E3G

Imperial College London Consultants

REPORT MARCH 2021

OFFSHORE WIND IN THE NORTH SEAS

FROM AMBITION TO DELIVERY

SIMON SKILLINGS & GORAN STRBAC

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Goran Strbac is Professor of Electrical Energy Systems at Imperial. The results of the modelling work undertaken by Professor Strbac and colleagues from Imperial represents their independent opinion and the work was conducted through Imperial Consultants.

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EXECUTIVE SUMMARY

The North Seas region provides excellent energy resources that could be the engine of the UK's future economic activity and ensure delivery of net zero emissions by 2050. Developing an integrated and interconnected electricity grid in the North Seas and northwest Europe is key to unlocking the significant wind resources, zero emissions energy sources and grid flexibility that will be needed.

The UK government recognises the need for an integrated network for offshore wind. The time window available to act is however tight and 3 challenges remain to be solved:

- *Minimising environmental impacts and costs*: The immediate priority is to find a solution that reduces adverse impacts on local environments from grid connections whilst maintaining the rate of deployment in line with government targets of 40GW by 2030. Reducing the number of network connections to the onshore grid by moving to an approach involving co-ordinated offshore connection to hubs across the North Seas represents a promising solution. Our modelling suggests there are £23-45bn (in the period out to 2050) in cost savings available from such a move.

  Recommendation: The Government should work with the Electricity System Operator (ESO), project developers and environmental advocates to identify an implementation plan before the end of 2021 (and ideally before COP26). This should migrate as much of the current and future pipeline of offshore wind projects as possible to co-ordinated grid connection whilst avoiding excessive cost and disruption to projects.

- *Realising benefits from UK-EU coordination*: The cost advantage of ensuring offshore grid design is co-ordinated with, and interconnected to, European neighbours is significant. We estimate a value of around £25bn across the North Seas in the period out to 2050. Whilst the post-Brexit trade agreement requires EU and UK parties to establish a technical discussion to address this issue, effective arrangements for network design and electricity trading will require new governance arrangements and shared control between countries. These are difficult political decisions and will not emerge from bottom-up technical working groups.

  Recommendation: The Government should undertake the analysis to compare the benefits of multi-purpose interconnectors with a fully meshed grid to identify the ultimate objective of collaboration with the EU. It should immediately initiate the multi-level engagement processes to capture this win-win political opportunity to establish a collaborative UK-EU agenda post-Brexit. The initial priority should be to obtain top-level political agreement for the implementation of a new approach for offshore network planning and electricity trading by the mid-2020s.

- *Enabling optimal decision making*: The key factors driving offshore network design are new and uncertain. They include demand for green hydrogen, electrification of heat and transport, improvements in energy efficiency, deployment of decentralised energy resources, and deployment of smart, controllable demand side response. Previous approaches and institutions cannot be relied upon to deliver coherent, integrated infrastructure planning.

Recommendations:

- The government should establish a transparent and independent process or body to identify future technology costs and deployment potentials. This would be used to determine low regret deployment pathways for offshore wind resources.

- The government must provide the ESO with a framework which sets out how other demands for offshore spatial resources should be incorporated into the offshore network planning process. This framework must comply with strict requirements to limit marine and coastal environmental impacts.

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THE NORTH SEAS AS THE DRIVER OF THE UK'S LOW CARBON FUTURE

The North Seas have been vital to the economic development of the UK in providing transport, trade routes, food, and natural resources to coastal communities and the wider population. The UK's coastal regions along the North Sea have been important since the industrial revolution and can now lead the transition from fossil fuel production to become an engine of the UK's clean economic growth. The geography and geology of the region, with abundant clean natural resources, explain why it has already enabled the UK to become the world leader in offshore wind. Delivering net zero greenhouse gas emission by mid-century will rely heavily on the North Seas and the range of clean technologies they can support. These include not only offshore wind farms, but floating wind turbines, wave and tidal arrays, electricity interconnectors to other countries, and the future production of green hydrogen.

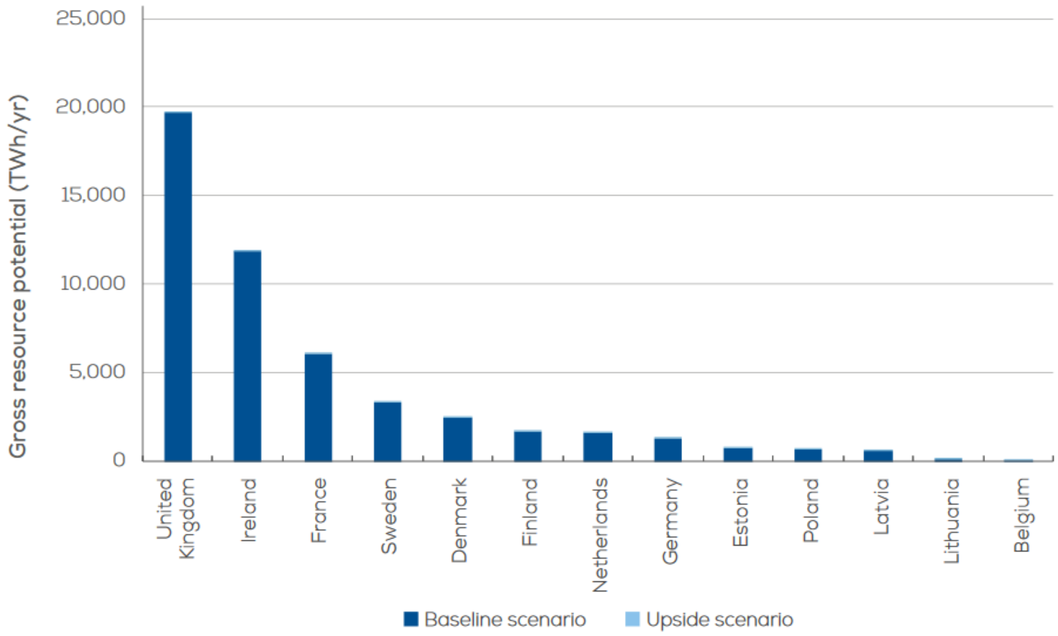
There must be a huge step-up in the production of low carbon electricity if the UK is to decarbonise the power sector and supply growing demand from the electrification of heating, transport, and industry. The more offshore wind production that can be efficiently accessed and integrated into the power system, the easier this will be. Moreover, this would establish North Seas coastal communities at the heart of the green energy transition, providing jobs and economic activity. These new and expanded industries can help the North Seas region transition from dependence on the declining oil and gas sector and provide long-term and quality employment for workers.

However, developing the low carbon opportunities that the North Seas presents will require a significant expansion of electricity grids and infrastructure both offshore and along the east coast. This will inevitably impact the seabed and coastal environments. The challenge is to buildout infrastructure at pace whilst minimising environmental impacts. This will require important decisions to be made about how infrastructure is planned, deployed and regulated, and these decisions must be taken soon.

