North Sea
Wind Power Hub

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THE VISION

The Hub-and-Spoke concept as modular infrastructure block to scale up fast

The Consortium

The North Sea Wind Power Hub consortium has joined forces to realise climate goals. The consortium her work is based on research, stakeholder interaction and experience from earlier projects.

Port of Rotterdam

Biggest port in Europe with a strong ambition to become the most sustainable port in the world

ENERGINET

Danish transmission system operator working for a green, reliable and sustainable energy supply of tomorrow

gasunie

European energy infrastructure company serving the public interest and facilitating the energy transition by providing integrated infrastructure services

TenneT

TenneT is a Dutch-German electricity TSO and is one of Europe's major investors in national and cross-border grid connections on land and at sea in order to enable the energy transition.

Executive Summary

Meeting the Paris Agreement requires a major overhaul of the energy system of the North Sea countries, including the large-scale roll-out of offshore wind

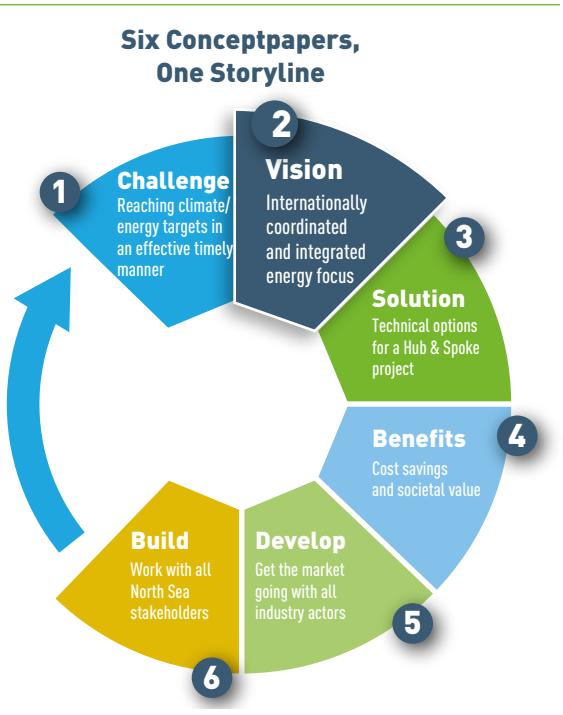
The consortium sees the modular Hub-and-Spoke concept as an important solution to meet the climate goals in time. In addition, it brings forward several key benefits:

- Ensuring cost-effective and timely ramp-up of offshore wind energy
- Providing flexibility to adapt each project to location specific needs
- Enabling offshore wind integration and providing energy system flexibility through interconnections and sector coupling

The consortium is well placed to develop and operate modular Hub-and-Spoke projects, and to advise on the techno-economic and operational impacts of the energy transition on the energy system

Six concept papers, one storyline

The goal of the concept papers is to inform North Sea stakeholders, and the general public, of the results the NSWPH has obtained working on the modular Hub-and-Spoke concept over the last two years. The six concept papers tell one story: from the challenge to meet the Paris Agreement, through the solution building on the modular Hub-and-Spoke concept, to the next steps required to meet the Paris Agreement timely and in a cost-effective manner.



Given the lead times and scale required to make the energy system compatible with the Paris Agreement towards 2050, it is crucial to act now.

Meeting the Paris Agreement requires a major overhaul of the energy system of the North Sea countries

