TOWARDS SPATIAL PLANNING OF NORTH SEA OFFSHORE WIND

North Sea Wind Power Hub

4 FEBRUARY 2019

Executive Summary

- International coordination is essential in spatial planning of offshore wind projects. A key pathway to meeting the Paris agreement could be based on a significant deployment of offshore wind energy in the North Sea: estimates indicate approximately 70 to 150 GW by 2040, and up to 180 GW by 2045 would be required. Some countries have more area available than national energy plans would require, while others have less. A coordinated action is needed to meet common targets and integrate offshore projects cost-effectively in the wider energy system.

- Long-term spatial planning and possible co-utilization of offshore wind areas in the North Sea needs urgent progress, as there is limited clarity on post 2030 offshore wind areas. Present use of the North Sea does not leave sufficient area available for offshore wind deployment if the traditional exclusionary approach is maintained. Furthermore, the remaining area in the North Sea, after subtraction of current uses, is rather fragmented. Small scale and scattered Offshore Wind Farm (OWF) areas do not allow for the full cost reduction potential: cost reduction potential that results from efficiently using the same infrastructure for multiple purposes e.g. transmission assets that can bring OWF generated power to shore or act as interconnectors.

- The consortium stands ready to initiate and facilitate discussions between policy makers and North Sea Stakeholders. The consortium can add the techno-economic perspective from grid developments and system impact to the discussion on spatial planning options considered by policy makers.

- A first Cost Evaluation of North Sea Offshore Wind Post 2030 study (Offshore Wind Cost Analysis for short) was conducted on behalf of the consortium which gave the following key insights:

    - Nearshore wind farms are most cost-effectively connected with radial AC connections while smaller, isolated OWF locations that are further offshore can be most cost-effectively connected with a radial DC platform connection concept. The Hub and Spoke grid connection concept is the most attractive alternative (from a techno-economic perspective) for offshore areas that can accommodate large scale capacity e.g. where several wind farms can be clustered around a central hub.
    - The benefits of using the Hub & Spoke concept as part of the solution for the North Sea offshore wind roll-out include a reduction potential in Levelized Cost of Energy (LCoE) supply of approximately 5-6%, compared to solely using radial connections (p. 79 Offshore Wind Cost analysis report).
    - By opening up co-utilization of areas for roll-out of offshore wind and other activities, the average LCoE of the offshore wind supply would increase by approximately 1-2% (p. 60 Offshore Wind Cost analysis report).
    - LCoE across locations differ based on various conditions. The Borkum Riffgrund area is on the lower end of the cost range; the Dogger Bank area is rather on the higher end with about 17% higher costs (p. 78 Offshore Wind Cost analysis report).

- When only nature areas are excluded (while including areas in somewhat deeper waters) the LCoE of the roll-out would increase by approximately 3% (p. 79 Offshore Wind Cost analysis report).
    - Not all impacts of offshore wind area use are straightforward to monetize (especially long-term environmental effects) and all carry substantial uncertainty which makes the cost increase estimate relatively conservative still. This all needs to be addressed in a spatial planning debate which clearly goes beyond a techno-economic analysis.
    - The consortium recognizes that the Offshore Wind Cost Analysis has its limitations, including conservative assumptions on wind farm density, decommissioning of oil & gas infrastructure, applicability of monopile turbine foundations in water up to 55 meter depth and is also limited by the applied geographical scope.
    - Power 2 Gas, including hydrogen transportation, was not included in the scope of this study.

- Going forward the consortium is pursuing several actions, including:
    - Continued analysis of three test locations based on different characteristics and apparent pros and cons, and which could deliver criteria for future identification of suitable Hub locations.
    - Continued outreach to North Sea stakeholders including policy makers, NGOs, wind energy developers and others.

Message

Long-term spatial planning and possible co-utilization of offshore wind areas in the North Sea requires urgent progress to unlock the regional cost-effective offshore wind energy potential of the North Sea contributing to the Paris Agreement goals. These wind farm and transmission infrastructure projects face already long lead times in planning and development. The consortium acknowledges that an internationally coordinated roll-out of offshore wind energy transmission and interconnection assets has substantial benefits, but also has an impact on the North Sea environment.