PROGRESS IN DELIVERING A NORTH SEAS GRID

The UK has the highest offshore wind potential in Europe, with a resource of nearly double that in any other country (see Figure 1)[1]. This is because the UK Exclusive Economic Zone (EEZ) allows access to resources in both the Atlantic and North Sea basins. The growth of UK wind has been remarkable since the first offshore windfarm was built two decades ago off the coast of Northumberland. The sector's share of electricity supply grew from only 0.8% in 2010, to 6.2% in 2017, before leaping to 10% in 2019[2]. The UK now has 10GW of offshore wind capacity, which is a quarter of the global total and makes the UK's offshore wind sector the largest in the world.

Figure 1: Gross resource potential in 2030 by country



Source: BVG Associates for WindEurope

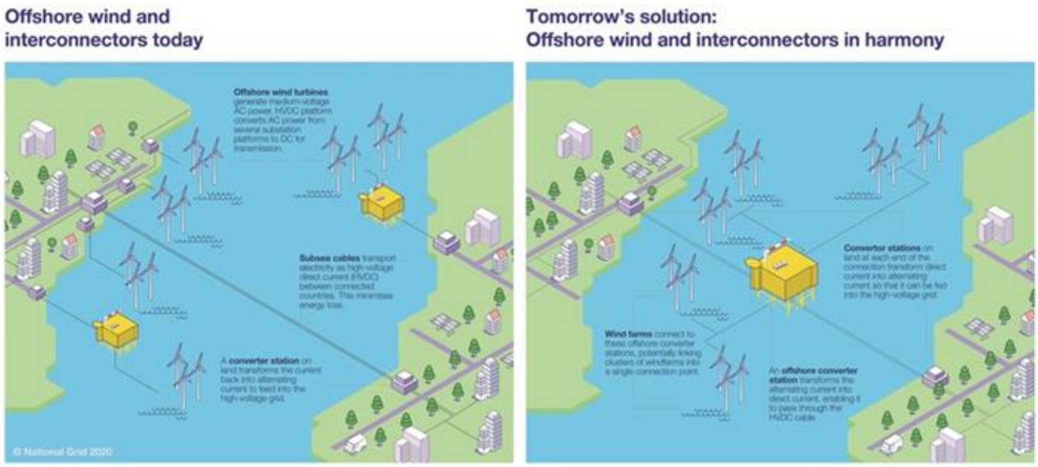
In October 2020, the Prime Minister increased the 2030 target for offshore wind capacity to 40GW. He also created a new target for floating offshore wind of 1GW by 2030, thereby opening the potential to access improved wind resources

[1] Wind Europe (2017): **Unleashing Europe's offshore wind potential A new resource assessment**

[2] BEIS (2020) Digest of UK Energy Statistics

further out to sea. Reaching these targets and continuing with the necessary expansion thereafter will require a huge growth of the sector, domestic supply chain, and electricity network infrastructure.

Figure 2: Radial and integrated grid designs



Source: National Grid

Currently all UK offshore wind farms have their own direct link onshore to transfer the electricity they generate to where it is needed – the so-called 'radial' approach. Separately, there are also cross-border interconnectors that allow the direct trade of electricity between the UK and European neighbours. There is already a significant body of evidence that radial connection and separate interconnectors are not the right approach to support significant expansion of offshore wind capacity[3]. Not only would it be unnecessarily expensive, but it would require a large amount of new infrastructure with associated environmental impacts. This is in addition to conflicts with other spatial demands such as military and fishing. An alternative integrated offshore grid design, which would combine these two types of infrastructure, offers the prospect of allowing more offshore renewable energy to be developed, cheaply and efficiently by limiting the amount of grid infrastructure involved (see Figure 2). This could be achieved either through combining wind farms and interconnectors into so-called 'multi-purpose interconnectors' or by creating a fully 'meshed' offshore

[3] See, for example: Goran Strbac, Rodrigo Moreno, Ioannis Konstantelos, Danny Pudjianto, Marko Aunedi, July 2014 Imperial College London "**Strategic Development of North Sea Grid Infrastructure to Facilitate Least-Cost Decarbonisation**".

grid[4]. However, a more integrated approach raises challenges relating to network planning and regulation, and the way the electricity is traded.

These challenges and potential solutions have been under consideration for some time. The North Seas Countries' Offshore Grid Initiative was a regional cooperation of 10 countries, including the UK, formalised by a memorandum of understanding in 2010. The objective was to facilitate the coordinated development of a possible offshore electricity grid in the greater North Seas area. Following the Paris Climate Agreement, this initiative was re-booted in 2016 with the establishment of the North Seas Energy Cooperation, which aimed to facilitate the cost-effective deployment of offshore renewable energy, in particular wind, and promote interconnection between the countries in the region. The UK left this initiative when it departed the EU in January 2020.

In July 2020, the UK Government announced a review into the way that the offshore transmission network is designed and delivered, consistent with the ambition to deliver net zero emissions by 2050[5]. Analysis by the Electricity System Operator in support of the Government review[6] suggests:

- An integrated approach offshore could save GB consumers approximately £6bn, or 18%, in capital and operating expenditure between now and 2050 provided this new approach is implemented in 2025. The benefit would reduce to £3bn if it is delayed until 2030.

- There are potentially significant environmental and social benefits, as the number of onshore and offshore assets, cables and onshore landing points could potentially be reduced by around 50% (30% if delayed until 2030).

The Energy Minister stated in Parliament on 5th November 2020 that: 'the argument for some form of offshore network system has been won' and the key point of debate has become 'when' rather than 'whether' a new approach

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[4] A multi-purpose interconnector is where offshore windfarms (or other energy resources) are connected directly into an interconnector with a single onshore connection in both countries that it links. A meshed offshore grid is where different offshore energy assets are connected through a more complex electricity network, including several onshore connections.

[5] It is also working on a hydrogen strategy that is due to be published in 2021. Also, the Treasury announced a £4.3m Offshore Wind Enabling Actions Programme as part of the Comprehensive Spending Review to be jointly run by DEFRA and BEIS which is 'designed to increase understanding of the environmental impacts of offshore wind and find strategic solutions to reduce barriers to its expansion in English waters'.

[6] Offshore Co-ordination Phase 1 Final Report, 16th December 2020

should be adopted. However, the relative lack of progress that has been achieved over the past decade, despite the compelling evidence, suggests that the problems raised are not easy to solve. The key obstacles that need to be overcome are:

> *Strategic planning*: Regulators/governments are concerned about 'picking winners' and landing future consumers with the burden of recovering stranded costs. Also, the transmission system operators that traditionally assume this role are not independent or expert in all relevant technologies and should not be making the big policy 'decisions' that are implicit in the planning process.

