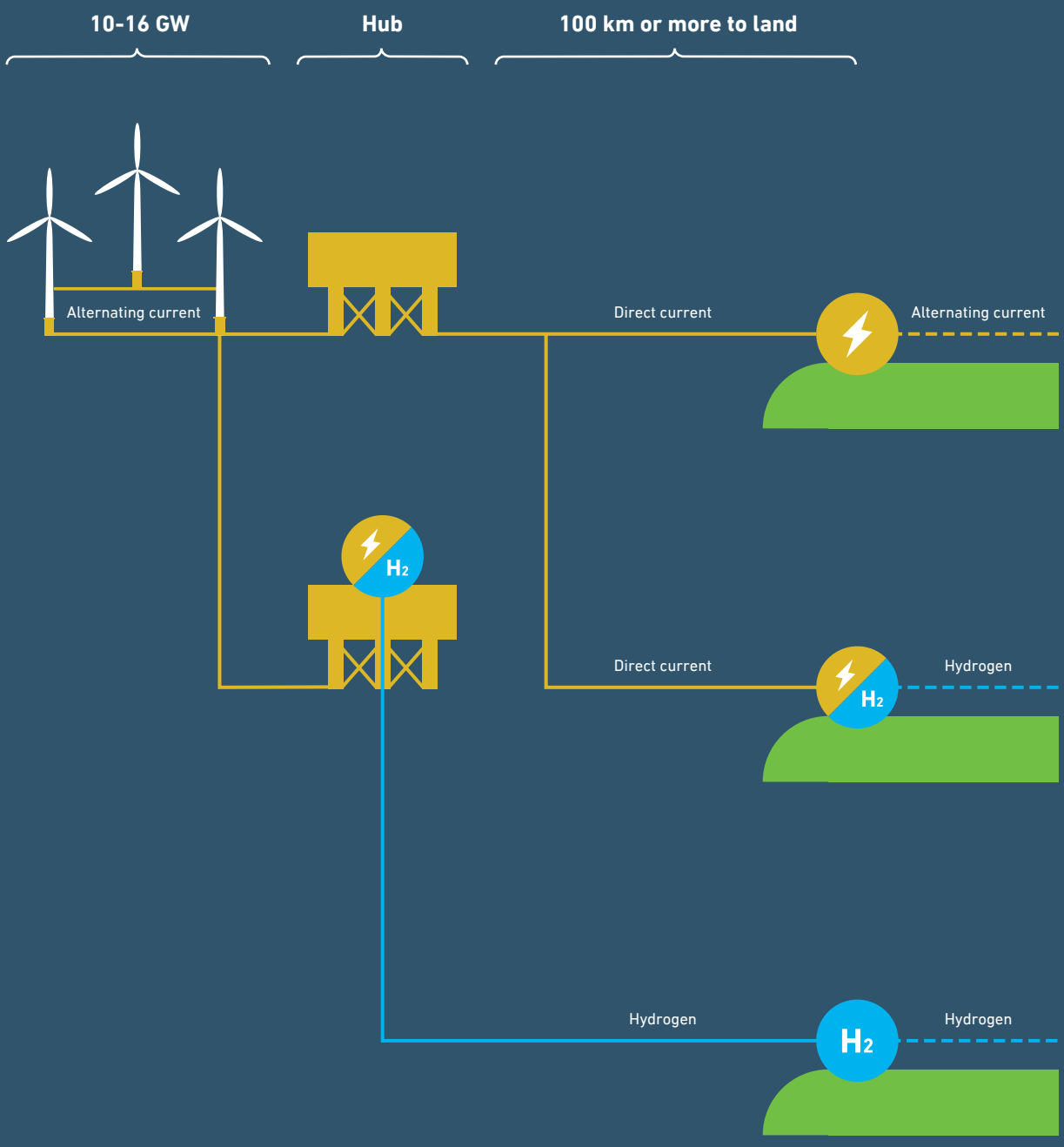
How this is best done is in no way obvious. Large infrastructure projects require a cost-benefit analysis based on a solid methodology. Mistakes can be costly. It has been necessary to develop a new approach to the analysis of large-scale offshore wind projects in order to match the innovative nature of what lies ahead. The consortium has successfully tested a new framework for hub-and-spoke projects across sectors, both onshore and offshore and internationally. We now have a credible answer to the question of how best to design the future energy system.

