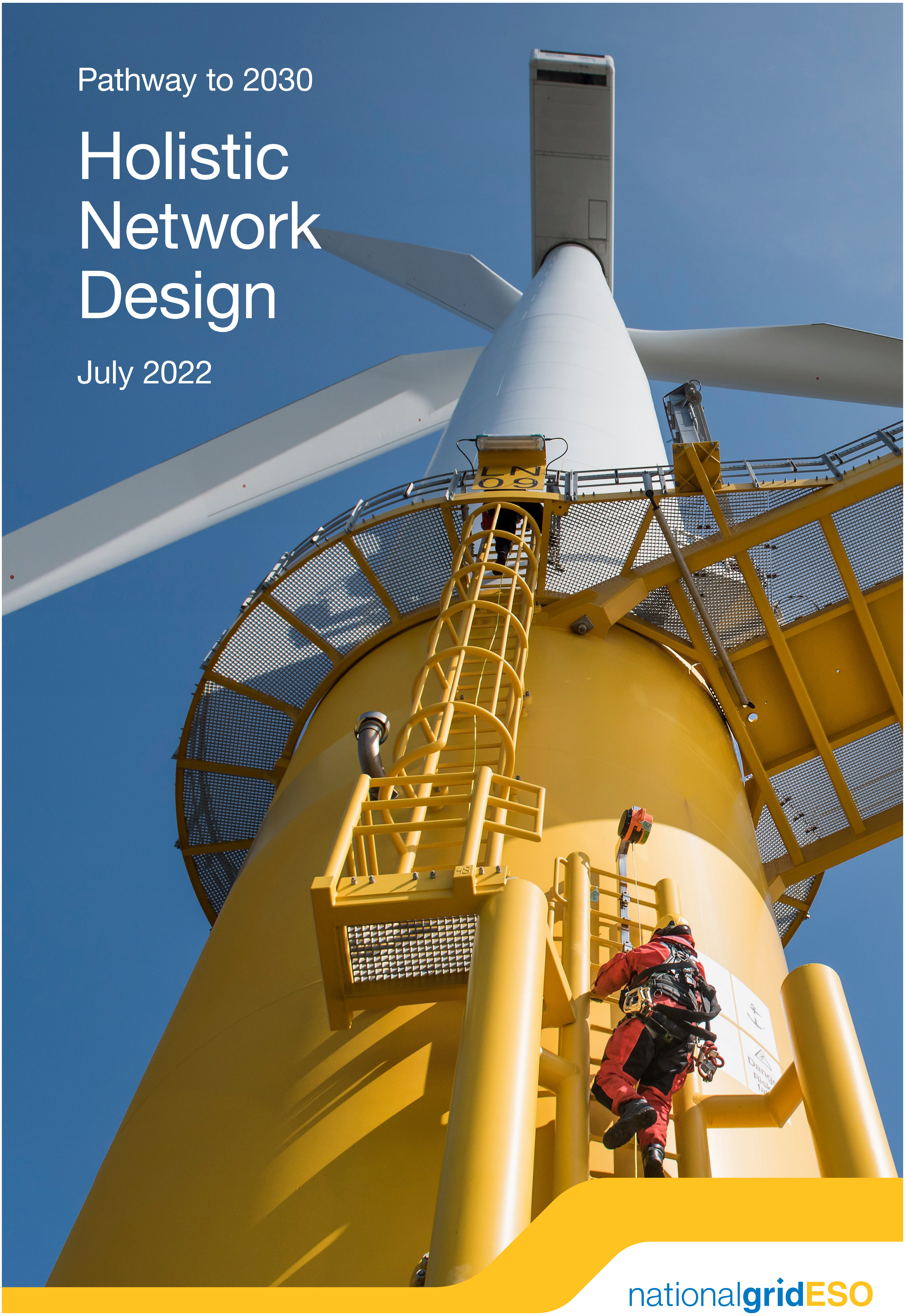
Pathway to 2030

Holistic Network Design

July 2022



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Document guide

Purpose

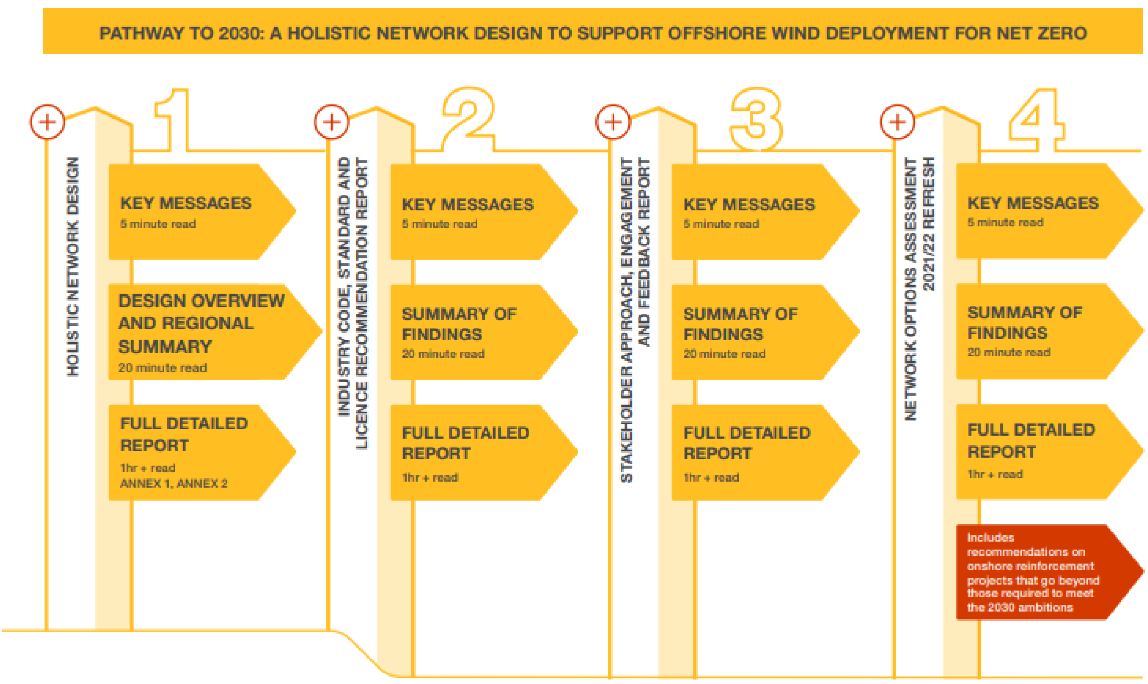
This document (the *Holistic Network Design* or *HND*) sets out the network requirements to facilitate the connection of the 23 GW of in scope offshore wind projects. When combined with existing offshore wind projects and those already further advanced in their development, the HND should enable the connection of 50 GW of offshore wind in Great Britain by 2030. This is a detailed document aimed at those who have a specific interest in the HND: a high-level summary can be found in the Pathway to 2030 document.