> *Trading between jurisdictions*: The UK is now operating outside the EU internal energy market and the new rules for electricity trading still need to be defined[7]. However, even within the current EU rules, many issues relating to the regulation of offshore grids and markets remain to be resolved[8].

> *Co-location of resources*: Currently, offshore wind and storage/electrolyser projects need to be developed and progressed separately and they cannot be combined to share network capacity and reduce network costs. This links directly to the absence of a clear strategic planning process.

> *Market design*: Defining a price for renewable generation that retains incentives to invest and supports efficient use of resources when renewable capacity is large compared to demand is a problem that regulators and policy makers are grappling with around the world. This problem is particularly acute offshore where demand will be low and renewable generation high. The government has indicated that it will be considering these issues in a forthcoming Call for Evidence on Renewable Support.

None of these obstacles are insurmountable given sufficient political will. The following sections reinforce the increasing economic and political imperatives that demand appropriate actions are taken.

[7] Alternative arrangements which allow trade and mutual support for security of supply to continue are being implemented in the interim and will endure until the agreed trading model can be put in place.

[8] What is the licensing regime and how would it be governed (e.g. decommissioning obligations, economic regulation)? How would the costs of the shared offshore network be recovered – including costs associated with anticipatory investment? How would market support be allocated and how would renewable energy production be settled between countries?

MODELLING AN INTEGRATED AND INTERCONNECTED NORTH SEAS GRID

E3G and researchers from Imperial College London have collaborated to review the economic case for an integrated grid which they first established in 2014[9]. The new study uses a multi-stage transmission investment model to identify the optimal system design with a focus on nine countries in Northern Europe (UK, Ireland, Sweden, Norway, Denmark, Germany, Netherlands, Belgium and France). Two future offshore wind deployment scenarios have been considered:

> *Medium ambition*: Involves maximum utilisation of 'fixed-base' installation opportunities and is in line with the UK government 2030 deployment target. This gives a total offshore wind capacity of 340GW by 2050.

> *High ambition*: increases deployment by using floating offshore wind installations in the years beyond 2030. This leads to a total offshore wind capacity of 490GW.

The ENTSO-E ten-year network development plan (TYNDP) 'Global Ambition' scenario has been used to define the network (topology, generation mix, demand) for the nine countries. Whilst there are many limitations of this scenario (including high on-going dependence on gas and carbon capture and storage), it does provide an internally consistent set of data for the energy system which is aligned with the 2050 climate neutrality goal. However, using this data has highlighted the need for a consistent approach across the whole energy system, as described below.

Eight cases have been studied for each scenario. These have been designed to compare how system costs change between using the current radial connection approach, more strategic grid co-ordination within country regions (hub approach), and a fully interconnected grid both within and between countries around the North Seas. We have also explored how improved system flexibility through enhanced use of demand side response (DSR) and co-location of

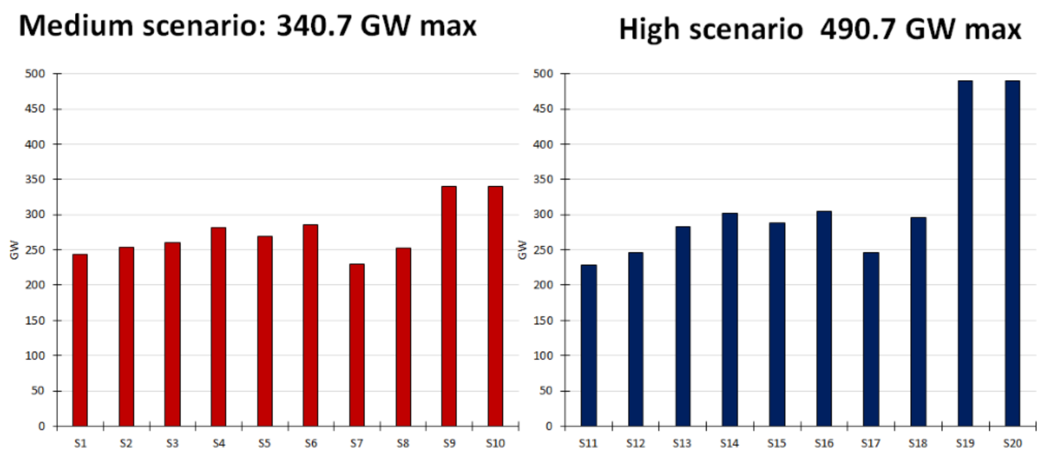
[9] Strategic Development of North Sea Grid Infrastructure to Facilitate Least-Cost Decarbonisation, Goran Strbac, Rodrigo Moreno, Ioannis Konstantelos, Danny Pudjianto, Marko Aunedi, July 2014 Imperial College London

offshore wind and hydrogen producing electrolysis plant can reduce system costs. These cases are summarised in the following table:

Table 1: Studies modelled for each scenario

Study index	Integration level	Connections	DSR	Hydrogen
1	None	Radial	N	N
2	None	Hub	N	N
3	Member-centric	Hub	N	N
4	Pro-European	Hub	N	N
5	Member-centric	Hub	Y	N
6	Pro-European	Hub	Y	N
7	Member-centric	Hub	N	Y
8	Pro-European	Hub	N	Y

Figure 3: Offshore wind capacity in each study



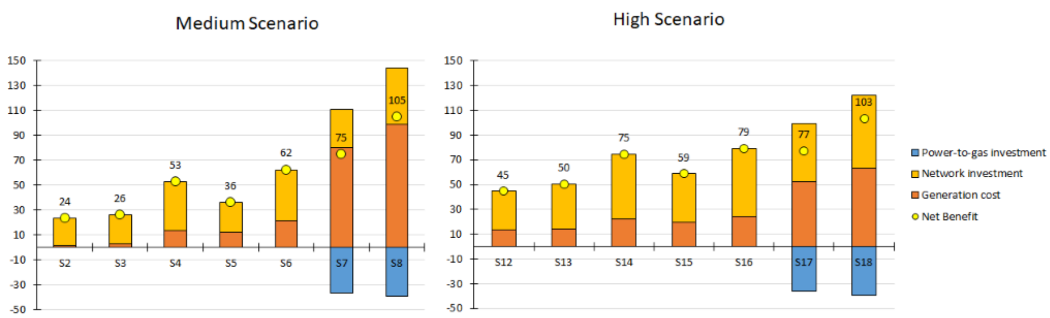
Each of these studies was constrained by the ENTSO-E demand assumptions and, therefore, the model did not choose to build all the potential offshore wind capacity available. A further two scenarios were run where demand was increased to produce hydrogen (study 9 with electrolysers offshore and study 10 with electrolysers onshore) such that all the potential capacity was utilised. High utilisation of offshore wind capacity could also be achieved by assuming surplus generation could be traded throughout the EU. The offshore wind capacity adopted by the model for each study is shown in Figure 3.