The hub-and-spoke design will have other advantages than cost effectiveness. They will increase international coordination in production and distribution. They can potentially reduce the build-out of capacity needed for transporting energy, which is no small investment in and of itself. They could allow for fewer landing zones onshore and mean less need to build infrastructure where people live.
If we choose hub-and-spoke as the design principle, we can expect positive economic benefits. Exact numbers are uncertain and depend on available alternatives, but overall the analysis shows it to be cost-competitive as well as future-proof. The hub-and-spoke concept is also easy to fit with current national plans for offshore wind as they are decided.

More information:
northseawindpowerhub.eu/cba-framework

Energy islands or hubs

The hubs will play a central role in the future green power plant in the North Sea. Either as platforms or energy islands. They collect power from wind turbines, they connect to shore or to other hubs, and in some cases they will even convert electrical power to hydrogen.



Insight 2 | System integration & pathways

A blueprint for the new energy highways

The challenge

Producing more wind energy at sea is a must, but so is bringing all the new energy to where it is needed. An obvious solution would be for each country to bring the energy from their own wind farms and energy hubs to shore for the national market, but is that really the best solution?

The insight

A coordinated roll-out with multiple energy connections between North Sea countries is much more efficient than just connecting every new wind farm to its home country by default. Now we even have a first blueprint for how best to do it. Through a combination of electricity and hydrogen corridors in the North Sea, we can show a pathway towards reaching the ambitious goals.

Description

Decades ago, European countries invested in roads and freeways that brought the continent together and allowed people to travel between countries quickly and safely. Since that time, traffic volume has exploded, and capacity is reaching its limits. This is true not just for roads, but in a figurative sense also for the energy infrastructure.

The time has come to build the power highways of the future. And the most important highways will be deep beneath the waves in the North Sea, bringing large amounts of offshore wind energy to shore.

Comprehensive energy system modelling by the North Sea Wind Power Hub consortium has now given us a glimpse of what this future grid could look like. And one thing is clear: just having each country build their own connections from sea to land is not the way to do it.

The map on this page shows some important features of this future grid. Most visible is a high-capacity connection between Dutch, German and Danish sites of minimum 2 GW and up to 6 GW. This allows the massive amounts of energy from the future Danish energy island to reach the Netherlands and Germany.

Multiple electricity corridors in the North Sea can be identified. They follow a North-South or East-West direction as they connect offshore wind locations, with potential branches to surrounding countries. This is the model called hub-and-spoke. These results of the modelling are consistent for the period 2030 to 2050.

Connecting wind farms and distributing power is not sufficient to achieve integration of the northern European energy systems. Hydrogen connections are also an essential part of the future energy highways. Electrolysers that convert power to gas, in combination with imported hydrogen, will provide a constant stream of energy for sectors of the economy that can't run on electricity. And converting power to gas or gas to power can balance the electricity network in times of high or low production.