The HND includes the offshore transmission network, the onshore works essential to facilitate each connection and the network needed to transport the electricity around the country. It also includes two Appendices: 1) Comprehensive List of Onshore and Offshore Network Recommendations, including connections, enabling works and wider works and 2) Environment and Community Appraisal Summary.

The design seeks to balance the needs of consumers, developers, communities, and the environment. The delivery of a coordinated offshore network will enable zero carbon generation to connect in an efficient way, supporting the government's 50 GW ambition whilst minimising the impact on consumers and communities.

This document forms part of the HND suite of documents. The structure of these documents is shown in the diagram below. The documents also provide stakeholders a comprehensive view of the methodology used to develop the design, the recommended changes in industry standards, codes, and licence conditions required to achieve the design and the stakeholder feedback that we have considered in the design process.

Figure 1 – HND suite of documents



Note that the methodology document was published in February 2022 and can be found on our website[1].

A glossary[2] also explains the more technical terms used across the suite of documents.

[1] https://www.nationalgrideso.com/document/239466/download

[2] https://www.nationalgrideso.com/document/262701/download

Navigating this document

The main body of this document is split into seven main sections:

1. Executive Summary – this section provides context and sets out the key messages.
2. Introduction – this section explains the network design objectives and which projects are in scope.
3. Methodology– this section provides a brief explanation of the methodology we used to develop the design.
4. Network design guidelines and network overview– this section describes the network design guidelines and provides an overview of the recommended network design.
5. Regional overview– this section describes the recommended design and other variations considered for each region, and provides a system-wide view for onshore works.
6. Overall conclusions and next steps – this section summarises the contents of the report and provides an overview of the next steps in progressing the design.
7. Optimised radial design- this section explains the optimised radial design for each region.

1. Executive Summary

1.1 Context

The Department for Business, Energy and Industrial Strategy (BEIS) launched the Offshore Transmission Network Review (OTNR) in July 2020. It is playing a key part in enabling the vital role offshore wind has in meeting the UK Government's target for net zero. The objective of the OTNR is to ''ensure that the transmission connections for offshore wind generation are delivered in the most appropriate way, considering the increased ambition for offshore wind to achieve net zero. This will be done with a view to finding the appropriate balance between environmental, social and economic costs''.

Three workstreams were created in the OTNR to address offshore wind projects at different stages of development, namely Early Opportunities, Pathway to 2030 and Enduring Regime.

The Holistic Network Design (HND) is part of the Pathway to 2030 workstream and goes hand in hand with the Office of Gas and Electricity Market's (Ofgem) Minded-to Decision on the delivery model for the offshore network. Offshore wind projects in scope for the Pathway to 2030 workstream are at a fairly early stage of development and primarily those that secured seabed leases through The Crown Estate's Offshore Wind Leasing Round 4 and Crown Estate Scotland's ScotWind Leasing Round. It also includes assumed projects in the Celtic Sea and a small number of additional projects due to connect at a similar time and/or location as others in scope.

For the first time, the HND enables delivery of a network that simultaneously handles the connection of offshore windfarms to shore as well as transporting the power to where it will be used. Led by the Electricity System Operator (ESO), in close consultation with the onshore Transmission Owners (TOs) through the Central Design Group (CDG), the HND has looked holistically across four objectives when considering the connection arrangements for offshore wind farms:

- Cost to consumers.
- Deliverability and operability.
- Impact on the environment.
- Impact on local communities.

The HND recommends the optimal transmission network based on these four design objectives to both connect the offshore wind farms to the transmission network and transport their power to where it is needed. Offshore wind generation will play a key part in the transition to net zero, and additional network infrastructure is needed for it to connect. The HND has been developed to provide a sufficient level of detail to enable a Detailed Network Design (DND), which will make decisions about specific network assets.

The HND contains recommendations on the potential location of infrastructure, including offshore cable route corridors and the locations of new substations, as well as technology choices for the offshore network. At the same time, the HND does not limit the ability of parties undertaking the DND to exercise their engineering judgement or discharge their detailed planning obligations.

The HND seeks to balance the needs of consumers, developers, communities, and the environment. For the 2030 ambitions to be achieved, the ESO, Government, Ofgem and TOs will work innovatively and collectively to deliver the level of ambition set out in the HND, and as committed to in the British Energy Security Strategy (*BESS*) and equivalent activities in Scotland. This includes:

- Significantly reducing the time taken from development to construction of strategic infrastructure projects, including expediting the consenting and regulatory approval processes.
- A regulatory framework to allow for strategic and anticipatory investment within the Pathway to 2030 workstream.
- The designation of transmission network infrastructure required for 2030 as strategic[3].

[3] The definition of strategic investment in this context will be outlined in Ofgem's ETNPR consultation decision document

- Commitments from the TOs to accelerate delivery of their reinforcement projects once detail of the changes set out in the *BESS* are confirmed, with the aim of delivering all necessary infrastructure by 2030.
- Supply chain availability to deliver the recommended network.
- The consideration of mitigation and strategic environmental compensation where needed.

1.2 Key Messages

Our recommended design is a combination of radial and coordinated connections. Of the 18 wind farms in scope, nine connect with a radial connection and nine use coordinated connections. Two of the radial connections in the Irish Sea use a shared cable corridor, but with separate cables and offshore infrastructure.

When compared to an optimised radial design, the HND is expected to lead to overall net consumer savings of approximately £5.5 billion. The recommended design leads to an additional £7.6 billion of capital costs due to the additional offshore infrastructure, but this is outweighed by the £13.1 billion savings in constraint costs that are expected to result from the additional network capacity this infrastructure provides[4]. These costs relate to connecting the 23 GW of offshore wind which is in scope of the HND.

A coordinated offshore network will reduce the requirement for curtailment of wind generation due to network constraints. This will lead to a reduction in cumulative CO_2 emissions from gas powered generation between 2030 and 2032 by 2 million tonnes of CO_2 – equivalent to grounding all UK domestic flights for a year - through the facilitation of the flow of cleaner, greener energy, more of the time, displacing and reducing our reliance on fossil fuel generation.

The recommended design reduces the total number of cables being laid to shore by up to a third due to the use of HVDC technology, reducing the impact on the seabed. Interconnections are included in the recommended design to provide north to south routes on the east and west coast. These are needed because they minimise network constraints, enabling more zero carbon wind energy to be utilised and offset the need for less environmentally friendly energy generation. They also reduce the need for future infrastructure which would be needed to achieve the same emission reductions and do this while minimising environmental impact though designing the offshore network in a coordinated way. The total length of cable route corridors in the recommended design is therefore slightly more than in the radial design.