This highlights that the optimal buildout of offshore wind in the North Sea will depend on several key assumptions. These include demand for green hydrogen, the deployment of smart and controllable demand side response, improvements in energy efficiency, the volumes of decentralised energy resources, and the electrification of other sectors. Planning an offshore grid therefore requires deep expertise in the technology developments and deployment potentials in these areas.

Key conclusion 1: The institutional governance of the North Seas offshore grid must ensure deployment plans are based on a deep understanding of developments across the whole energy system and are co-ordinated as part of a whole system delivery plan.

The net cost benefit for each study compared to the radial connection counterfactual has been calculated by comparing network and generation costs (and electrolyser costs in studies S7, S8, S17 and S18). These results are shown in Figure 4.

Figure 4: Net benefit (£bn) of each study compared to the radial base case



This shows that the largest cost savings come from co-ordinating connections to offshore hubs (between £23bn and £45bn) and fully integrating the offshore grid with UK and EU power networks (a further saving of ~£25bn). Significant savings are also available through mechanisms that improve system flexibility and allow more effective integration of offshore wind generation (demand side response and electrolytic hydrogen production). Whilst establishing an offshore network between hubs within national waters does create some additional savings (£2-5bn), these are small compared to savings created through integration between countries.

Key conclusion 2: The economic benefits of co-ordinating grid connections around offshore hubs are very significant.

***Key conclusion 3*: The economic benefits of establishing a fully integrated and interconnected grid across the North Seas are very significant.**

This analysis did not consider the potential benefits associated with multi-purpose interconnectors which represent a level of integration beyond co-ordinating connections but less than a fully meshed grid. A useful piece of further analysis would be to consider how much of the benefits could be captured through this intermediate approach.

Additional studies were run to investigate how much hydrogen could be produced through the full utilisation of offshore wind capacity in the scenarios. The additional electricity generated that could be converted into hydrogen is summarised in the following table:

Table 2: Electricity available for hydrogen production

Year	Medium Scenario (TWh/year)	High Scenario (TWh/year)
2030	0	0
2040	0	165
2050	258	941

This highlights that production of significant quantities of green hydrogen from offshore wind in the North Seas will not happen quickly and will require very ambitious goals for offshore wind deployment. These studies compared the costs of building additional power networks and producing hydrogen onshore with the co-location of hydrogen production at offshore wind hubs. In the latter case, it is assumed that existing gas network would be re-purposed to pipe hydrogen ashore. The additional costs of the power network are significant (£37.5bn in the medium scenario and £141.5bn in the high scenario). Assuming the costs of re-purposing gas pipes to transport hydrogen onshore is significantly lower than these amounts[10], this suggests that the preferred approach for green hydrogen production will involve co-location of electrolysis and offshore wind generation. This further highlights the importance of integrated whole system planning of the offshore grid network and the creation of offshore energy hubs.

[10] Note that the costs of re-purposing onshore gas infrastructure and appliance for hydrogen use are high and uncertain and this analysis draws no conclusions about onward transmission within the onshore gas network or the extent of the overall hydrogen demand.

Further details relating to the modelling approach and key assumptions are provided in the Appendix.

OTHER POLITICAL BENEFITS

Growth and jobs

A key benefit of an enhanced initiative to develop the offshore wind resource is that it will help drive economic growth and employment as the UK recovers from the pandemic. Moreover, it will achieve this objective in a way that supports the levelling up agenda to address geographical inequalities by targeting jobs in areas that will suffer economically through the transition away from fossil fuels.

The UK already has significant low carbon engineering expertise and is building the supply chain that will ensure the net zero transition, both nationally and globally, will create an economic dividend. Expanding the renewables supply chain will be crucial in ensuring new, quality jobs are provided as the domestic fossil fuel industry shrinks. More UK-made low carbon technology will support the manufacturing sector as it delivers to markets at home and abroad. Building 30GW of new offshore wind capacity by 2030 was estimated to create 27,000 jobs[11] and more would be required to support the new 40GW target. The government has suggested this target could create 60,000 jobs[12].

The offshore wind sector already employs around 10,000 people (2018) in a broad supply chain that involves companies from across the UK[13]. This can be expected to increase significantly if growth aspirations from the sector are fulfilled. Importantly, there is a density of companies in localities previously dependent on fossil fuels that supply the offshore wind industry. For example, clusters exist in Teesside and the East Anglia coastal regions in England, and Aberdeen Bay and the Firth of Forth in Scotland. These are key regions for the existing offshore oil and gas industry and new jobs supporting offshore wind deployment will help boost local economies as demand for fossil fuels declines. The UK's low carbon sector already supports more jobs than the oil and gas industry, employing more than 430,000 people in 2018[14] compared to 259,000 jobs in oil and gas[15]. Importantly, most jobs associated with oil and gas are in the

[11] Renewable UK (20 March 2018) **UK Offshore Wind Industry Reveals Ambitious 2030 Vision**

[12] https://www.gov.uk/government/news/pm-outlines-his-ten-point-plan-for-a-green-industrial-revolution-for-250000-jobs

[13] ECITB (2019) **Industry 4.0: The impact of technological change on the Engineering Construction Industry** p.33

[14] **BEIS (2019) Industrial Strategy: Offshore Wind Sector Deal**, p.2

[15] **Oil and Gas UK (2019) Workforce Report 2019**

supply chain, support services, or non-direct related businesses, and are well-positioned to shift to support offshore wind deployment. Only 30,400 people were employed directly by companies extracting oil and gas. This is approximately the same as the workforce of online retailer Amazon[16].

Technology leadership and innovation

Offshore wind is a technology with huge global growth potential since it provides access to sites of high wind resources close to key markets that can be developed quickly at gigawatt (GW) scale. It is estimated that the global market will grow from just 23GW in 2018 to 228GW in 2030 and near 1,000GW in 2050[17]. Current deployment is concentrated in China, UK, and Germany, but is expected to increase significantly in North America and Oceania over the coming years. In addition, many emerging markets are now setting targets for offshore wind deployment.

Several providers of materials and components required for offshore wind development have located manufacturing facilities in the UK to meet local demand and this investment is likely to expand over the coming years as demand increases. Whilst it is unlikely that UK-based manufacturing will be used to meet global increases in demand, the UK and its offshore wind energy supply chain can take advantage of the rapidly developing export market through owning the appropriate intellectual property and through system integration knowledge[18]. The UK government can make the most of this opportunity by continuing to support research and innovation in offshore wind and related activities.