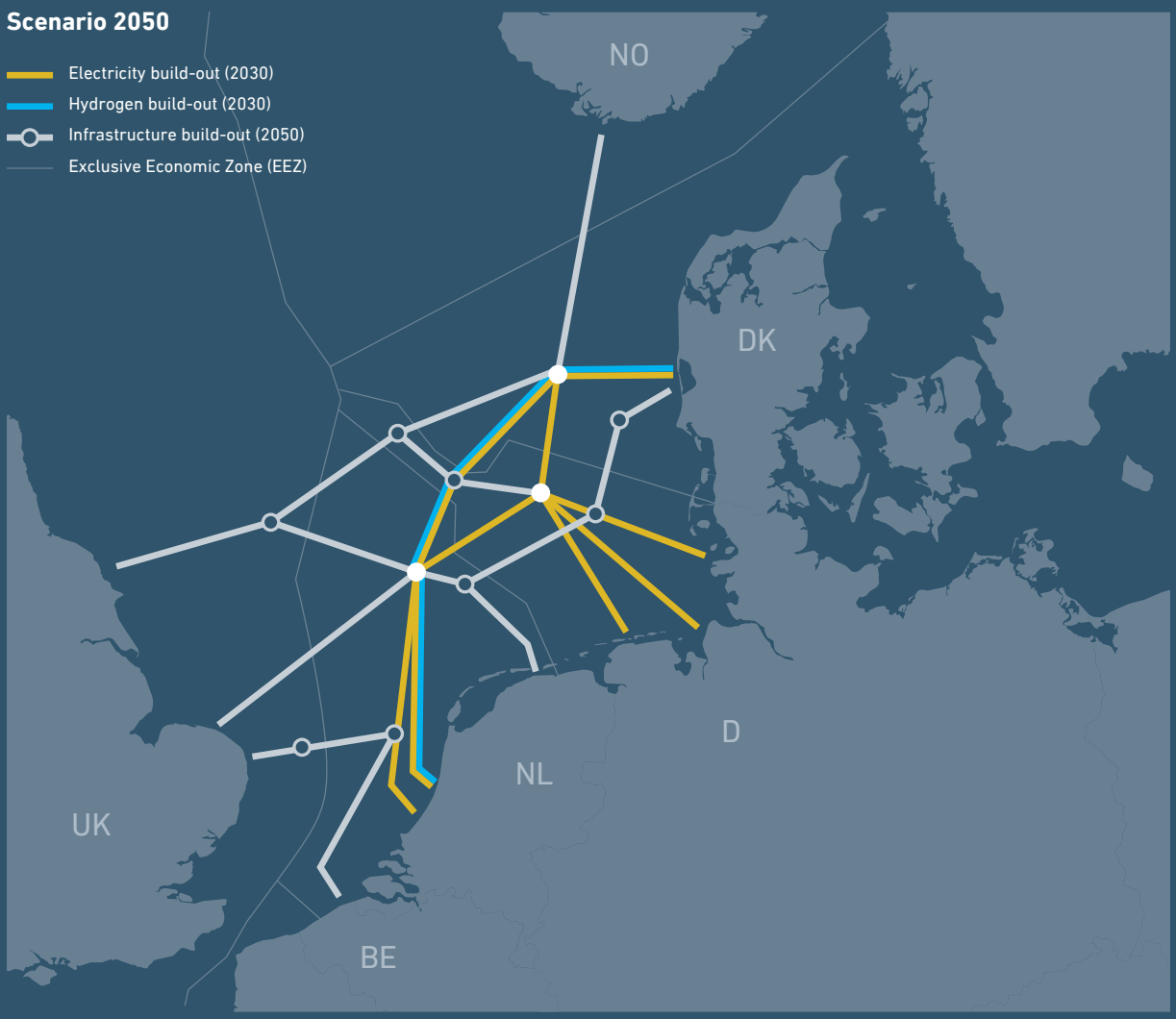
Interestingly, this way of looking at the problem not only shows where to build the connections, but also the best sites for the new offshore wind farms. With the right approach, the roll-out can be made approximately 5% more cost efficient. That amounts to billions of euros saved.

These energy highways will transport solar, hydro or wind power. Some will even carry hydrogen, as power-to-X will play a leading role in the build-out and be key to the decarbonization of large industries.

More information:
northseawindpowerhub.eu/integration

Offshore energy highways

A coordinated roll-out for 2050 could look as shown in this map. It shows multiple north-south and east-west energy connections able to transport electricity and hydrogen. All are connected to the backbone of the scenario for 2030 as shown on page 4. While the 2030 scenario includes just Denmark, Germany, and the Netherlands in an integrated system, the 2050 scenario includes Belgium, Norway and the United Kingdom as well. Through the interconnected hubs, the corridors continuously bring electricity to shore in any country, no matter where the wind turbines generate it.



Insight 3 | Feasibility of modular build-out

Build for the future today

The challenge

Building for the future is difficult. The design choices we make today must anticipate technological innovations and regulatory and market conditions in 2050 and beyond. Can we make intelligent choices today to make sure what is built now is also good for the long run?

The insight

A modular build-out of hub-and-spoke projects is possible. This can ensure that an initial 2030 project will be compatible with design choices that follow towards 2050 and beyond. But it requires investment up front today that will only pay off in the long run.

Description

When building the North Sea green power plant, we are building for both now and the future. We can already anticipate significant technological leaps over the coming years, making new solutions available to generate, convert, and transmit energy.

The solution is a modular build-out of a hub-and-spoke system – a design principle that gives increased flexibility and more options moving forward as new technology is introduced. Modularity means not designing for just one specific technology but making sure that the first hub build can connect with later hubs in an integrated system. This means different technologies can supplement each other down the road.

This can be compared to LEGO bricks. They come in many colours and shapes. They have developed massively from simple rectangular shapes into new and elaborate designs. At the core of the technology, the studs that allow every LEGO brick to connect with any other brick are the same. So what you build in the beginning does not determine where you end up. The solution becomes a platform that you can expand upon, without needing to tear down what you first assembled.

To achieve this, it is necessary to make all the parts of the hub-and-spoke concept work and fit together in a standardized design. Extensive work by the North Sea Wind Power Hub consortium has shown that this is possible. The results cover all elements of a hub-and-spoke project including the underwater substructure, the electric system for transforming and distributing power to the grid, and more.