The recommendations within this report cover 23 GW of new offshore wind generation. Where we are aware of future offshore generation due to connect in each region, we have sought to ensure that our recommendations are future proof. A follow up exercise to the HND will commence following the publication of this document and will provide in scope developers with our HND follow up process recommendations in Q1 2023.

The HND also requires significant investment in our existing onshore system to transport electricity to where it will be used. It recommends 94 reinforcements totalling £21.7 billion, to be delivered by the end of the decade.

- 11 reinforcements require acceleration in their delivery to meet 2030 targets, these options would be reliant on the commitments outlined in the *BESS*.
- Many of the remaining 83 projects will need to be delivered before 2030 to smooth the requirements on the supply chain and allow coordination of access to the main transmission network during construction.

Whilst preparing the recommendations within this document, we have sought input from a wide range of stakeholders, including offshore wind developers, TOs and environmental stakeholders. Where possible, we have sought to make changes in response to the feedback we have received.

[4] All cost savings are calculated over a 40-year asset life period, starting in 2030, using 2021 prices, unless otherwise stated.

1.2.1 The HND builds upon previous recommendations

The HND is made up of a number of individual recommendations for the development of the onshore and offshore networks. These recommendations are expressed in terms of a need to be able to transmit power from one point to another, whether that is offshore, onshore or a combination of the two.

Each of these recommendations needs to be considered carefully, designed in detail, and developed subject to the applicable planning and consenting processes.

Many of the HND's recommendations have been highlighted previously through our NOA process, where their description, driver and status are reassessed and published annually. New proposals for reinforcing the transmission system start with an initial assessment of early options submitted into the NOA. Following recommendations to 'proceed' these projects are progressed and developed in more detail by the TOs. Some of these projects are now sufficiently advanced in development to have been shared with affected stakeholders and local communities.

When considering the development of the transmission system, smaller, incremental reinforcements utilising existing assets are considered first. This begins with reduced and no build options such as commercial arrangements to manage flows on the network, followed by increasing the capability of existing assets. Once these options are exhausted, new reinforcement options must be considered. These include the construction of new transmission assets, or longer subsea cables to provide power transfer capability over greater distances

Figure 2 - Shows those recommendations that have been identified as necessary previously.

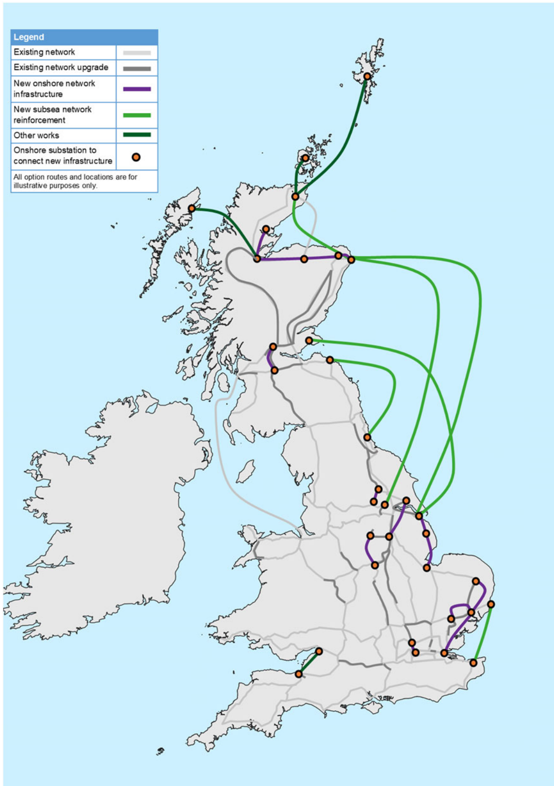


Figure 2 illustrates the previously identified and known development requirements for the onshore transmission system, highlighting upgrades to existing assets in dark grey with proposed new onshore transmission assets in purple and new subsea network reinforcements in light green.

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1.2.2 New network needs identified through the HND

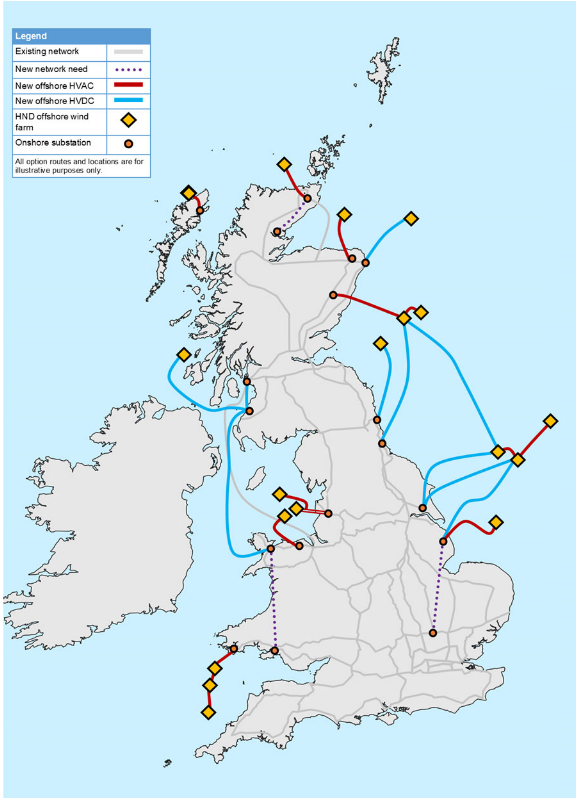
Through the HND process we have developed a recommended offshore network design. This design provides a greater level of coordination between offshore wind farms, optimising the number of landing points. In addition, we have recommended that some offshore wind farms connect further south than would have otherwise been considered through our usual connections approach. This coordination results in different power flows on the onshore network, driving some new network needs.

These new network needs are illustrated in *Figure 3*. The HND has identified new needs for network located offshore, as well as three new requirements located onshore, which build on the existing network and on previously planned development. These new network needs have not been previously published, unlike the other planned network reinforcements, which have been regularly assessed and documented in our NOA process.

These new onshore network needs are still in the early stages of development and were assessed in the HND via the *NOA 2021/22 Refresh*, which has recommended the continued development of options with similar capabilities. As these options have been shown to provide significant benefit, further detailed design assessments will need to be undertaken by the Transmission Owner to ensure a solution which balances the needs of the electricity system, environment and cost to energy consumers is taken forward. This will include exploring many different route options, including onshore, offshore or a combination of both. The selected option will then be taken forward to public consultation by the relevant TO as part of detailed design and consenting.