Therefore, a coordinated international outlook on the development of offshore wind areas in the North Sea is required soon. This is an urgent topic to be brought to the attention of policy makers. The consortium is eager to initiate and facilitate discussions between policy makers and North Sea stakeholders to align objectives and mitigate delays in deployment. The consortium is also ideally placed to add a techno-economic perspective to the discussion regarding the impact of spatial planning decisions on grid developments. A first exercise was conducted on behalf of the consortium to analyse a cost-optimal roll-out of offshore wind considering spatial planning restrictions[1]. While policy makers decide on maritime spatial planning, the NSWPH consortium requires clear scenario assumptions in its planning processes. Several scenarios can be applied to demonstrate the potential impact of policy choices and market functioning.

Reaching the Paris Agreement

To meet the ambitious targets as set in the Paris Agreement, various estimates indicate that an offshore wind energy capacity in the North Sea of approximately 70 to 150 GW by 2040 will be required, and up to 180 GW by 2045[2]. Going in a similar direction, the ENTSO-G/E TYNDP 2018[3] scenarios are projecting 70 to 100 GW of installed offshore wind capacity in 2040. These all show the significant increase of offshore wind energy ahead. An increased spatial use by offshore wind energy and transmission infrastructure is then expected accordingly. The consortium has taken a leading role in exploring technical options to reduce societal costs for the connection of offshore wind farms and interconnectors by a Hub & Spoke concept. The process is in an early assessment phase with various options under consideration. Preparing for an internationally coordinated roll-out in a robust stepwise approach requires clarity on spatial development areas for energy infrastructure beyond 2030. It is important to get timely directions from policy makers on spatial planning given the significant lead times for these types of infrastructure and further increasing offshore wind energy deployment rates foreseen after 2030.

State of Play

The combination of today's national maritime spatial plans is not yet in line with the projects offshore wind capacity increase, mainly by the lack of appointed offshore wind farm areas after 2030. Across the North Sea energy declaration countries only Germany identified offshore wind farms areas for tenders and commissioning post 2030, with a clearly indicated capacity of 2.4-2.8 GW in total[4]. The available offshore area in the southern part of the North Sea is limited (about 14,000 km^2) and relatively scattered. Therefore, an exclusion strategy will likely not allow for a full deployment of any conceivable future energy system including offshore wind capacity, green hydrogen facilities, hubs and grid connections (Figure 1).

[1] NSWPH, 2018. North Sea Potential Offshore Wind Farm Locations Post 2030 - Spatial study   Available from: www.northseawindpowerhub.eu
[2] Ecofys a Navigant Company, 2017. Translate COP21 Available from: www.northseawindpowerhub.eu
[3] ENTSOE, 2018. Ten Year Network Development Plan 2018. Available from: https://tyndp.entsoe.eu/
[4] BSH, 2018 Vorentwurf Flächenentwicklungsplan 2019 für die Deutsche ausschließliche Wirtschaftszone der Nord- und Ostsee. Available from: www.bsh.de
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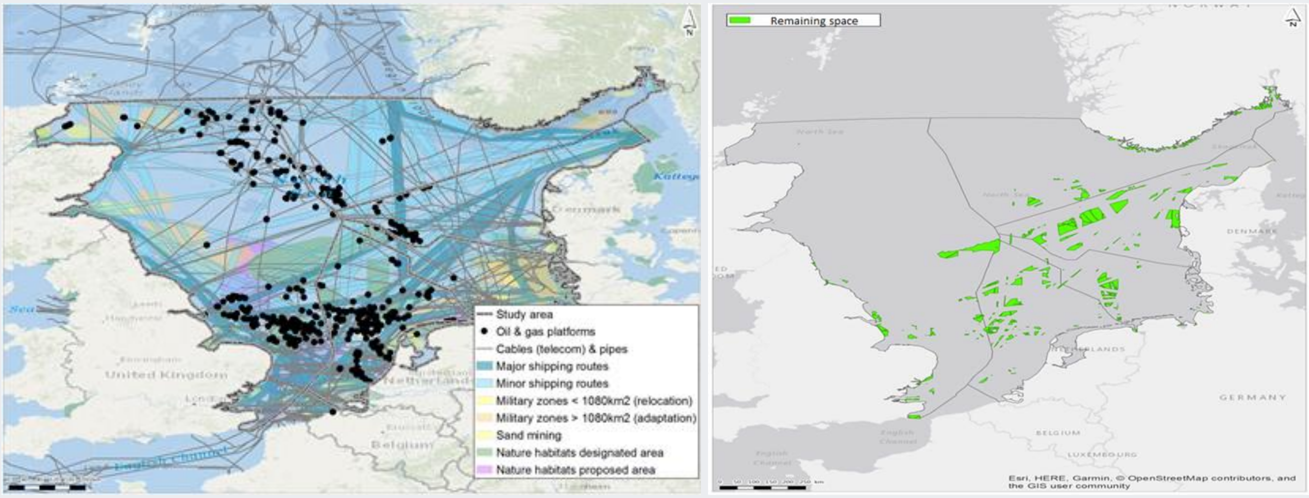