Global political leadership in the run-up to COP26

A successful COP26 at the end of 2021 will be critical, not only in addressing the climate crisis, but in reinforcing the role of the UK on the international stage post-Brexit. This will require smart diplomatic skills, leveraging the commitment the UK has demonstrated to the cause of decarbonisation supported by bold and concrete measures to reduce domestic emissions. This must go beyond

[16] ONS (2018) **Statistical Bulletin – Low carbon and renewable energy economy, UK: 2018**

[17] Future of wind, Deployment, investment, technology, grid integration and socio-economic aspects, IRENA, 2019

[18] The UK Offshore Wind Industry: Supply Chain Review, January 2019, Martin Whitmarsh

statements of ambition and show that practical steps are being taken to transform the economy.

The Prime Minister has already identified the potential opportunity of offshore wind in the North Seas. However, this ambition can be reinforced by confirming the intention to create an integrated North Seas grid and initiating the supporting actions that are required. This not only has the potential to provide policy insights to those countries that are already considering how to exploit their offshore wind resources, but to inspire action amongst countries who currently rely on fossil fuels but could switch to renewable power produced by offshore wind. It would significantly bolster the efforts of the UK Government through the COP26 Energy Transitions Council.

Local acceptance and community buy-in

Whilst communities along the east coast are set to reap an economic dividend from the development of offshore wind in the North Sea, they will also need to suffer the inconvenience and potential damage to local environments associated with onshore connections to the national grid[19]. An integrated offshore network offers the potential to realise the benefits for decarbonisation whilst minimising impacts on local communities and sensitive coastal and marine environments. Re-purposing existing gas network infrastructure to transport green hydrogen from offshore to onshore to meet hydrogen demand will further reduce the requirement for new power network infrastructure.

A group of five east coast MPs have been promoting this solution to protect the interests of their constituents[20]. Despite accepting the offshore grid concept, the Government is reluctant to delay existing projects until such a grid can be developed, although it is exploring options for 'quick-wins'. It remains a key challenge to balance the imperative for early deployment with the need for environmental sensitivity. Early progress in resolving this dilemma is required to maintain the support of local communities.

[19] A group of environmental NGOs recently wrote to the Prime Minister outlining concerns about potential environmental impacts (see **here**).

[20] See **this** article in the East Anglian Daily Times published on 2nd November 2020

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REALISING THE BENEFITS

New governance to manage technology risks and opportunities

Renewable resources in the North Seas represent a highly promising source of energy that will deliver a major benefit for decades to come. However, there remains uncertainty over the total amount of these resources that will be required. Future demands for electricity may differ from current expectations and competition may emerge from new technologies. Nevertheless, it is necessary to plan and build network infrastructure that will have a useful lifetime well into the second half of the century and may be necessary to meet demand way beyond current expectations.

It is not appropriate that important judgements about future infrastructure requirements are made by regulators and network operators through planning processes conducted as part of separate price control reviews. The increasing integration of the energy system means that this work must be consistently applied across all infrastructure planning decisions (including those relating to delivery of demand side assets such as efficiency measures and smart controls). Key decisions should also be independent of vested interests. It is, therefore, necessary to **establish a national centre of expertise in energy solutions which is required to identify future technology costs and deployment potentials and use this information to determine low regret technology requirements on the pathway to net zero.** This will provide a rigorous basis for deciding which options should be ruled out and which should be kept open.

A robust and independently derived analysis would be able to form the basis of network design processes. In the case of the offshore grid, the relevant system operator(s) would use this information to ensure grid buildout provides efficient connection capacity for low regret volumes of offshore wind, with the option to extend connection capacity at low cost if required. It would also identify which existing gas pipelines should be re-purposed to carry hydrogen and where offshore hubs to connect offshore wind farms and host hydrogen production electrolysis facilities should be located.

E3G has previously discussed the functions of an independent technical body, which we call the Clean Economy Observatory[21]. European institutions are also currently considering the creation of a similar body (the European Climate Change Council) as part of new climate legislation[22].

Co-ordinated grid connection

A new approach to grid planning is required if the UK is to exploit the significant wind resources in the North Sea whilst limiting costs for consumers and impacts on coastal environments. The radial approach to connection has delivered benefits through introducing competition into the process for building network assets, but this approach cannot be credibly scaled to take advantage of the opportunities that exist. Our modelling suggests that huge savings are available through co-ordinating the connection of offshore windfarms to hubs from where electricity can be transported onshore through a single transmission line.

It is necessary to **identify and locate offshore hubs that anticipate the subsequent connection of the large volumes of offshore wind.** These hubs should provide the connection capacity that is expected to be required to meet the UK net zero objective and to meet the potential demand for green hydrogen. The connection capacities provided should be readily scalable to accommodate future increases in the level of ambition and provide the basis for creating a fully integrated offshore grid (see below). It is important that the benefits of competition are not lost, and this should remain an integral part of the procurement of network delivery services.

Independence and consistency of approach across sectors and along the value chain is not only important in deciding future infrastructure requirements, but also in the detailed planning of system architecture. The 'Transmission System Operator' model that exists across most of Europe brings deep expertise of power system operation but limited awareness of developments in other sectors or the opportunities presented by new resources such as those provided by the demand side. Indeed, this creates an implicit bias than can result in the construction of excess network capacity. This issue has been recognised in Great Britain and the Electricity System Operator (ESO) is now largely independent of

[21] https://www.e3g.org/publications/briefing-summary-eu-energy-system-transformation-agenda/

[22] See, for example: https://www.euractiv.com/section/energy-environment/interview/mep-canfin-eu-countries-must-face-sanctions-for-non-compliance-with-climate-goals/

other National Grid activities with Ofgem recently recommending complete separation[23].

The ESO should build the capability and associated models that allow it to plan optimal network requirements in line with the assumptions and outcomes provided by independent technical experts. It will also require inputs relating to other offshore spatial demands (e.g. shipping, military, fishing) and a clear understanding of marine and coastal environments that must be avoided to limit environmental damage. **The government must ensure that a framework is provided for the ESO which sets out how these other dimensions should be incorporated into the planning process**. The most immediate policy challenge is to migrate as much of the current and future pipeline of offshore wind projects as possible to co-ordinated grid connection without incurring excessive cost and disruption to projects. **The Government should work with the ESO, project developers and environmental advocates to identify an implementation plan before the end of 2021**. The longer this is delayed, the more avoidable economic cost and environmental impact will be incurred. Ideally, this decision would be announced before COP26 as part of a package to reinforce UK leadership in the deployment of offshore wind.

Once network development proposals are approved by regulatory authorities, they can be packaged into a construction programme that ensures timely provision of offshore connection assets and allows for competitive tendering to procure network build and operational services. The hubs, and the design of any interconnecting network, will remain optimal provided other resources (e.g. electrolysers to produce hydrogen, efficient and controllable demand) are delivered to time, in the right places and in the volumes required. It will be important to ensure an appropriate and co-ordinated set of delivery policies are in place such that asset shortages do not create bottlenecks in the delivery of a zero-emissions power system.