For more details on these new network needs and the wider transmission system requirements for 2030 see the *System-wide view section 5.5*.

Figure 3 - Shows the new network needs identified through the HND.



1.3 Minimising impact

The nature of the infrastructure required means the HND cannot be without impact. However, careful consideration has been given to the design to minimise cumulative environmental impacts.

The recommended design reduces the total number of cables being laid to shore by up to a third (in the best case) due to the use of HVDC technology. However, the total length of cable in the recommended design is greater (4%) than the optimised radial design. This is due to the additional cable needed to provide north to south routes on the East and West Coast. These cable routes are beneficial because they minimise network constraints and reduce the need for future infrastructure, by designing the offshore network in a coordinated way.

The design takes account of environmental constraints and seeks to minimise the impact on sensitive habitats through the coordination of wind farm connections to shore. Cable route corridors can avoid many of the identified environmentally sensitive features, however this is not possible in all cases. Further consideration will need to be given to cable routing in the DND stage to minimise environmental and consenting risks. While the environmental mitigation hierarchy should be followed, it is likely that environmental compensation measures will be required, assuming no viable alternatives are identified in the DND stage. This might include measures at a regional or national level. However, in the first instance measures to alleviate pressures on and protect sensitive habitats both within and outside Marine Protected Areas (MPAs) should be considered, and compensation seen as a last resort.

1.4 Next steps

The HND will be followed by a DND and consenting process that will develop the HND recommendations further to determine technology choices, transmission routes, and the locations of substations and converter stations. The DND and consenting process will be conducted by the party responsible for developing each asset. It is during this process that statutory consultations and relevant environmental assessments take place.

We are also currently developing the HND follow up process, which aims to provide in scope developers with recommendations in Q1 2023. We will start this process following this publication in July 2022. This will include the remaining ScotWind leaseholders, and any capacity made available through the ScotWind clearing process. It is also expected to include approximately 4 GW of Celtic Sea capacity.

The details of the follow up process, including confirmation of scope, a more detailed timeline, and other key aspects, such as the methodology to be used for the process, will be communicated in the summer.

2. Introduction

Offshore wind has been identified as a critical technology in achieving net zero greenhouse gas emissions by 2050. To help realise this target, a step change in both the speed and scale of deployment of offshore wind is required. One of the challenges to delivering the ambition for offshore wind deployment in the timescales required will be making sure that the offshore and onshore transmission networks enable this growth in a way that is efficient for consumers and takes account of the impacts on coastal communities and the environment.

The current approach to designing and building offshore transmission was developed when the offshore wind sector was in its early stages of development, and industry expectations for offshore generation were significantly lower. The current approach places the project developers in control of building the offshore transmission assets to bring the energy onshore and has led to individual connections from each project to the onshore network. While this approach has served the industry well and matured the offshore wind industry in Great Britain, it may not be the most efficient approach for connecting the much greater capacity of offshore wind that the government has committed to.

In the context of increasingly ambitious targets for offshore wind, constructing individual point to point connections for each offshore wind farm could become a major barrier to delivery given the considerable environmental and local impacts, particularly from the associated onshore infrastructure required to connect to the National Electricity Transmission System (NETS). Offshore wind is expected to play an important role in delivering net-zero emissions by 2050, and it is right that the framework for delivering offshore transmission connections is reviewed in the context of our increased ambition.

To address these challenges, The Department for Business, Energy and Industrial Strategy (BEIS) launched an Offshore Transmission Network Review (OTNR). The OTNR will review the way the offshore transmission network is designed and delivered, consistent with the ambition to deliver net zero emissions by 2050.

As part of the OTNR, we launched the Offshore Coordination Project in March 2020. The first phase of the project progressed at pace to assess the costs and benefits of a coordinated offshore transmission network that facilitates windfarm connections to the onshore transmission network compared to the current radial (point-to-point) approach for connecting windfarms to the onshore transmission network. Phase 1 also assessed the technical and procedural considerations to achieve coordination.

Following completion of Phase 1, BEIS and Ofgem asked the ESO to carry out further work as part of the OTNR. We are working closely with the OTNR project partners (The Crown Estate, Crown Estate Scotland, The Department for Environment, Food and Rural Affairs (Defra), Marine Scotland, The Marine Management Organisation, The Department for Levelling Up, Housing and Communities, Ofgem, The Welsh Government) and wider stakeholders to realise the economic, local and environmental benefits of a coordinated approach as identified in Phase 1. Our current work involves delivering the ESO led activities of the OTNR across three workstreams and time horizons:

- Early Opportunities – working with developers of projects that are fairly well advanced in their development, the TOs and other stakeholders to assess the costs, benefits and various implications of projects that have put themselves forward to explore early coordination. Also, identifying and progressing required changes to industry codes, standards and processes.
- Pathway to 2030 – developing an Holistic Network Design (HND) for a coordinated onshore and offshore network to support delivery of the government's 2030 ambition and assessing and progressing the required changes to relevant industry codes and standards.
- Enduring Regime – engaging with the Enduring Regime workstream of the OTNR, contributing to the discussion and development of relevant areas. This will be further shaped by the conclusions of the September 2021 BEIS consultation on the Enduring Regime and Multi-Purpose Interconnectors.

This document forms part of the Pathway to 2030 workstream.

The terms of reference (ToR) for the HND were agreed with the OTNR partners and set out that the HND should ensure an economic, efficient, operable, sustainable and coordinated National Electricity Transmission System (NETS) (onshore and offshore) required to connect offshore wind. This should support Government offshore wind targets of 40 GW by 2030 for Great Britain, including 11 GW by 2030 for Scotland, as well as net-zero by 2050 for Great Britain and by 2045 for Scotland. In the British Energy Security Strategy (*BESS*)[5], published April 2022, the UK Government increased its ambition for offshore wind to 50 GW by 2030. The HND considers four network design objectives as set out below.

2.1 Network design objectives

In collaboration with OTNR project partners, we defined a range of network design objectives that should be considered on equal footing while developing the design. These objectives ensure that the design is holistic in considering the impact of the design on the environment and communities and delivers value for consumers.

Table 1 provides an overview of the four objectives that have been considered throughout the design:

Table 1 - Network design objectives

Objective	Description
Economic and efficient costs	The network design should be economic and efficient
Deliverability and operability	The network design should be deliverable by 2030 and the resulting system should be safe, reliable and operable
Environmental impact	Environmental impacts should be avoided, minimised or mitigated by the network design, and best practice environmental management incorporated in the network design
Local community Impact	Local community impacts should be avoided, minimised, or mitigated by the network design

[5] https://www.gov.uk/government/publications/british-energy-security-strategy

2.2 Projects in Scope

In August 2021, we identified the projects in scope for the HND in accordance with the Terms of Reference[6] of the HND as agreed under OTNR governance. The total volume of offshore wind generation was aligned with the FES 2021 Leading the Way scenario. This total is made up of offshore wind generation in regions across Great Britain.