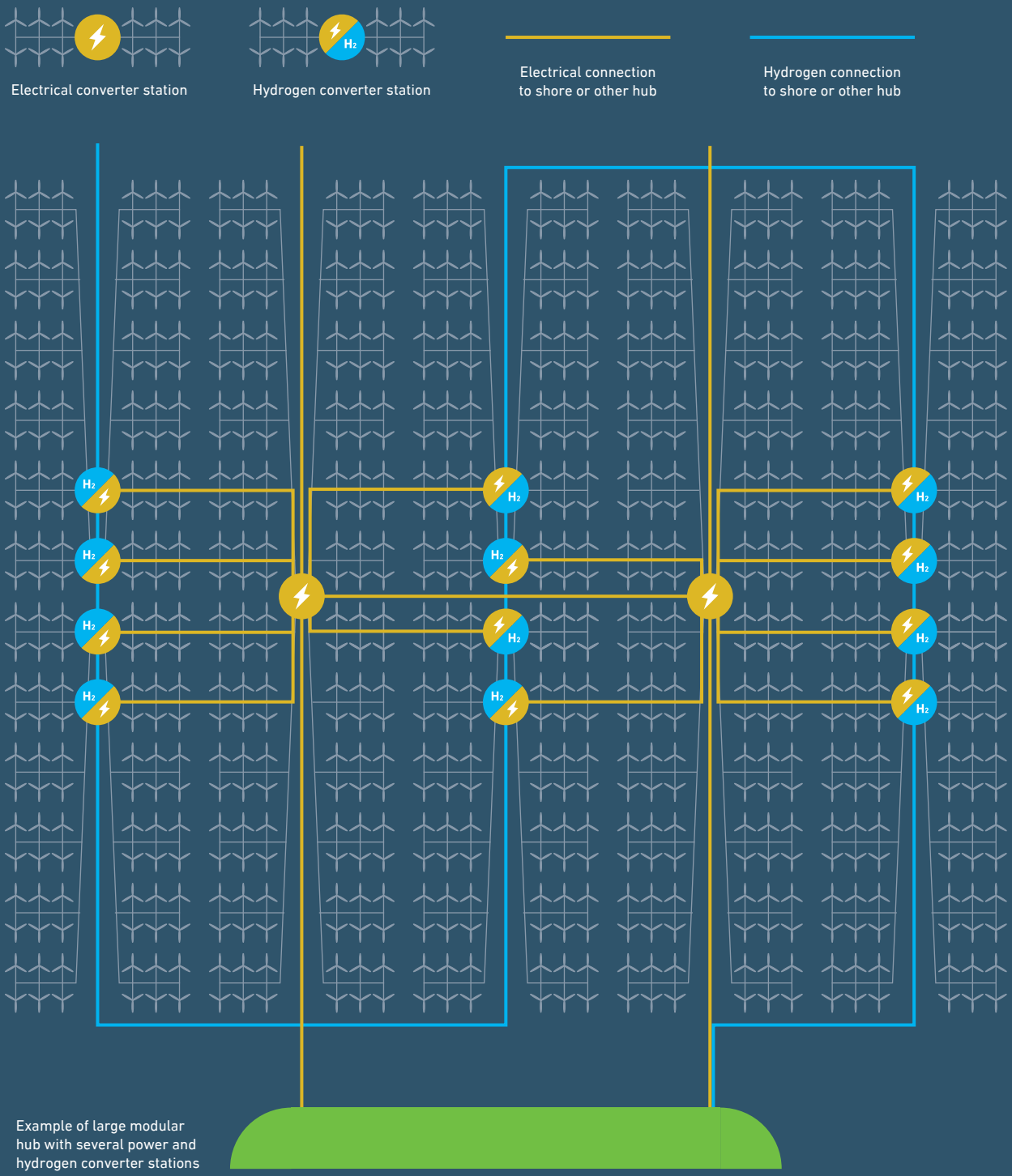
A modular build-out can be more expensive. It requires extra investment of 10-15% of the costs today as opposed to a solution that is only optimised for the short term and doesn't have the flexibility that comes with a modular design. But this extra investment today makes sense. It will be cost-effective and could potentially save billions in the future.