Figure 1: Current use functions in the North Sea regions (left), and remaining area (up to 55 m water depth) after subtraction of current use functions (right)[1]

Co-utilization with e.g. nature, shipping and fisheries and using a long-term perspective (e.g. use after decommissioning rate of oil and gas rigs) must be seriously considered to unlock the cost reduction potential of an internationally coordinated approach. In addition, not all countries have sufficient offshore area available to accommodate their own offshore wind energy needs (such as Germany and Belgium[5]), which shows an additional necessity for joint ambitions and international coordination. Currently several processes are ongoing on a national level regarding spatial planning, such as the Crown Estates market engagement for Round 4. It is essential in these processes to consider all aspects, including synergies for connection infrastructure on an international level. The European maritime spatial planning directive (2014/89/EU)[6] already calls for national integrated planning processes which cover all possible activities and are coordinated with neighbouring countries. First efforts on more enhanced international coordination are currently being undertaken such as the “Joint statement to further the deployment of offshore energy in Europe”[7], potential new EU mechanisms for cross-border renewable energy projects[8], and the “Political Declaration on energy cooperation between North Seas Countries”[9].

The consortium’s input to spatial planning discussions

Policy makers consider multiple criteria for spatial planning of new offshore wind farm locations. These criteria range from environmental impact to techno-economic considerations (such as water depth, wind resource, cost and subsidies), existing spatial claims, and other public concerns such as visibility. The consortium needs to follow spatial planning decisions for offshore wind farms in both legs of its overall vision:

Leg 1 - North Sea International Coordinated Roll Out: An internationally coordinated roll out (ICRO), delivering infrastructure costs saving for society, relies on a coherent long term vision of the regional development of offshore wind. Earlier studies demonstrated that an internationally coordinated roll-out strategy has the potential for cost reductions of approximately 30% by optimising offshore connection concepts, economies of scale and synergies with interconnection functionality[10]. Presently the

[5] Ecofys a Navigant Company, 2017. Translate COP21 Available from: www.northseawindpowerhub.eu
[6] EU, 2014. DIRECTIVE 2014/89/EU. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32014L0089
[7] WindEurope, 2017. Joint statement to further the deployment of offshore energy in Europe. https://windeurope.org/wp-content/uploads/files/policy/topics/offshore/Offshore-Wind-Statement-of-Intent-signed.pdf
[8] EU, 2018. Establishing the Connecting Europe Facility and repealing Regulations (EU) No 1316/2013 and (EU) No 283/2014. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM%3A2018%3A438%3AFIN
[9] European Commission, 2016. North Seas Countries agree on closer energy cooperation. http://europa.eu/rapid/press-release_IP-16-2029_en.htm
[10] NSWPH 2017, Concept paper on Modular Hub and Spoke. https://northseawindpowerhub.eu/wp-content/uploads/2017/11/Concept-Paper-2-Modular-Hub-Spoke.pdf

integration of the power system with hydrogen solutions, and the impact of offshore concepts on onshore grid corridors and landing points are explored to further minimize societal costs.