In some situations, the generation capacities included within the HND, connection applications and inferred from published seabed lease outcomes do not match. The generation capacities used within the HND were sourced from connection application and offer data.

We have included the following generation:

- A total of 8 GW of projects successful in The Crown Estate Offshore Wind Leasing Round 4 (referred to as R4_X within this report, with X representing numbers used to refer to individual projects).
- A total of 11 GW of projects successful in the ScotWind leasing round, with capacity located in each of the leasing zones (referred to as SW_X, with the letters W (west), N (north), E (east) and NE (northeast) denoting the respective leasing zones).
- Assumptions on 1 GW floating wind from the upcoming Celtic Sea leasing round (notional projects referred to as CS_FW_X). For the purposes of the analysis within the HND we assumed three projects which a combined capacity of 1 GW. We expect to revisit this analysis in further design work when specific projects within the Celtic Sea are confirmed.
- 3 GW of other sites that are located near to Round 4 and ScotWind sites, to test whether there are opportunities for coordination (referred to as PA_X).

Please note that the design is our best view based on the information available at the time. The design may change as the network develops through the Detailed Network Design and other project development stages.

Following the publication of this document, we will start work on a follow up process to include additional generation into the next iteration of the HND. Although we recognise that additional synergies could potentially have been achieved by considering more generation in a single exercise, this would have delayed giving certainty to developers who could have had certainty at this earlier stage without having to wait for the conclusion of a follow up process. The follow up process is expected to include the remaining ScotWind leaseholders, any additional capacity awarded through the ScotWind clearing process and approximately 4 GW of Celtic Sea capacity (replacing the 1 GW of notional projects considered in this iteration). It will provide in scope developers with recommendations in Q1 2023. However, we have sought to ensure that the decisions made within the HND do not lead to inefficient outcomes for generation due to connect in the future.

The full list of projects and their capacities considered in the HND is shown in *table 2*. In some cases (SW_NE4, SW_NE7, SW_E1a) this does not represent the full capacity of the project, and the remaining capacity will be considered in the follow up process.

[6] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1059676/otnr-central-design-group-network-design-tor.pdf

Table 2 - Full list of projects and capacities

Project name	Location	Capacity (MW)
R4_1	North Sea – East of England	1500
R4_2	North Sea – East of England	1500
R4_3	North Sea – East of England	1500
R4_4	Irish Sea	1500
R4_5	Irish Sea	480
R4_6	Irish Sea	1500
PA_1	North Sea – East of England	1320
PA_2	North Sea – East Scotland	1800
SW_W1	West Coast of Scotland	2000
SW_N1	North Coast of Scotland	2250
SW_N4	North Coast of Scotland	740
SW_NE4	North Sea – North East Scotland	1500
SW_NE7	North Sea – North East Scotland	1500
SW_E1a	North Sea – East Scotland	1500
SW_E1b	North Sea – East Scotland	1200
CS_FW_1	Celtic Sea	300
CS_FW_2a	Celtic Sea	300
CS_FW_2b	Celtic Sea	400

2.3 ScotWind projects in scope

Prior to the outcome of the ScotWind leasing round, we were undertaking network design and study work based on an assumed capacity informed by the Marine Scotland Sectoral Plan. However, as the ScotWind leasing outcome resulted in a significantly greater capacity than expected, we needed to align the ScotWind volume within the HND to a subset of the ScotWind projects. This would maintain consistency with the 2021 Leading the Way FES scenario and our Terms of Reference.

We worked with OTNR project partners and other key stakeholders to review the leasing round outcome to understand how we should act upon the ScotWind results in the HND. The assessment used is summarised in *Table 3. Option 1* was selected based on the overriding priority to reach a conclusion as early as possible and maintain a July 2022 publication date.

Table 3 – ScotWind Approach

Option	New Work	Pros	Cons
1. Minor capacity and spatial changes to the PT2030 generation background by: a) reviewing information from the ScotWind leasing round and Sectoral Marine Plan; & b) assessing existing connection application/offer information, as confirmed with successful applicants	Revision of planning datasets Refinement of network design options with a potential need for a small number of new proposals	Allows design to proceed in line with plan Needs of non-ScotWind developers can be met	Perceived short- term winners and losers from ScotWind HND perceived to be out of date Follow up exercise required to ensure ScotWind connections are managed appropriately
2.Significant capacity and/or spatial changes to the PT2030 generation background by: a) reviewing information from the ScotWind leasing round and Sectoral Marine Plan: & b) consulting with successful applicants on their connection requirements	Engagement and information gathering with developers Major revision of planning datasets Need for a significant number of new design proposals including technical, spatial and environmental assessments	Improved view of ScotWind applicants' plans	A further delay relative to the original January date (3 to 5 months) No established process for assimilating new information Perceived short- term winners and losers from ScotWind Disadvantages non-ScotWind developers HND out of date once FES2022 published

Option	New Work	Pros	Cons
3. Reconstruct PT2030 generation and supply scenarios to accommodate up to 25 GW of ScotWind generation by a) reviewing information from the ScotWind leasing round & Sectoral Marine Plan; b) consulting with successful applicants on their connection requirements; & c) reassessing the broader generation and supply background	Engagement and information gathering with developers and broader stakeholder group Major revision of planning datasets Need for a significant number of new design proposals including technical, spatial and environmental assessments	Improved view of ScotWind applicants' plans Potential to reconsider how targets are applied in ToR and ensure strategic options are explored	Longer Delay (4 to 6 months) Disadvantages non-ScotWind developers No guaranteed improvement for ScotWind developers

We therefore needed to make some capacity and spatial changes to the generation background which had been taken from *FES 2021*. This involved reviewing information from the ScotWind leasing round and Marine Scotland Sectoral Plan and assessing existing connection application and offer information.