Without a modular approach, there would be a need or wish to redesign the build-out to keep a high level of efficiency and to utilize the best technological approaches when we approach 2040 and 2050. These redesign phases are not cheap and can require large-scale reconfigurations of existing installations. With a modular approach, we can ensure that an initial 2030 project will be compatible with design choices that follow towards a 2050 final design of the North Sea green power plant.

For more information on the technical feasibility of hub-and-spoke elements, please see **northseawindpowerhub.eu/technical**

Modular build-out – add more bricks

A modular buildout can be compared to building with LEGO bricks. You can add more clusters of wind turbines, more power converter stations, more hydrogen production and ultimately more hubs over time without tearing down or rebuilding earlier parts. A large part of the work done by the North Sea Wind Power Hub consortium has shown how this is possible for both the electrical and the hydrogen side of production.



Example of large modular hub with several power and hydrogen converter stations

Insight 4 | Technical feasibility of offshore hydrogen production

Hydrogen production could take place at sea

The challenge

Electrolysis, the process where electricity is used to produce hydrogen fuel, has not been developed at the scale we need onshore, let alone offshore. We need long-term capacity of 20-fold or more above what has been achieved today. The offshore environment brings unique challenges in terms of design, installation and operation. So is it even possible?

The insight

Green hydrogen production at the scale we need is possible onshore as well as offshore. Facilities hundreds of miles out at sea might sound more expensive – but they have benefits and can fully compete with onshore alternatives.

Description

The green power plant in the North Sea must be able to convert electric power to hydrogen fuel. This is crucial, especially on very windy days or at times of low immediate electricity demand when there is a surplus of wind energy in the system. Hydrogen is also vital if we are to achieve carbon-neutral industry and other sectors.

The obvious solution could be to send electricity to land and then convert to hydrogen onshore. After all, when we build offshore today it is usually because we have to, for example when producing oil and gas. Wind energy is different, so why not bring as much of the production onshore as possible and save on the costs?

Analysis by the North Sea Wind Power Hub consortium has shown that offshore construction is possible. The analysis also presents design options for both onshore and offshore production. Even though the cost of building offshore is considerably higher, the solution turns out to not only be possible but also cost-competitive compared with an onshore alternative under the right conditions.

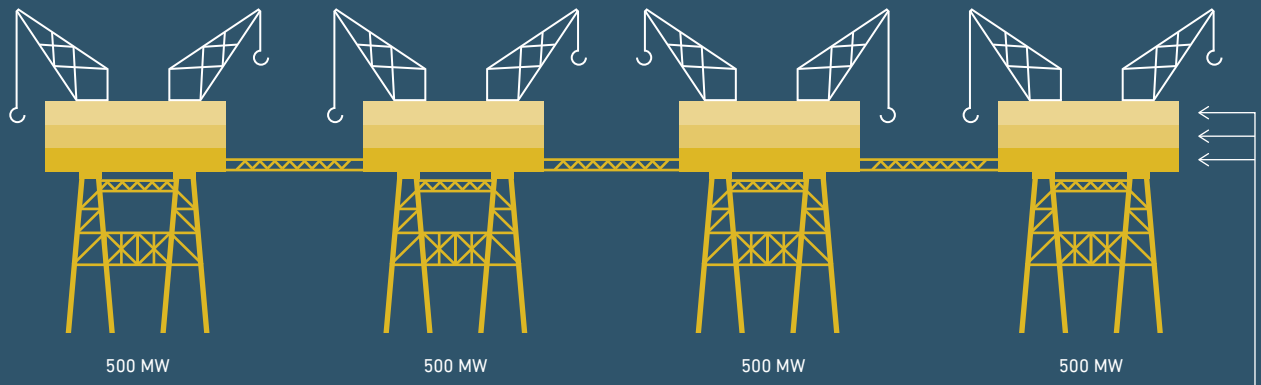
There are certain advantages in offshore green hydrogen production compared to onshore. Among other things, offshore production could require only a fraction of the area compared to onshore. One reason is the need to convert power onshore before it is used. Offshore production takes the alternating power produced by wind turbines and feeds it straight into the hydrogen production facility. On the other hand, offshore green hydrogen production requires desalination, while onshore typically uses town water that has no salt content.

All in all, offshore hydrogen production at the scale of multiple gigawatts needed for the build-out of wind energy in the North Sea will be possible and cost competitive with the onshore alternative in the decade from 2030 to 2040. To fully harvest the potential in the long term, we will in all likelihood need both types.