Leg 2 - First concrete project: The consortium identified potential cost savings based on a Hub & Spoke Grid Connection System compared to radially connected High Voltage Direct Current (HVDC) platforms to connect far offshore wind farms to shore. As an initial location to evaluate this concept the Dogger Bank was considered based on its unique combination of shallow water depth, strong wind resources and central location. The Dogger Bank is a Natura2000 area and thus given particular attention in various national spatial plans. The NSWPH consortium's Offshore Wind Cost Analysis explored the LCoE[11] levels throughout the North Sea region and highlighted that other currently unassigned areas may have lower to similar LCoE levels as Dogger Bank.

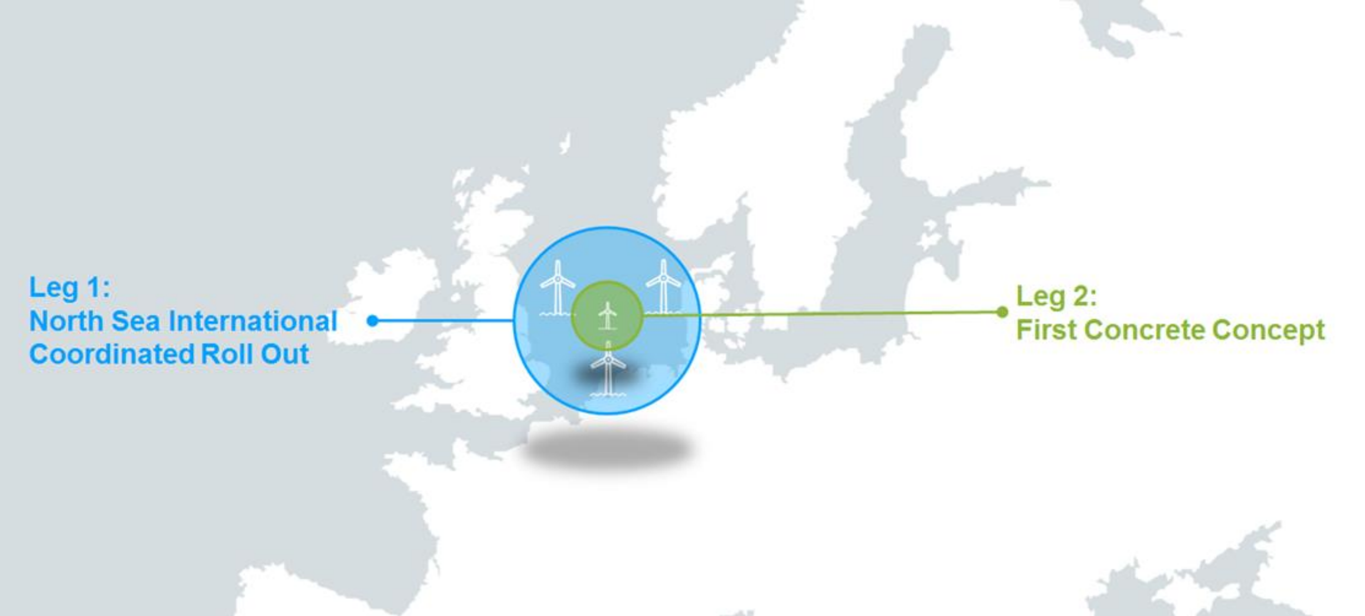

Figure 2: The NSWPH consortium vision consists of two legs: an international coordinated roll-out, and a first concrete concept

Offshore Wind Cost Analysis: Available Area in the North Sea for Offshore Energy Infrastructure

This initial Cost Evaluation of North Sea Offshore Wind Post 2030 (the Offshore Wind Cost Analysis for short) study shows that co-utilization will likely be necessary in some form because today's exclusion strategy (i) will not yield the required area for deployment of offshore wind, and (ii) leaves the remaining available area rather scattered which provides limited potential for infrastructure synergies to reduce costs. Looking ahead, additional space in the North Sea could be required due to demand for other energy forms e.g. green hydrogen.