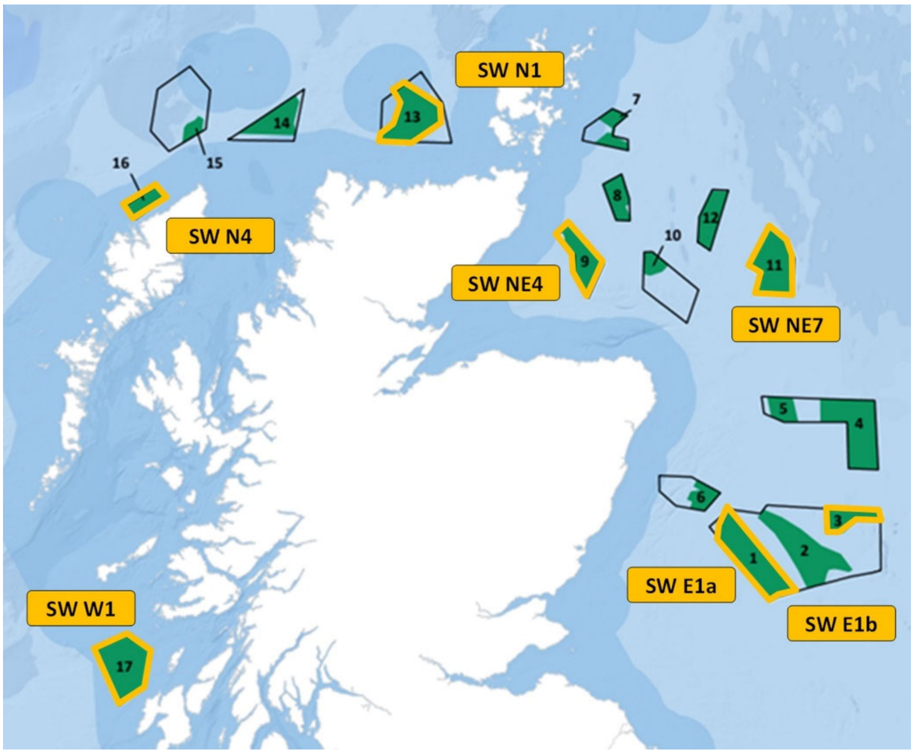
We ensured that some capacity was included in each of the ScotWind major zones, to allow us to assess the value of coordination between zones. We ordered capacities in line with contract signature dates, as confirmed through post-announcement communication[7]. The method we followed in allocating projects was:

1. Include projects that align with the Scotwind leasing announcement (i.e. use the spatial information provided in the ScotWind announcements to produce a list of applicable projects by reference to connection applications and agreements)
2. Order capacities in-line with connection application and offer information as confirmed through our post-announcement engagement
3. Ensure capacity is included in each zone
4. Where there's an excess, consider staging
5. Add sensitivities to address key strategic questions

The outcome of this process is that we included 11 GW of ScotWind capacity within the HND and brought our total of offshore wind capacity in the HND to 50 GW, of which 17 GW will be located in Scottish waters.

[7] https://www.nationalgrideso.com/document/239686/download

Figure 4 ScotWind Results[8]



The projects that are included are not necessarily the projects that will progress the most quickly, and our assumptions do not indicate preference for certain projects over others. The remaining projects will be included in a follow up design exercise, which will use learnings from the HND.

[8] https://www.crownestatescotland.com/resources/documents/scotwind-map-of-option-areas-170122

3. Methodology overview

3.1 Objective

The objective of the Holistic Network Design (HND) is to provide an economic, efficient, sustainable, and coordinated National Electricity Transmission System (NETS) that supports the delivery of Great Britain's 2030 offshore wind ambitions. The approach for producing the HND needs to consider and compare multiple onshore and offshore design options including future generation and demand scenarios, the existing NETS, and total capital and operational costs. Significant coordination and data transfer between each step in the design is required to deliver a holistic design.

This section of the report provides an overview of the design methodology. The design methodology is a standalone document that is available for readers who would like further detail on the design approach[9].

This methodology was developed based on the Offshore Transmission Network Review (OTNR) HND terms of reference (ToR). The HND ToR were agreed with the OTNR partners and set out that the HND should ensure an economic, efficient, operable, sustainable, and coordinated NETS (onshore and offshore) required to connect offshore wind. This should support Government offshore wind targets of 40 GW by 2030 for Great Britain, including 11 GW by 2030 for Scotland, as well as net-zero by 2050 for Great Britain and by 2045 for Scotland. In the British Energy Security Strategy (*BESS*)[10], published April 2022, the UK Government increased its ambition for offshore wind to 50 GW by 2030.

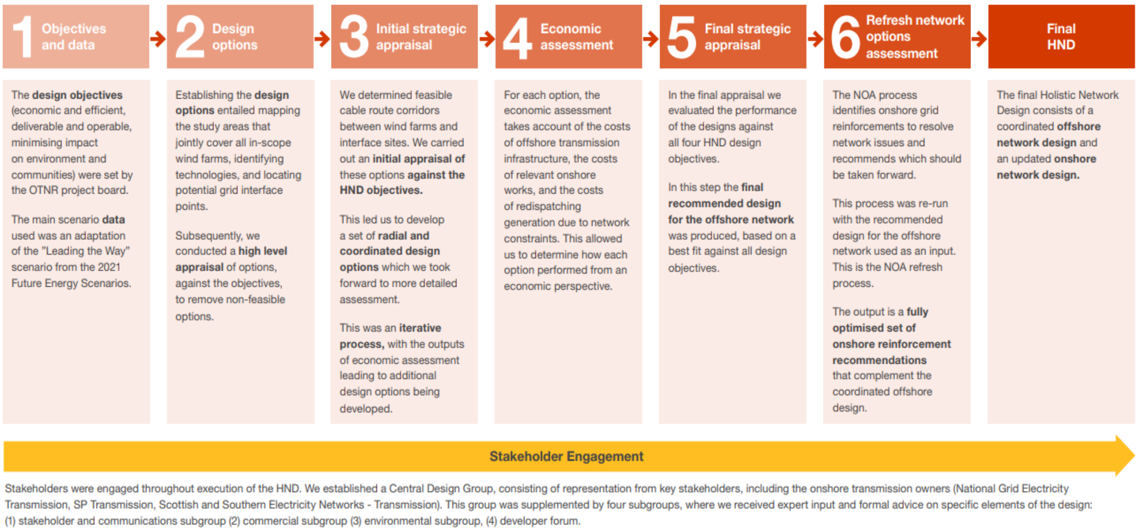
The methodology was designed to ensure that all objectives were considered on equal footing.

- To ensure the design is economic and efficient, we used an economic optimiser to determine the optimal economic design from a range of proposed design options. The economic optimiser takes into account network costs, market conditions, and system benefits to determine the optimal design considering economic factors.
- To ensure the design is deliverable and operable, we developed a deliverability assessment framework that considered a range of factors including supply chain of technologies, construction timeframes, and consenting challenges. The framework has been used to ensure that any designs used in the economic optimiser are deliverable and operable.
- To ensure the design considers environmental impact, we conducted assessments of environmental constraints using a range of Geographical Information System (GIS) data sources to determine the location and the severity of environmental constraints. Any proposed designs that would cause severe environmental impacts were not provided as inputs to the economic optimiser.
- To ensure the design considers community impact, we conducted assessments of community constraints using a range of GIS data sources to determine the location and the severity of community constraints. Any proposed designs that would cause severe community impacts were not provided as inputs to the economic optimiser.