The work of the technical expert body and the ESO will enable a long-term trajectory for offshore wind to be defined. This trajectory will involve a schedule for new connection capacity to become available along with the location of these connection opportunities. This effectively defines **a long-term plan for procurement of offshore wind capacity via contract-for-difference feed-in-tariff auctions** (or subsequent investment framework that might replace the existing

[23] https://www.ofgem.gov.uk/publications-and-updates/ofgem-recommends-independent-body-help-lead-britain-s-green-transformation

model – see below). Commitment by government to this plan will provide the long-term certainty that will encourage the development of a pipeline of projects along with investment in the supply chain capacity that is necessary to deliver the broader economic dividend.

The potential energy resources from offshore wind are vast and the technical expert body should be constantly reviewing whether the rate of growth in offshore wind capacity should be increased further – for example, if the costs of floating turbines become cheaper than alternative renewable technologies. The processes should be in place to ensure such recommendations are transparent and promptly reviewed by government. This will allow immediate instructions to be given to Ofgem and the ESO to increase network capacity accordingly. Whilst the technical recommendations will include assumptions about the ability of the supply chain to respond to increased demand, it is important that government responds quickly to new recommendations to provide the long-term signals that investors in supply chain assets require.

International regime for network design and electricity trading

The potential economic benefits of a fully integrated and interconnected grid in the North Seas have been appreciated for some time and have been confirmed by our modelling work. The EU North Seas Energy Cooperation (NSEC) initiative has been exploring these issues for several years, although the UK has only been able to participate in discussions 'in exceptional circumstances …. when it is necessary in the interest of the EU'[24] since it left the EU. The post-Brexit trade agreement requires EU and UK parties to build on this previous initiative and establish a specific forum for technical discussions relating to offshore grid development and the large renewable energy potential of the North Seas region.

Effective arrangements for network design and electricity trading will require new governance arrangements and shared control between countries. These are difficult political decisions and significant progress cannot be expected from bottom-up technical working groups. This is a win-win political opportunity to establish a collaborative UK-EU agenda post-Brexit. **The Government should**

[24] https://ec.europa.eu/energy/topics/infrastructure/high-level-groups/north-seas-energy-cooperation_en

immediately initiate the multi-level engagement process with the EU. This should aim to identify the new governance structures that will be required to deliver co-ordinated network planning and agree efficient trading arrangements in the North Seas. It is crucial that this includes **top-level political agreement to ensure that a new approach is established by the mid-2020s**.

Power systems across the world are grappling with the challenge of designing market arrangements that cope effectively with high penetrations of low-cost variable renewable energy sources. The combined objective of incentivising efficiency in both investment and use of resources is difficult to achieve with traditional approaches based on short run marginal cost pricing and the provision of grid services by fossil fuel generators. These challenges will be particularly acute for offshore grids where there will be high levels of generation from offshore wind farms, little associated demand, and considerable reliance on efficient trading with neighbouring markets. The interaction between support mechanisms and market design will be critical and will need to address questions related to 'who pays?' and 'who benefits?'. Whilst these issues will ultimately need to be addressed in all market contexts, solutions for offshore networks are required now and work must be progressed with urgency. The government announced a forthcoming "Call for Evidence on Renewable Support alongside the Comprehensive Spending Review". This process must work alongside the on-going "Offshore Transmission Network Review" and the working groups established under the post-Brexit Trade Agreement to provide long-term clarity on these issues.

SUMMARY OF RECOMMENDATIONS

The Government should:

> Establish a transparent and independent process to identify future technology costs and deployment potentials. This information is required to determine low regret deployment pathways for offshore wind resources and form the basis of network design processes. Ideally, this will involve the creation of an independent technical expert body.

> Ensure that a clear and definitive framework is provided for the ESO which sets out how other demands on offshore spatial resources should be incorporated into the offshore network planning process. This framework must comply with strict requirements to limit adverse marine and coastal environmental impacts.

> Work with the ESO, project developers and environmental advocates to identify an implementation plan before the end of 2021 to migrate as much of the current and future pipeline of offshore wind projects as possible to co-ordinated grid connection without incurring excessive cost and disruption to projects.

> Commit to a long-term plan for procurement of offshore wind capacity via contract-for-difference feed-in-tariff auctions (or subsequent support mechanism that might replace the existing model). This plan should be transparent and consistent with the new connection capacity that will be created by the ESO offshore grid design.

> Respond quickly to updated recommendations from the independent technical expert body to provide revised instructions for Ofgem and the ESO.

> Compare the benefits available from multi-purpose interconnectors to a fully meshed grid to help identify the desired objective for collaboration with the European Commission and EU member states.

> Immediately initiate the comprehensive engagement processes with the European Commission and EU member states which is necessary to identify the new governance structures required to deliver robust system architecture in the North Seas. This should involve the top-level political mandate to establish forums charged with implementing co-ordinated network planning and efficient electricity trading arrangements by the mid-2020s.

> The forthcoming Call for Evidence on Renewable Support must work alongside the on-going Offshore Transmission Network Review and the

working groups established under the post-Brexit Trade Agreement to provide long-term clarity for project developers on future market and regulatory arrangements for offshore wind projects in the North Seas.

The ESO should:

> Develop the capability and associated models that allow it to plan optimal network requirements, including the potential to expand connection capacity in future at low cost and impact on the environment. Whilst this will depend on a deep understanding of power system operation, this must be balanced by equivalent expertise in the opportunities presented by new system resources such as those provided by the demand side.
> Produce a plan for offshore connection hubs that provide a schedule for new connection capacity to become available along with the location of these connection opportunities.
> Set in place a planning process that can rapidly respond to updated instructions from government.

Ofgem should:

> Develop new arrangements for recovering the costs of the offshore network, striking a fair and equitable balance between those parties who pay and those who benefit.
> Design and implement competitive procurement mechanisms for the construction of offshore transmission assets.
> Support the work of the technical expert groups established as part of the post-Brexit trade agreement to identify the new governance structures that will be required to deliver co-ordinated network planning and agree efficient trading arrangements in the North Seas.
> Support government in the design of future market and regulatory arrangements for offshore wind projects in the North Seas.