More information:
northseawindpowerhub.eu/offshore-p2g

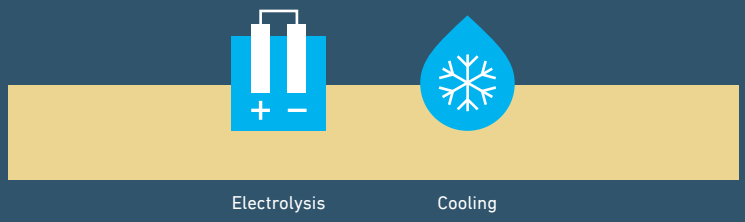
Hydrogen factory in a box

Hydrogen production at sea could take place on large, specialised platforms. These are like factories "in a box", complete with all the necessary functions packed into one standardised design. Stringing a number of these platforms together, each with a capacity of 500 MW, would make it possible to reach any desired capacity.



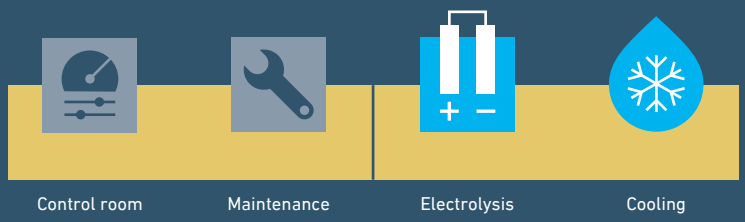
Level 3

The top level of the platform is used for electrolysis. Here electricity from the wind turbines nearby is used to derive hydrogen from sea water. The process requires considerable cooling, where sea water is used.



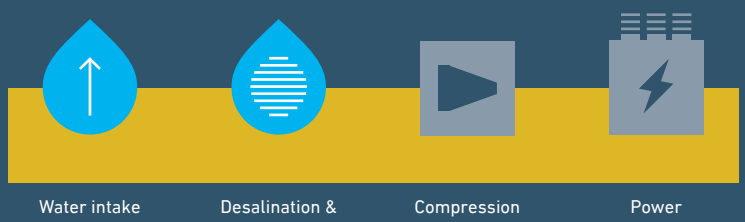
Level 2

This level contains further electrolysis and colling installations. It also has maintenance and control rooms for operating the installation.



Level 1

Process functions needed to drive the electrolysis are performed on the lower level. Sea water is fed in and desalinated, as salt in the water inhibits the process. The power from the wind turbines that drives the electrolysis is also brought on board, interconnected and distributed.



Insight 5 | Offshore bidding zones

A market setup that is truly international

The challenge

The electricity and hydrogen flowing from the North Sea will change energy markets in Northern Europe. Providing clarity on the market setup for energy hubs and future offshore wind farms is crucial to create the right investment climate for private and institutional investors.

The insight

The full benefits of the North Sea as a green power plant for wind energy will only emerge if nation states take a truly international approach. This means creating offshore bidding zones where power can be distributed both to the home market and to other hubs and on to other countries depending on demand. This setup is possible within current regulation.

Description

No one country can deliver the comprehensive and integrated solution that will realise the full potential of the North Sea. This is true for the technical build-out and, as it turns out, it is also true for how the energy market is set up.

The most efficient market is one where goods can flow unimpeded to where the supplier can demand the highest price. In the traditional setup, each wind farm is connected to its home country, where the offshore wind farms bid and dispatch electricity into their home markets and receive the electricity price of their home market. An offshore bidding zone is international. The wind farms are connected via a hub that matches onshore demand across countries with offshore electricity generation. Here, the price is determined by the flows of the electricity prices in connected bidding zones and better matches overall demand, rather than always sending electricity to the home market – even in times of low prices.

This thinking is confirmed by a closer analysis: An offshore market setup for offshore energy hubs is more beneficial than the traditional home market setup. The creation of offshore bidding zones is possible within current regulation.

The market regulation needs to be set now to make it possible to enable clear business cases and investment decisions. A delayed decision on the market setup could make future projects more expensive or even delay or hold off investments and development needed to reach the ambitious offshore wind targets.