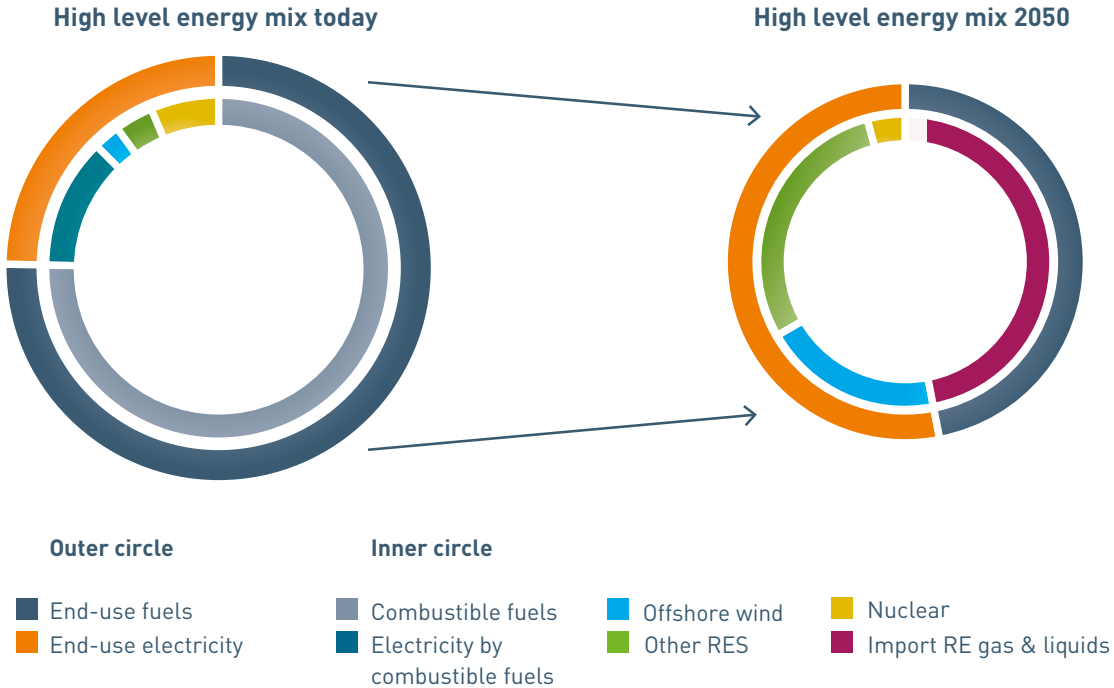
Meeting the goals as laid out in the Paris Agreement requires swift and massive changes in the total energy system (as outlined in Concept Paper 1). The 2050 energy system will look very different from what it is today, and has been in the past. Given the significant lead times and scale that is required to realise the projects that make the energy system compatible with the Paris Agreement towards 2050, it is crucial to act now.

Historically, electricity and gas grids were designed to accommodate peak demand load from end users. The electricity supply mix consisted mainly of nuclear, hydro and combustible fuels such as coal and gas and to a smaller degree electricity from wind and solar photovoltaic, and is flexible enough to meet load variability. Most of the energy use in industry, buildings and transport is fossil-fuel based, and most energy was imported from outside of the EU (energy import dependence in the EU was over 50% in 2016[i]). This energy mix resulted in high CO^2 emissions which are incompatible with the Paris Agreement.

Today, individual energy systems are designed, operated and regulated in silos. No large-scale sector coupling efforts are undertaken to provide system flexibility and decarbonisation. Energy supply chains are still very linear: centralised production units serve demand through transmission and distribution infrastructure. Transmission infrastructure reinforcements are relatively modest, incremental and straight forward to plan; no large-scale grid corridors are required on short timelines.

Offshore wind projects are planned and developed on a national level without intensive international coordination in terms of spatial planning. Projects are developed and connected in a radial manner, often connecting at the nearest onshore connection point. Also, interconnector assets are treated as stand-alone binational and radial projects without leveraging synergies from combining interconnectors and offshore wind farm transmission assets.

All this is changing...[ii]



The consortium sees the modular Hub-and-Spoke concept as an important solution to facilitate the energy transition because it brings forward several key benefits