Other studies such as "Future of the North Sea"[12] by the Netherlands Environmental Assessment Agency (PBL) also indicated that combining offshore wind farms with nature reserves or fishing grounds could help to address the increasing spatial pressure. WindEurope[13] called upon governments to "coordinate the timeline of tenders" and "cooperate in spatial planning

[11] Levelized Cost of Electricity (LCoE) is a metric to express all direct economic costs (mainly related to development and operations) of the infrastructure in relation to delivered energy. This includes wind farms and transmission to shore (including onshore substation).
[12] PBL, 2018. Future of the North Sea. https://www.pbl.nl/sites/default/files/cms/publicaties/pbl-2018-the-future-of-the-north-sea-3193.pdf
[13] WindEurope, 2017. Unleashing Europe's offshore wind potential. https://windeurope.org/wp-content/uploads/files/about-wind/reports/Unleashing-Europes-offshore-wind-potential.pdf

analysis and site development" to make sure areas with lowest costs are considered. As the cooperation of North Sea countries initiated a joint working group on this topic, progress is being made and should keep momentum.

Offshore Wind Cost Analysis: Techno-Economic Assessment of a Hub & Spoke Concept across the North Sea

The Offshore Wind Cost Analysis furthermore highlights how nearshore areas (up to approximately 80 km from shore) can be most cost-effectively connected through AC radial connections. However, this offshore distance range would not yield sufficient offshore wind capacity. For areas further offshore, DC radial connections (for isolated areas) and Hub & Spoke connections (for larger clustered areas) would be more efficient. The Hub & Spoke concept yields relatively comparable low LCoE values throughout most of the North Sea region indicating it can provide nearshore LCoE levels relatively further offshore. The study reconfirms that the benefits of a Hub & Spoke concept as part of the full offshore wind roll-out bring a LCoE reduction of 5-6% as compared to deploying only radial connections (derived from the Offshore Wind Cost Analysis, p.79). With regards to the capacity sizing of Hub & Spoke projects the study concludes there is an optimal sizing based on a balance between economies of scale, inter-park wake losses and increasing costs and losses for AC cabling of wind farms towards the Hub. In addition, the study identifies an optimal wind power density to be between 6.4 and 14.4 MW/km^2. This pure techno-economic analysis shows that the efficiencies are gained by employing large-scale Hubs with high power densities. However, the actual optimum balance needs to be carefully considered against other with other spatial considerations (both tangible and intangible).

Offshore Wind Cost Analysis: Cost of Co-Utilization

As highlighted, limitations in area for the roll-out of offshore wind capacity raises an urgent need for clarity on co-utilization. The Offshore Wind Cost Analysis sought to identify a first order cost impact of co-utilization in offshore areas that currently have a specific use function such as nature or fishery. The study identified areas which could be added to the offshore wind roll-out based on their total cost level (incl. costs for co-utilization) to ensure sufficient offshore wind deployment. Figure 3 shows all identified areas required for such roll-out. Note that the cost levels of the co-utilization areas vary significantly. Borkum Riffgrund is at the lower end. Other areas with relatively higher LCoE levels include Danish coast (+3%; derived from spatial study p78), Dutch coast (+6%; derived from the Offshore Wind Cost Analysis p78, East Anglia, Eastern German coast, Jyske Rev and North of the Wadden (+8%; derived from spatial study p. 78), North Norfolk Sandbanks (+14%; derived from the Offshore Wind Cost Analysis p. 78) and Dogger Bank (+17%; derived from the Offshore Wind Cost Analysis p. 78). The consortium is further evaluating some of these locations.