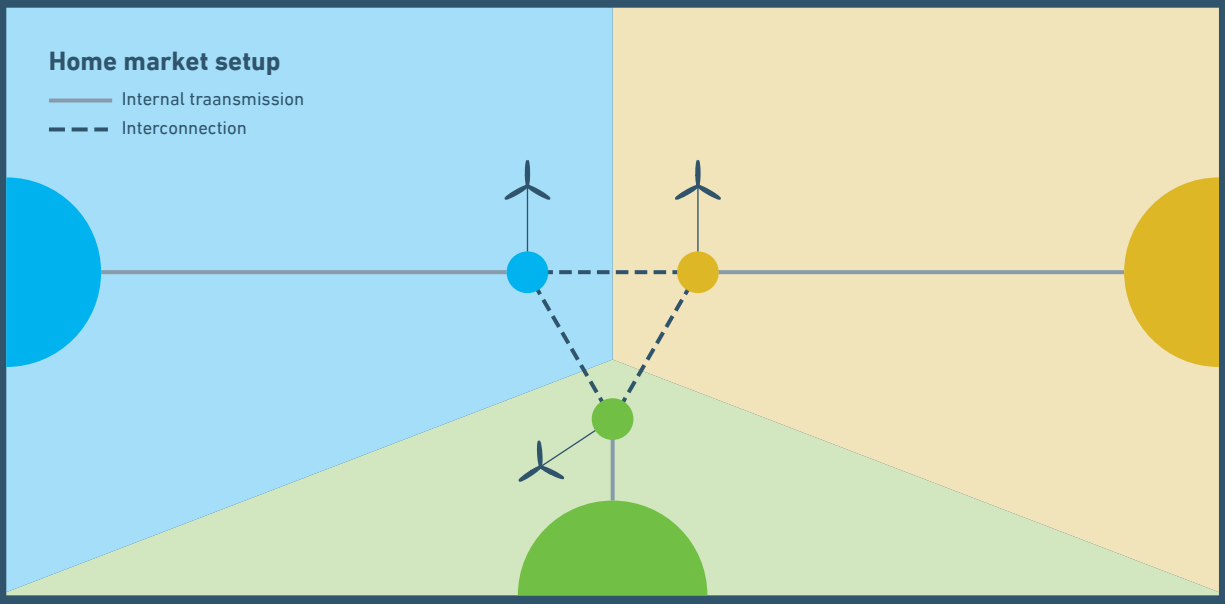
Analysis by the North Sea Wind Power Hub consortium has also shown that current regulation makes it possible to establish new offshore bidding zones within a relatively short time period of 9 to 18 months. This is half the time compared to what usually applies today. It makes it much quicker to establish the market setup that will govern prices for new build-outs, and thus allow potential investors a clear picture of what business case will be possible before deciding to produce a bid.

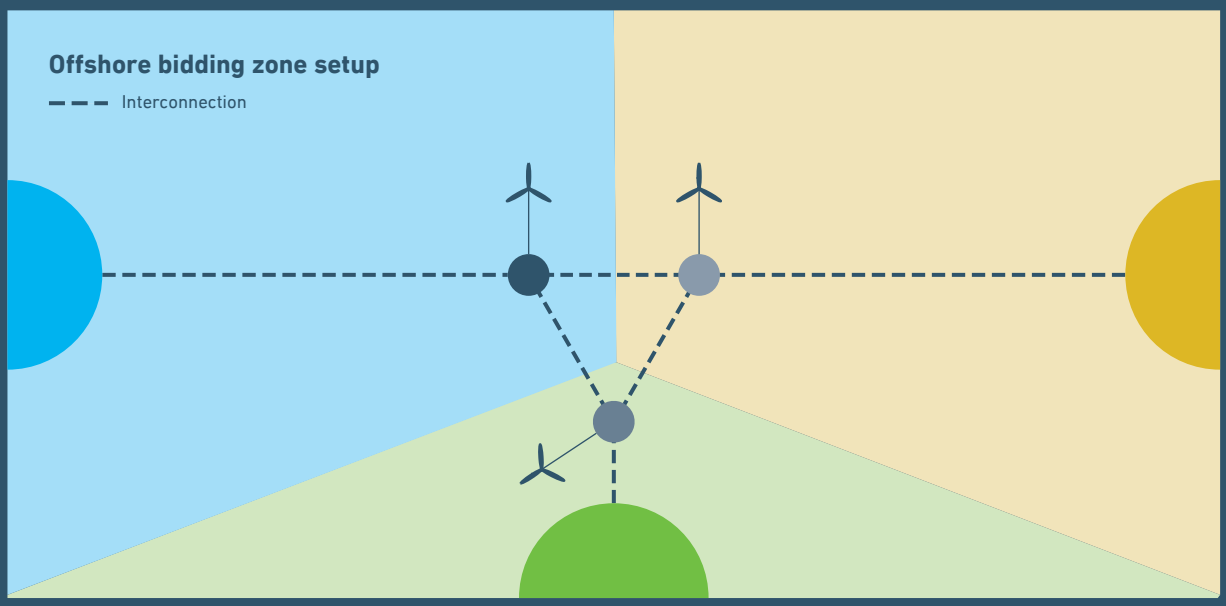
This information is crucial for decision makers both in politics and in business.