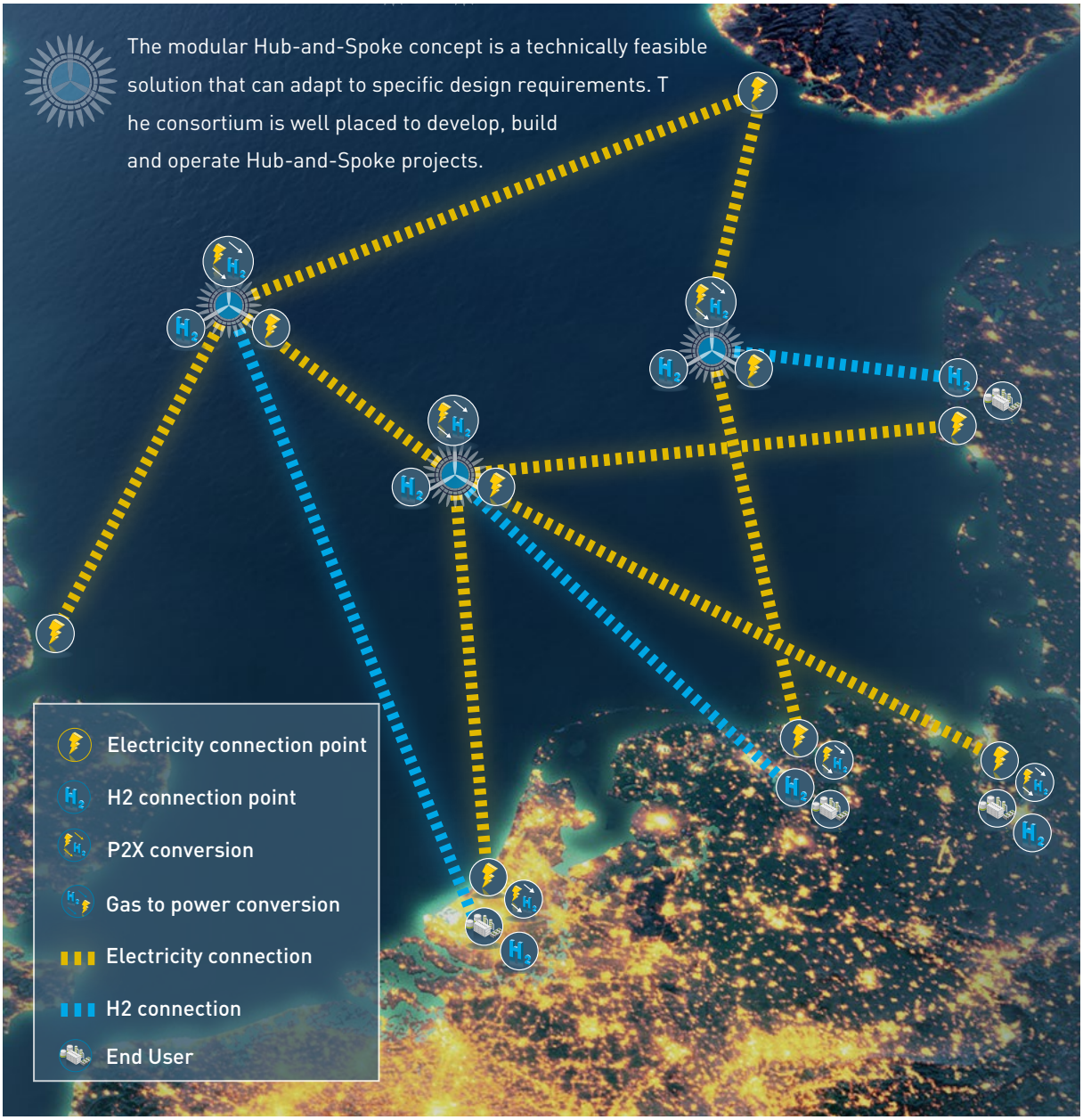
In the energy system transformation, offshore wind will grow significantly as energy provider for electricity end use, and likely as source for other energy carriers such as renewable gasses and liquid fuels, or industry feedstock. Offshore wind areas further offshore are needed to accommodate the growth in offshore wind capacity, increasing the cost for the connection of offshore wind. Integration of large-scale offshore wind energy in the wider energy system must be cost efficient, optimise benefits for society and environment, and maintain security of supply. The consortium sees the modular Hub-and-Spoke concept as an important solution to facilitate a step-by-step integration of large shares of offshore wind energy into the wider regional energy system as opposed to the current radial and incremental roll-out approach.

The Hub-and-Spoke concept consists of modular hubs in the North Sea connecting offshore wind farms with interconnectors to bordering North Sea countries and facilitates sector coupling through power-to-Hydrogen conversion. It ensures a modular build-out approach that can start development today without having to rely on cutting edge innovation to reach sufficient maturity and reliability in fields such as DC grid protection strategies. The concept is based on a combination of offshore transmission hubs, where power is collected and brought to shore via high capacity (DC) export cables, and builds on the experience of German collection hubs with DC export technology. The export cables are connected to onshore grids in a smart and coordinated manner to locations with minimal impact on existing grid capacity and space available. By making smart connections between hubs and multiple countries, export cables also provide interconnection capacity, reducing the need for point-to-point interconnection capacity. In addition, the concept enables sector coupling, which can facilitate onshore integration of offshore wind through e.g. P2X[1] conversion and re-using existing gas infrastructure, reducing space requirements. It can support maintaining security of supply by providing flexibility to the energy system through hydrogen storage and gas to power conversion, and can support decarbonisation of end use sectors such as industry and transport. It is likely that P2X will initially be located onshore, and in the future may become an integrated part of the offshore hubs, enabling energy transport through gas pipelines.

The modular Hub-and-Spoke concept (see visual on page 6) in an internationally coordinated roll-out brings forward several key benefits:

- **Higher utilisation and lower costs through combined transmission and interconnection:** combining offshore wind transmission and interconnection functionality increases utilisation of assets and reduces costs at the same time, compared to a separate interconnection line and radial wind farm connection.
- **Optimised roll-out and connection of offshore wind areas through international coordination:** international coordination of offshore spatial planning enables allocation of sufficient contiguous area, and areas of sufficient capacity, to leverage the full potential of the Hub-and-Spoke concept. International coordination with regards to onshore grid integration ensures offshore wind is connected where congestion, and the need for grid reinforcements, are minimised. It increases the security of delivering on the Paris Agreement as the risk for delays and stranded assets are reduced. In addition, an internationally coordinated approach can ensure a steady offshore wind deployment throughout the North Sea region, securing market stability to further reduce cost for offshore wind and realise the required upscaling of the entire supply chain and introduce the necessary innovations.
- **Providing flexibility to the energy system by facilitating sector coupling:** in addition to the flexibility provided by increased interconnection levels, the Hub-and-Spoke