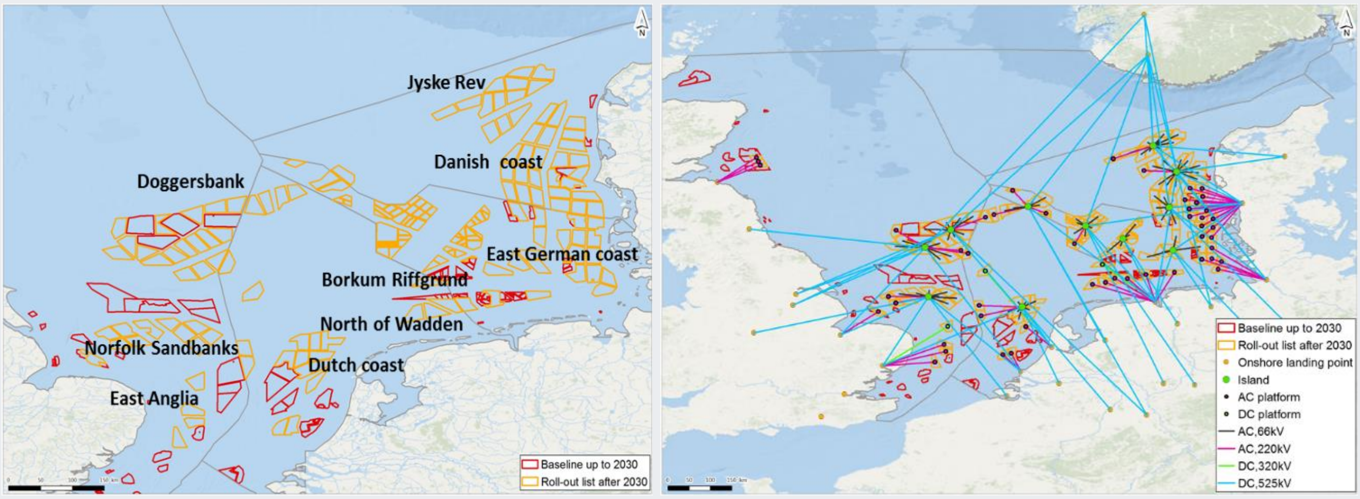

Figure 3: Offshore areas required for roll-out of up to 180 GW of offshore wind, including areas with co-utilization, based only on a first order assessment of the cost impact of co-utilization.

The study initially assumed that the cost impact of co-utilization on the total roll-out could be fairly limited with an average cost increase of 1-2% (derived from the Offshore Wind Cost Analysis, p. 60). When only nature areas are excluded (and e.g. deeper waters have to be sought to meet the required offshore wind deployment), average costs of the total roll-out are found to increase by approximately 3% (derived from the Offshore Wind Cost Analysis, p. 79) and the analysed roll-out scheme would evolve as depicted in Figure 4.

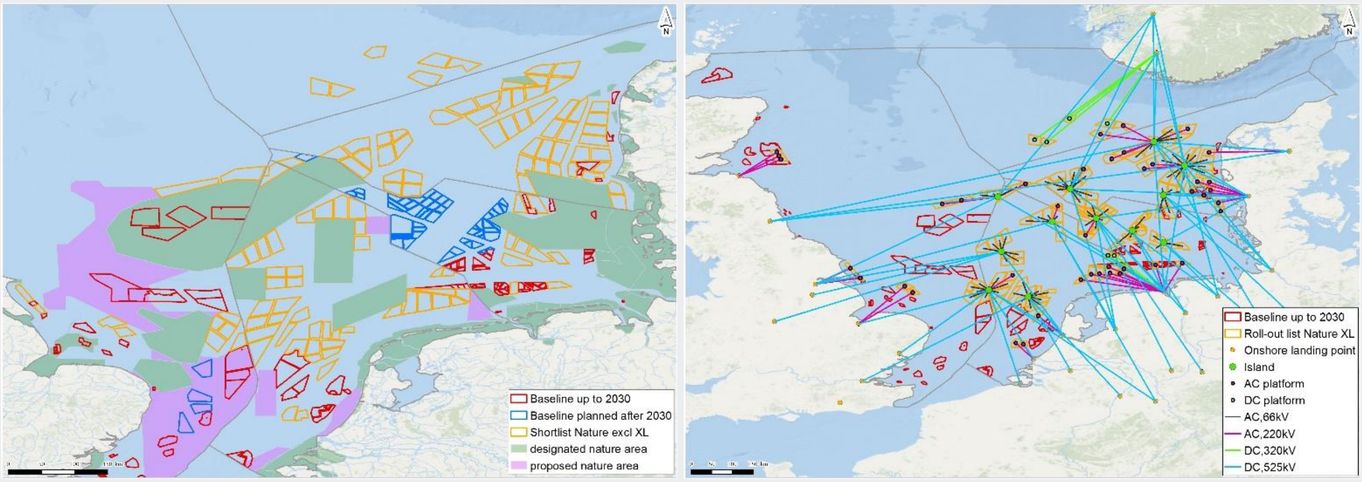

Figure 4: Post 2030 potential roll-out of offshore wind area and connection infrastructure when only nature areas are excluded. OWF areas depicted provides a point of departure to stimulate discussion among various stakeholders and does not represent any policy recommendation by the consortium.