We have developed a structured design approach that considers these design objectives. The design process, shown in *Figure 5*, consists of six key building blocks, that are required to produce the final HND.

[9] https://www.nationalgrideso.com/document/239466/download
[10] https://www.gov.uk/government/publications/british-energy-security-strategy

Figure 5 - Methodology building blocks



3.2 Establishment of HND data set

Once the design objectives had been agreed, the next step in developing the HND was to establish the scope of the study and the background data sets required, taking account of the non-exhaustive list of inputs for the HND specified within the Central Design Group (CDG) terms of reference.

Determining the data sets included establishing the offshore generation in scope and developing a suitable generation background on which the NETS could be studied. The HND uses the 2021 Future Energy Scenario (FES) Leading the Way as the basis of the background for which studies and analysis are completed. The FES scenarios underpin the ESO's network planning process and provide a robust and justifiable data set on which to base our economic and power system analysis.

The 2021 Leading the Way scenario has been modified for the purposes of the HND to align this scenario with the wind generation in scope for the HND. This scenario includes offshore wind of approximately 50 GW by 2030. The FES 2022 scenarios were not finalised in time to be included in the HND analysis.

The full set of generation included in the baseline assumptions is commercially sensitive and therefore not provided in this report.

3.2.1 Onshore network topology

Our starting point was a model of the transmission network for 2030, assuming that all essential works for connections would progress as planned. This included four separate offshore Eastern HVDC links between Scotland and England, which had already been found optimal by the Network Options Assessment (NOA) process previously.

All reinforcement options described in *NOA 2021/22* for which the TOs had stated an Earliest In Service Date (EISD) of up to and including 2033, excluding those determined as essential for connections, were made available to the economic optimisation process. The optimisation tool assumed that any reinforcements which were "optimal", i.e., whose economic benefit exceeded their cost, could be built by 2030. To realise the benefits of our holistic approach we are working closely with the TOs to identify and highlight which onshore reinforcements require acceleration in their delivery to facilitate 2030 targets.

To emphasise our ambition to accelerate the delivery of onshore works, we have introduced a new term for the *NOA 2021/22 Refresh*: Required in Service Dates (RISDs). RISDs only apply to reinforcement options that the TOs have determined have an EISD of later than 2030. Achieving these RISDs may require changes to planning, consenting and regulatory processes.

EISDs are provided by the TOs utilising their expertise and knowledge of delivering capital projects under the existing planning, consents, and regulatory processes. Accelerating the delivery of a project beyond an EISD would require government intervention in the form of legislative changes, as suggested in the recent publication of the British Energy Security Strategy (*BESS*), and Office of Gas and Electricity Markets (Ofgem) intervention in regulatory processes. Other factors may also impact the expected delivery dates of a project and it is anticipated that relevant industries and suppliers will also need to scale up to support the 2030 ambition. The inclusion of RISDs in the *NOA 2021/22 Refresh* serves to differentiate what is currently achievable from what could be achieved with greater change and intervention. Delivering onshore reinforcements on their RISDs will allow earlier network reinforcement and drive greater consumer benefit.

3.2.2 Environmental and community data

To address the environmental and community design objectives, the design process used Geographical Information System (GIS) data from a range of sources to assess the impact of various options on the environment and communities. Further detail on the environmental and community assessment within the HND can be found in Appendix 2.

To develop the HND, the following datasets were gathered:

- GIS maps;
- Environmental constraint data;
- Community constraint data;
- Technical constraint data;
- Generation maps and associated data;
- Future energy scenarios;
- NOA 2021/22 onshore reinforcements and boundary capabilities;
- Electricity market data;
- Forecast network demand;
- Forecast interconnector flows;
- Onshore and offshore asset cost data; and
- NETS interface points.

3.3 Interface points and design options

After the scope of the study and the background data sets were finalised, offshore designs and potential interface points for the connection of in scope generators connecting to the NETS were identified. An interface point is the point at which the onshore and offshore transmission network connect. Typically, within the HND this is at a substation located onshore.

A number of design options, including transmission technology, offshore interconnection (in the coordinated designs) and potential interface points, were identified. A high-level appraisal was used to remove unfeasible options while maintaining as many options as possible for further analysis. The feasibility of options was considered from an environment, community, and deliverability perspective.

The HND scope and datasets were assembled on a Great Britain wide basis. However, to facilitate data management and work planning, the potential interface points and design options were identified on a regional basis. Potential connection locations were considered at a high-level in a workshop with the three onshore TOs in terms of deliverability and environmental and community impacts. A shortlist of potential options was then produced for each region.

Radial design options were developed first by considering the potential interface points and network design guidelines described in Section 4. Subsequently, we developed coordinated design options that considered the same potential interface points and network design guidelines.

Each of the radial and coordinated design options were shared with the TOs to determine the feasibility of the design considering their requirements for onshore network reinforcement. The onshore TOs provided us with cost data for each option. Where designs were considered unfeasible from a TO perspective, these were removed from further assessments.

Our environmental advisors provided indicative routes for each option, based on a desktop evaluation of environmental, community and technical constraints. These were used to calculate the cost of each option, but do not mandate the choice of a particular route. Routing will form part of the Detailed Network Design (DND) process, and we will provide the information obtained to date to those carrying out the DND for each part of the network.

The design options included consideration of the environmental and community constraints. Environmental constraints are areas which are sensitive to cabling, as identified by the relevant authorities. Definitions of each type of environmental constraint are included in the glossary[11]. Community constraints are built-up areas or areas which would be negatively impacted by cabling or infrastructure associated with the network.

3.4 Initial Strategic Options Appraisal

The objective of the initial strategic options appraisal process for the HND is to enable the consideration of the potential design options against four design objectives on an equal footing.

A Black, Red, Amber, Green (BRAG) assessment was conducted to assess the options in line with the design objectives. Black scoring indicated that the option did not align with the design objectives and therefore could not be considered for further assessment. The assessment considered mitigation measures that could be implemented to improve the alignment of the option with the design objectives. We did not assign a monetary value to the non-economic objectives.

Following the assessment of the option against the four design criteria, each option was assigned an overall BRAG rating based on considering the assessment across all four objectives.

We carried out high-level appraisal of these options, looking at how each would perform against each of the four HND objectives on an equal footing, and gave each option an overall rating.