[1] *P2X includes power-to-gas (mainly H2 as well as methane) and other options (such as fuels, feedstock, food, oxygen, residual heat, etc.)*



concept facilitates the integration of gas, electricity and heat sectors through e.g. P2X conversion, renewable gas and liquid fuels storage and gas to power. P2X conversion can utilise excess amounts of electricity (at low to negative prices) to produce e.g. hydrogen which can be stored and used to produce power when needed. This provides stability to the energy system and helps to maintain security of supply. Another benefit is that existing gas transmission infrastructure can be re-used to reduce the need for new post 2030 electricity transmission corridors. It provides robustness to energy markets with high infeed of variable renewable energy sources by mitigating scarcity situations (and the resulting high prices to consumers) as well as energy excess situations (low to negative prices). P2X conversion can also provide a means to decarbonise end use sectors such as industry and transport.

- **Modularity, adaptability and scalability:** the Hub-and-Spoke concept allows for a step-by-step approach, to adjust scale, lead time and functionality of individual projects based on the needs of the specific local conditions. For example, a first modular hub project in the early 2030s is likely to be largely all-electric providing hybrid offshore wind connection and interconnection functionality. Subsequent hubs will increasingly include P2X conversion and hydrogen storage and transportation functionality, based on increased

maturity and scale of the required conversion technologies. Significant hub sizes (of 10-15 GW[2]) enable additional cost reduction through economies of scale.

The consortium is well placed to develop and operate modular Hub-and-Spoke projects, and to advise on the techno-economic and operational impacts of the energy transition on the energy system

To capitalise on the benefits of a Hub-and-Spoke project, swift action and collaboration is required across all stakeholders. The consortium can facilitate an international coordinated roll-out by examining the techno-economic feasibility for different hub concepts, spatial locations, operational requirements to ensure grid stability and security of supply and means for integration in the onshore energy infrastructure. The consortium members are all players in large energy infrastructure and are committed to realise long term climate goals by developing the energy infrastructure of tomorrow. We act out of societal responsibility, to ensure security of supply at the lowest cost for society, today and tomorrow.

The consortium's vision for the modular Hub-and-Spoke concept builds on two legs. For the long term, it aims to ensure that proper and robust incentives across all stakeholders throughout the roll-out and energy transition are in place. For the short term, it aims at starting the development of first projects soon because of the small time window of opportunity to realise the required system changes needed to capture the benefits of an internationally coordinated roll-out of offshore wind. These legs are inter-dependent and require continuous interaction and feedback. They combine short term activities with developing and facilitating a long-term vision and change journey.

Leg 1: North Sea Internationally Coordinated Roll-out. An internationally coordinated roll-out and integration of large-scale offshore wind on the North Seas countries' energy system, requires a long-term holistic view on development and operation of the integrated infrastructure. The consortium considers its societal responsibility to develop this vision, in close cooperation with stakeholders, to ensure security of supply today and throughout the energy transition, at minimal societal cost and maximum likelihood of meeting the Paris climate goals.

Leg 2: Towards the first modular Hub-and-Spoke projects. To make the vision reality, initial feasibility studies have been conducted by the consortium to assess technical feasibility of the concept, potential environmental impacts (Concept Paper 3), cost saving potential relative to an uncoordinated and radial approach, and the role of sector coupling to mitigate congestion management issues and provide system flexibility (Concept Paper 4), requirements for a supporting market design and regulatory framework (Concept Paper 5) and the need for integrated and multi-use spatial planning (Concept Paper 6).

2 At larger capacities, scale benefits do not outweigh additional costs for additional infrastructure (platforms) connecting the wind farms further from the hub, and the additional wake losses introduced by the larger wind farm area.

Sources

[i] *Eurostat, 2019. From where do we import energy and how dependent are we? https://ec.europa.eu/eurostat/cache/infographs/energy/bloc-2c.html*

[ii] *Visual is based on 2016 final energy demand and electricity generation mix in EU: https://www.eea.europa.eu/data-and-maps/indicators/final-energy-consumption-by-sector-9/assessment-4, https://ec.europa.eu/eurostat/statistics-explained/index.php/Electricity_production,_consumption_and_market_overview#Electricity_generation;*

and the 2050 energy flows are based on trends in EC, IN-DEPTH ANALYSIS IN SUPPORT OF THE COMMISSION COMMUNICATION COM(2018) 773. https://ec.europa.eu/clima/sites/clima/files/docs/pages/com_2018_733_analysis_in_support_en_0.pdf

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