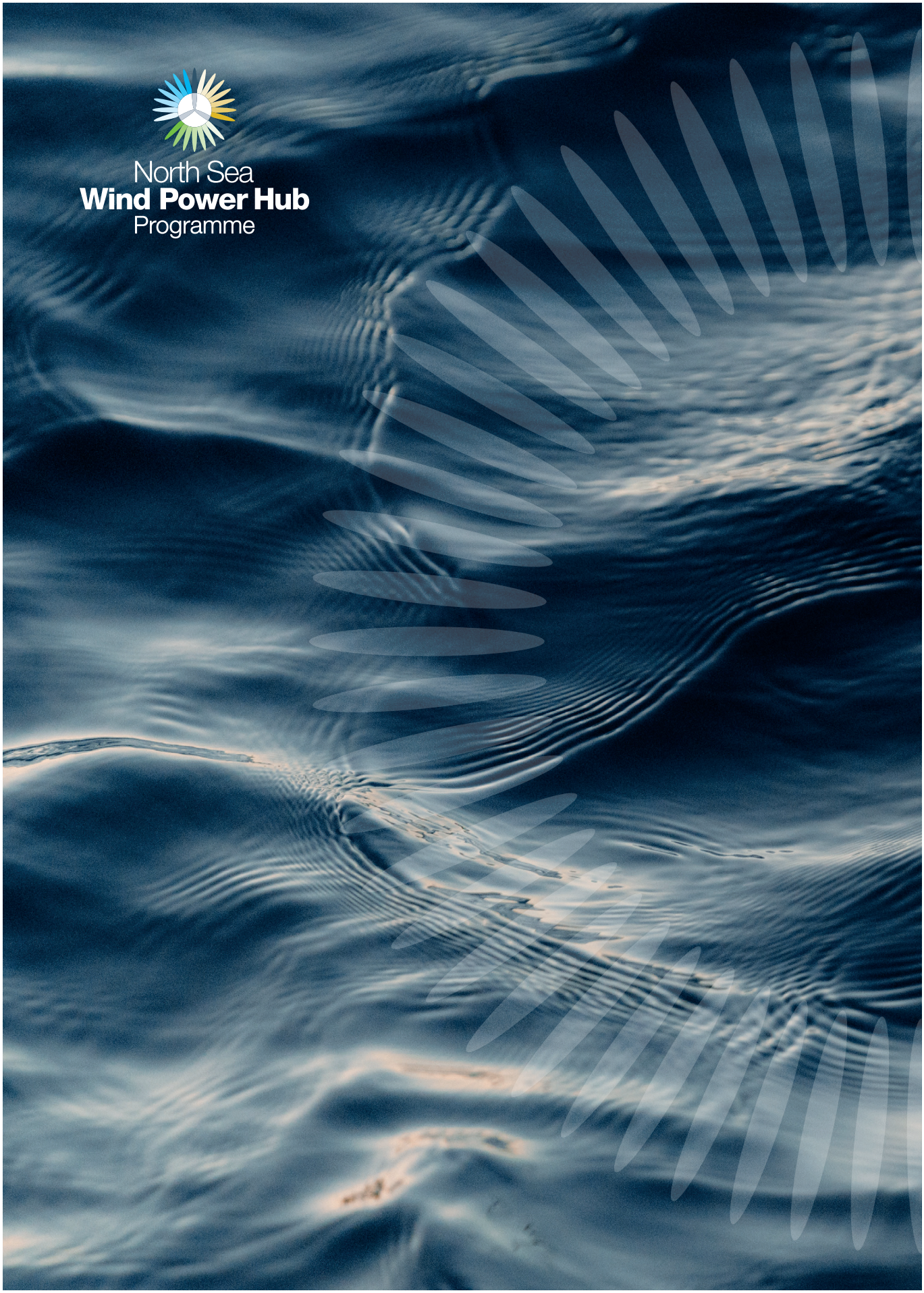
More information:
northseawindpowerhub.eu/obz

Home market or offshore bidding zone – which to choose?

The offshore bidding zone setup is an international approach to build-out of wind energy. Instead of tying the energy hubs to a home country, they are considered their own electricity markets where prices are set independently. This allows for energy to flow where demand is highest and ensures the best price for investors.







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northseawindpowerhub.eu