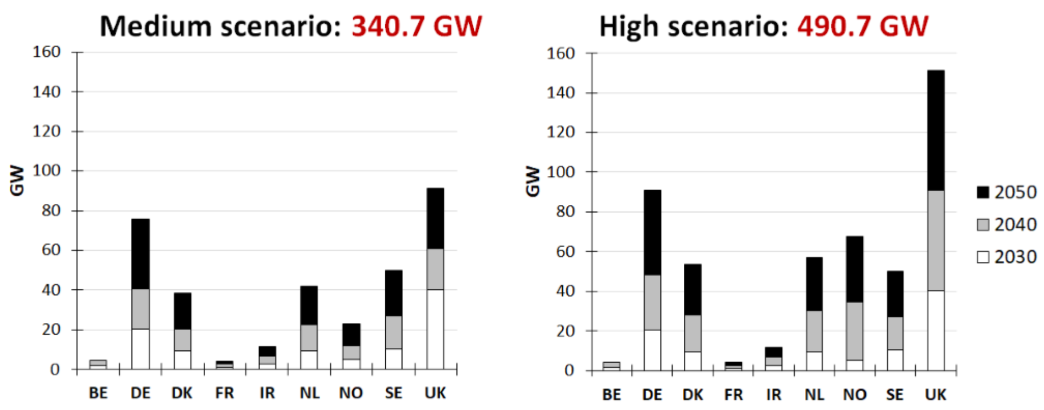
APPENDIX – MODELLING THE NORTH SEAS GRID

Consultants from Imperial College London modelled the optimal network design given future offshore wind scenarios using their ‘Advanced Dynamic Transmission Investment Model’[25]. The ENTSO-E ten-year network development plan (TYNDP), ‘Global Ambition’ scenario has been used to define the network (topology, generation mix, demand) and the 2025-2050 period has been split into 3 stages: epoch 1 from 2025 to 2030, epoch 2 from 2030 to 2040, and epoch 3 from 2040 to 2050.

In addition to those assumptions taken from the ENTSO-e TYNDP, other key assumptions are:

- Wind and PV data from ‘NASA MERRA’ database
- Average PV load factor of 13%
- Average onshore wind load factor of 31%
- Average offshore wind load factor of 56% (fixed) and 68% (floating)
- Undersea cable cost: fixed = 70,000 £/km/year, variable = 115 £/MW/km/year

Figure A1: Potential offshore wind capacity by country

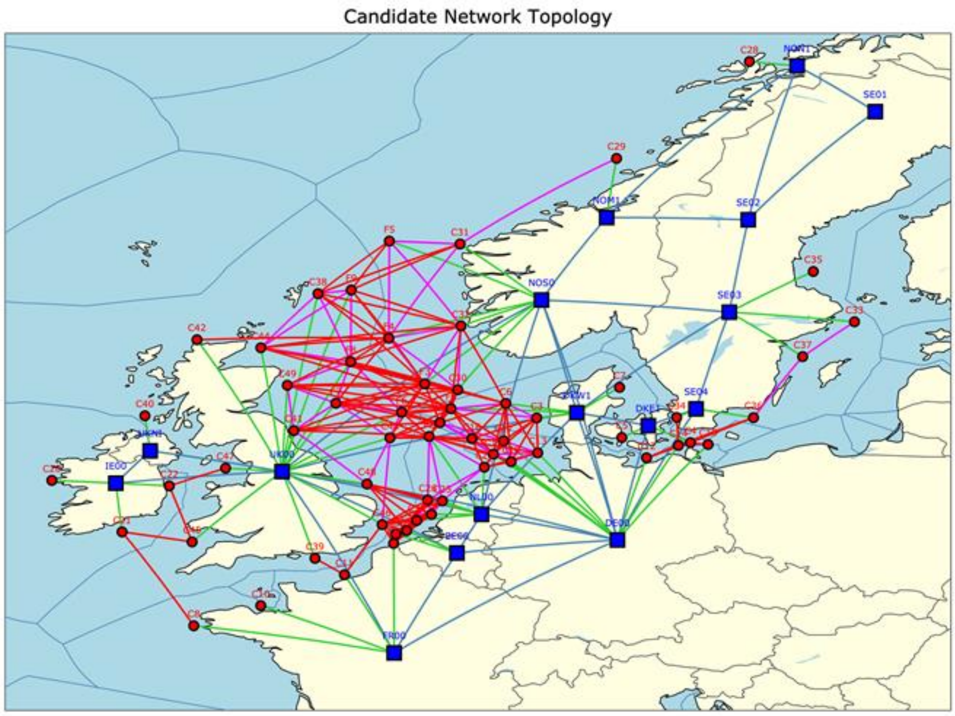


[25] See: https://spiral.imperial.ac.uk/bitstream/10044/1/28452/2/NorthSeaGrid_Imperial_E3G_Technical_Report_July_2014.pdf

A medium offshore wind deployment scenario was created using 580 fixed-bottom offshore wind projects giving a total potential capacity of 340.7GW. A further 150GW of floating windfarms were defined to give a high scenario with a total potential capacity of 490.7GW. Potential projects were allocated to a series of offshore connection hubs. Deployment potential is broken down by country in Figure A1.

A network of 272 potential new transmission connections between the hubs were considered by the model as illustrated in Figure A2.

Figure A2: Candidate network topology investigated by the model



The TYNDP demand assumptions proved particularly important. They have been based on a scenario with modest electrification (i.e. high proportion of gas) and significant deployment of distributed generation. Both assumptions suppress demand for electricity to the extent that they are inconsistent with high deployment scenarios for offshore wind. The model did not, therefore, choose to build all the potential offshore wind capacity unless demand was elevated through green hydrogen production or onward trading throughout continental Europe. The capacity utilised in each study is illustrated in Figure A3.