Not all impacts of offshore area use are straightforward to monetize (especially long-term environmental effects) and all carry substantial uncertainty. This all needs to be addressed in a spatial planning debate which clearly goes beyond a techno-economic analysis. The cost impact of co-utilization as assessed in the Offshore Wind Cost Analysis should thus be seen as a conservative estimate.

Offshore Wind Cost Analysis: Limitations

The consortium sees the Cost Evaluation of North Sea Offshore Wind Post 2030 study as a first step in understanding the techno-economic impact of potential spatial planning decisions by policy makers on the roll-out of offshore wind. The following aspects must be considered when interpreting the results of the study in further detail:

- No decommissioning of oil & gas platforms was assumed, which was found to yield approximately 9 GW of potential offshore wind capacity (at 5 MW/km^2) in the earlier Translate COP21 study[5].
- A relatively low wind farm density (3.6 MW/km^2) was initially considered as optimal wind farm density for the year 2030 (based on studies by TNO), and as such was used in this study. However, wind farm density can be significantly higher in practice, as is the case for the German offshore wind farms in clusters 1-8[14] which have an average wind farm density of 12 MW/km^2. Such higher wind farm density either allows for less spatial claim to host the same amount of offshore wind capacity (with potentially lower yields due to increased wake-losses), or enables the potential for a higher wind capacity roll-out in context of other energy scenarios including higher green hydrogen uptake.
- The offshore areas in Belgium and France are not included in the search for available area for the roll-out of offshore wind towards 2050, while they are part of the pathway for offshore wind deployment put forward by the consortium (70

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[14] Bundesamt fur Seeschifffahrt under Hydrographie, 2017. Bundesfachplan Offshore für die deutsche ausschließliche Wirtschaftszone der Nordsee 2016 /2017 und Umweltbericht https://www.offshore-stiftung.de/sites/offshorelink.de/files/documents/BFO_Nordsee_2016_2017.pdf

to 150 GW in 2040, up to 180 GW in 2045 across the entire North Sea). The study is focused on areas in the central North Sea which could be integrated through a Hub & Spoke concept.

- Deployment of monopile foundations for offshore wind turbines was assumed viable up to 55 m water depth. Jacket foundations could already be required before reaching 55 m water depth thereby potentially increasing cost levels significantly.
- Small differences in wind farm O&M costs between nearshore wind farms with low wave conditions and far offshore with high wave conditions (250 km distance to shore) were found (3 to 4%) which requires further analysis.
- A relatively low real discount rate of 2.9% was used resulting in very low LCoE levels. A low discount rate increases the relative importance of OPEX changes compared to CAPEX changes.
- Only fixed bottom offshore wind developments are considered up to 2050. Floating offshore wind projects could be deployed in waters beyond 55 m water depth but their deployment until 2030 is considered rather limited compared to fixed bottom offshore wind farms.
- Cumulative costs of co-utilization of an entire roll-out could be greater than that for sum of the individual offshore wind farm co-utilization costs.
- Power 2 Gas, including hydrogen transportation, was not included in the scope of the study.

Going forward: Ongoing Analysis

The NSWPH consortium has broadened the investigative space for Hub & Spoke projects in the North Sea, based on:

i. the spatial study, which indicated that the Dogger Bank location as initially being in focus may not have an overwhelming cost advantage;

ii. clear arguments from an environmental perspective to consider more thoroughly the possibilities of realizing hubs outside N2000 areas; and

iii. a longer-term vision that multiple hubs would be needed in the full-scale roll-out of offshore wind.