Figure A3: Offshore wind capacity utilised in each study

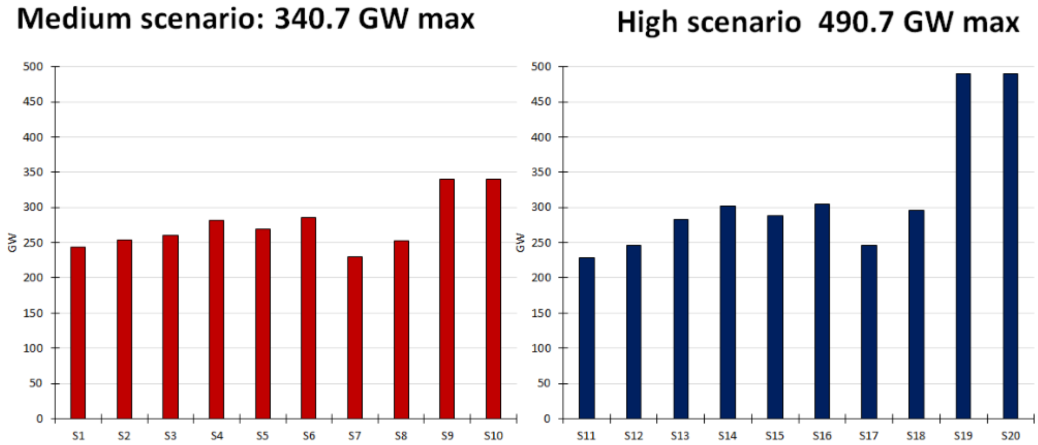
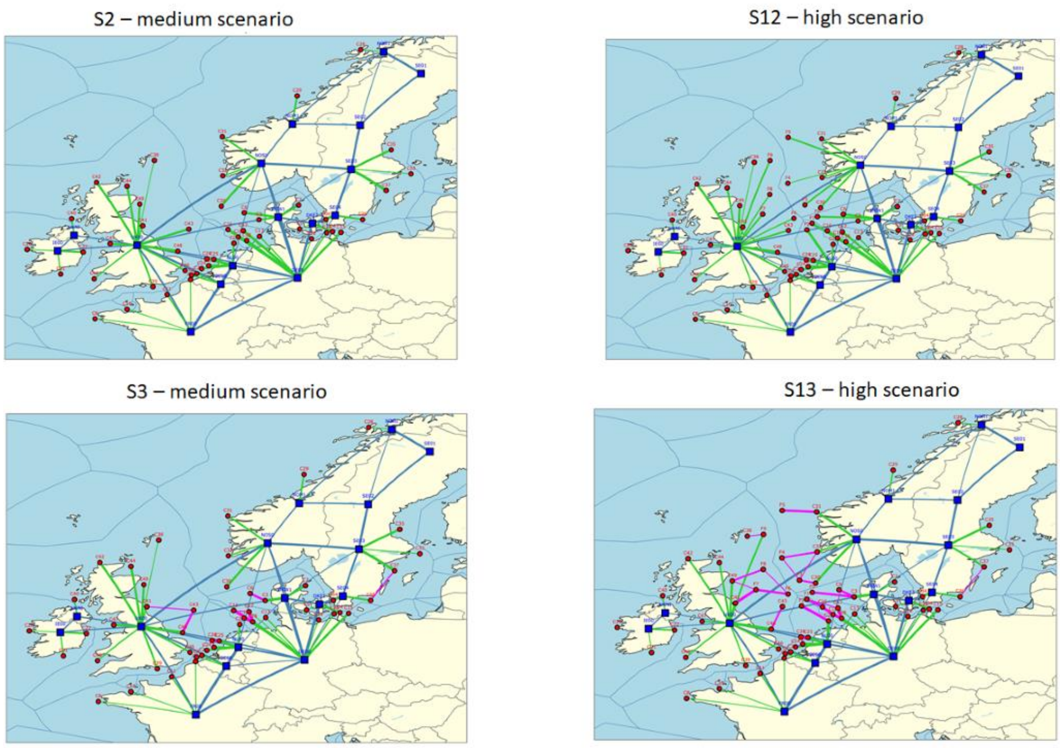
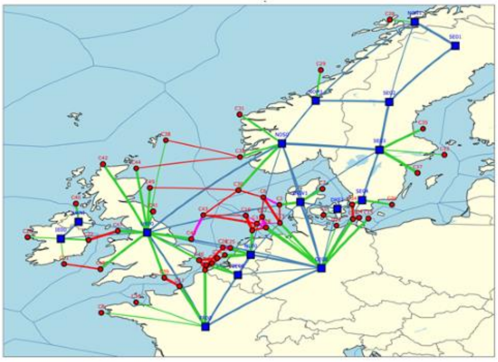


Figure A4 below shows the network topographies calculated for those studies considering hub connections, integration within national boundaries, and integration throughout the North Seas region.

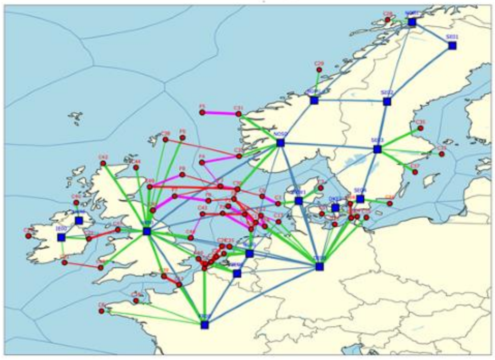
Figure A4: Network configurations with different levels of integration



S4 – medium scenario



S14 – high scenario



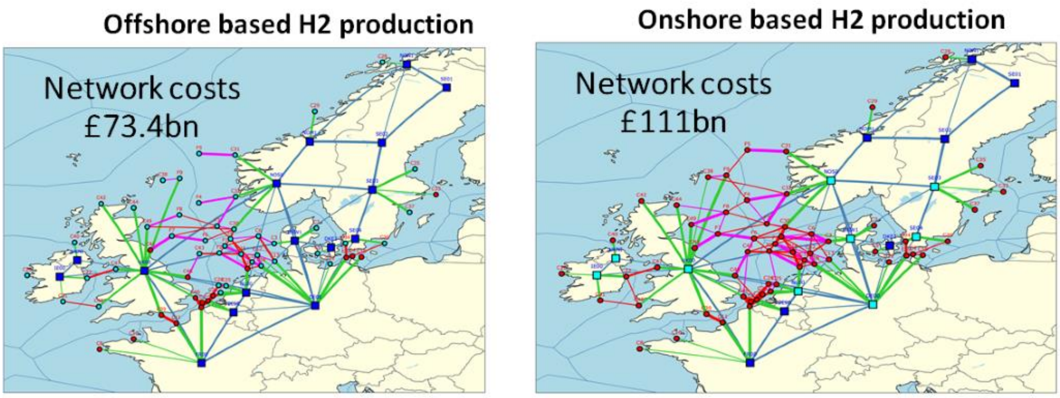
The major conclusion from this analysis was that overall costs reduced significantly by moving from radial to hub connections and then again to full integration. Grid integration within national waters had a smaller beneficial effect (see Figure 4).

The impact of improving system flexibility through demand side response was investigated by assuming 5%, 10% and 15% of energy could be moved within the same day in the first, second and third epochs respectively. This analysis showed material additional cost reductions of £5-10bn are available from enhanced demand side response (see Figure 4).

System flexibility can also be improved by installing electrolysers to produce hydrogen, either offshore, co-located with the windfarms, or connected to the onshore grid. The capital cost of electrolyser capacity was assumed to be 100 £m/year per GW installed. Four studies were undertaken in which the hydrogen produced was used to meet gas-fired power generation load, thereby preserving overall electricity demand. A further four studies investigated the opportunity to fully utilise offshore wind capacity by producing hydrogen for other purposes.

The improved system flexibility provided by hydrogen electrolysers can significantly reduce systems costs (see Figures 4). This is in large part due to the reduced capacity of offshore wind that is required to meet system demand (see Figure 3). It also appears that the cost savings available through co-locating electolyser capacity with offshore wind farms and re-purposing existing gas pipelines to transport hydrogen25 are significant. Figure A5 shows the different network configurations produced in the high scenario studies where hydrogen demand was increased to ensure full utilisation of offshore wind capacity.

Figure A5: Network configuration for offshore and onshore electrolysers for high scenario



The network investment for each line type and in each study is shown in Figure A5. This highlights that improved system flexibility and network integration can reduce the required capacity of offshore to onshore connections.

Figure A6: Network cost by line type for each study