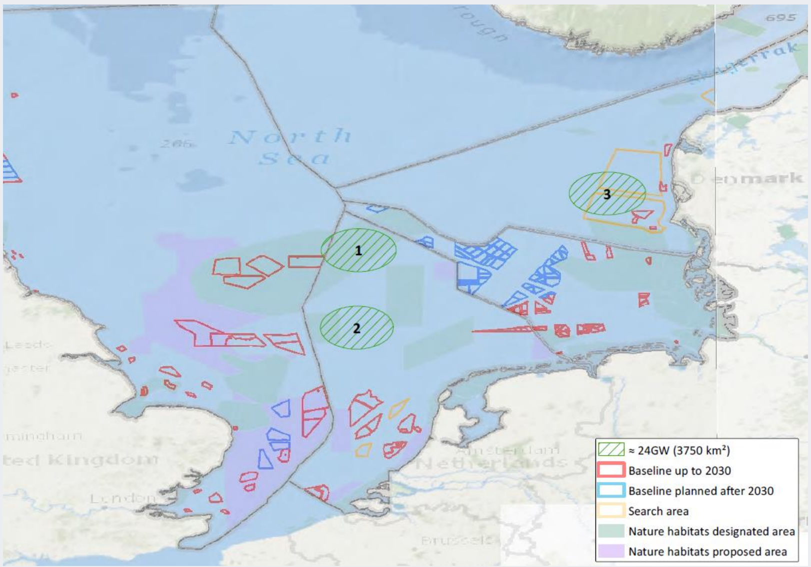

Figure 5: Three test locations for a first NSWPH project; note that these test locations should not be interpreted as preferential locations. Number of locations provides no indication of preference.

The consortium is conducting technical, economic and environmental analyses for three test locations based on a set of functional hub configurations. These test locations should not be interpreted as preferential locations; they cover different characteristics and apparent pros and cons as a base for further analysis. All three test locations hold a potential for large hubs and large-scale offshore wind farm developments (Figure 5).

1. Dutch EEZ on the Dogger Bank (Natura2000 area)
2. Dutch EEZ south of Dogger Bank
3. Danish EEZ west of Jutland

The consortium plans further environmental analyses focusing on habitats and species for the three selected test locations as well as for the North Sea as a whole. The consortium intends to synthesize available information, data and maps related to relevant habitats and species. The aim is to identify and close as much as possible any knowledge gaps by June 2019, and to establish a sound and broad environmental analytical foundation for further steps. As part of the three selected test locations, the consortium is also still considering alternative design options from an environmental perspective (sand filled island, jacket structure, floating) bringing general knowledge that could be used in assessing best hub options from an environmental perspective (i.e. with least negative impact) in also other potential locations in the North Sea. Finally, the consortium is discussing whether to include additional benefits in the concept such as seabed mattresses, bio huts for cod and special designed scour protection to improve conditions for flat oysters.

Going forward:
Direction from policy makers on spatial planning of new offshore wind farms is required to allow for an internationally coordinated approach with regards to planning of offshore wind farm areas, co-utilization and the onshore integration of offshore wind energy. This is urgently needed to ensure that energy decarbonisation ambitions can be met in a cost-effective manner. The consortium considers it essential to engage with stakeholders to initiate, facilitate and accelerate the discussions on spatial planning. This includes in particular:

- **Governmental organizations:** to engage on topics regarding post 2030 internationally coordinated spatial planning and the urgency for action
- **Environmental NGOs**: To engage on scoping of further studies. The spatial study serves mainly as a dynamic model and starting point for further analyses. Input from NGO's would greatly enhance environmental analyses.
- **Users/Suppliers**: To communicate rationale and results, actively asking for feedback/contribution to the knowledge group.

ABOUT THE NORTH SEA WIND POWER HUB

TenneT Netherlands, TenneT Germany, Energinet, Port of Rotterdam and Gasunie joined forces to develop a large scale European energy system for offshore wind in the North Sea. The NSWPH consortium partners consider the project to be an important possible alternative path of an internationally coordinated roll-out towards accomplishing the green energy transition and achieving the Paris Agreement. By developing the North Sea Wind Power Hub project, the consortium endevours to make the energy transition both feasible and affordable. Central to the vision is the construction of one or more hubs at a suitable location in the North Sea with interconnectors to bordering North Sea countries. The whole system may function as a hub for transport of wind energy, an interconnection hub to the connected countries, a working hub for offshore wind developers and a location for possible Power to Gas solutions.

CONTACT DETAILS

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