We chose the best performing options, identified the essential works for the options and calculated detailed costs using TO information for onshore assets and cost assumptions for offshore assets, and put them into the economic optimiser shown in *Figure 6*. More details about the economic optimiser can be found in the full methodology report[12].

3.5 Economic assessment

To determine which option is preferable from an economic perspective, it is necessary to consider the following costs:

- Capital costs of the investments required to reinforce the onshore network.
- Capital costs of the offshore network, including the costs of any associated onshore works.
- Costs of dispatching generation to meet demand.
- Costs of re-dispatching generation due to network constraints (including compensating renewable generation for lost subsidies when it is unable to generate due to network constraints, and the cost of bringing on other generation to make up for the shortfall).

All costs within this document are in present value terms using 2021/22 as the price base. We have used standard Cost-benefit Analysis (CBA) assumptions. Within these assumptions, the onshore assets are amortised over an assumed asset life of 40 years. The offshore asset capex is assumed to be amortised over 25 years, but any benefits exist for 40 years.

We used an economic optimiser to test the value of our design options. The optimiser's objective is to minimise the total cost (sum of the costs above), taking account of the following constraints:

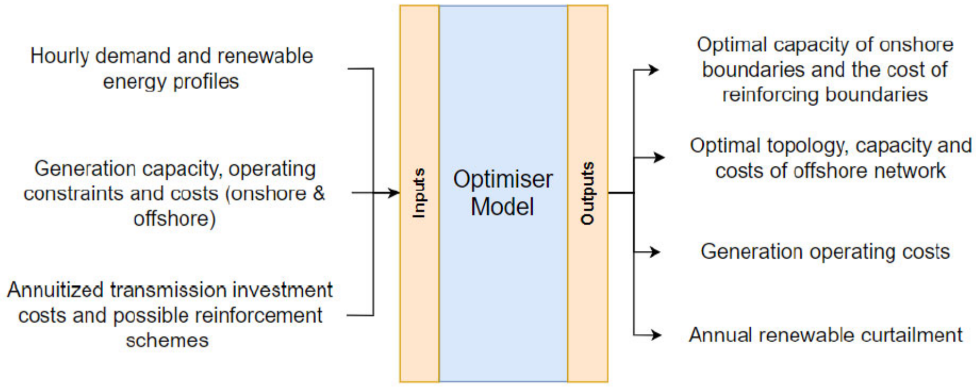
- Power transfer capability across boundaries.
- Generation must equal demand.
- Each offshore wind farm must have an appropriate capacity substation to connect to.

[11] https://www.nationalgrideso.com/document/262701/download

[12] https://www.nationalgrideso.com/electricity-transmission/document/239466/download

Overall, the aim of using the optimiser is to determine the lowest cost design option.

Figure 6 - Below summarises the inputs and outputs of the optimiser model



The optimiser determines the optimal offshore and onshore topology from an economic perspective. It chooses between all offshore options, considering the essential works for such connections (including some NOA reinforcements) in the overall cost assessment. For onshore works it considers all the NOA reinforcements as submitted to *NOA 2021/22* up to (and including) an Earliest In-Service Date (EISD) of 2033.

The essential works are considered fixed if that option is chosen, and their cost is included within the option assessment. The optimiser provides a list of 'optimal' onshore reinforcements for 2030, with the final onshore design being determined through the *NOA 2021/22 Refresh* process as described below. The optimiser considers a single-year snapshot, whereas the *NOA 2021/22 Refresh* optimises over a multi-year horizon, as well as considering new options beyond 2030 submitted by the TOs.

The hourly demand and renewable energy profiles used in the model match the modified Future Energy Scenarios data set as described above. The economic optimiser makes assumptions about how generation would be re-dispatched in the most economical way where there are transmission constraints. A slightly simplified version of the NOA dataset is used in this process. This allows us to calculate the constraint costs that would be incurred for each set of options.

In order to estimate the cost of connecting each wind farm to each onshore substation, our environmental advisors provided assumptions about the route which would be taken. This enabled the ESO to calculate the distance and make assumptions of technology type and thus the costs. Note that routing and technology choices described within this report are only indicative and will be confirmed by the party delivering the infrastructure within the Detailed Network Design (DND) stage.

The capital and operating costs of new offshore infrastructure are based on component unit costs derived from data provided by equipment suppliers. The input cost assumptions have been provided to in scope developers and OTNR stakeholders.

Possible onshore transmission reinforcement schemes and their costs are provided by the onshore TOs.

It is worth noting that the cost differentials quoted are based on high-level cost assumptions. The costs of each part of the design are expected to change as the design is developed in more detail during the DND stage.

In the optimiser, we have not monetised environmental and community impacts. Furthermore, we have not included any estimate of the costs of coordination between developers, or any impacts on the ability of developers to finance their projects. However, we have only recommended coordinated solutions where there is significant benefit compared to a radial solution, when considering the four network design objectives on an equal footing.

The optimiser was first used to determine the optimised radial design. The results from this radial optimisation provided insights regarding the system behaviours that were encountered. These insights highlighted where there was benefit in building additional infrastructure to connect generation to a different region of the country.

Considering the learning from assessing the radial designs using the optimiser, the coordinated designs were provided as inputs to the optimiser. Initial optimisations of the coordinated designs provided an improved understanding of how these designs performed from an economic perspective. This improved understanding enabled the creation of variations on the designs that provided improved economic results. These variations were assessed in the optimiser to determine a final set of preferred options.

The outputs from the economic assessment process were a set of radial and coordinated design options that would be assessed further in the detailed appraisal process.

3.6 Final Strategic Options Appraisal

Following the economic assessment of options, a shortlist of preferred radial and coordinated design options were progressed to a final strategic options appraisal. The final strategic options appraisal assessed how the options perform against the design objectives: 1) economic and efficient costs, 2) deliverable and operable, 3) minimal environmental impact, and 4) minimal community impact.

The options were assessed on a regional basis. We considered several radial and coordinated options within each region against the four network design objectives.

The options were subsequently written up into Options Appraisal Summary Tables (OASTs), which presented design options for each region and described how each option performed against the four network design objectives. These documents set out a preferred radial and coordinated design, and an overall recommended design, for each region.

To ensure that our recommended design was comprehensive and reflective of stakeholder views, the OASTs were shared with offshore wind developers, TOs and other OTNR stakeholders for their feedback.

Feedback from the above stakeholders resulted in a few minor additional studies being carried out to determine whether suggested variations to the design were more aligned with the four network design objectives. For some regions, the additional studies resulted in an updated recommended design, therefore these were adopted. An example of the changes made was moving to a southerly approach to Pentir in the North West Region. Some feedback received did not result in changes to the design recommendations, however it will be considered at the DND stage or in future iterations of the HND. Stakeholders who provided feedback were informed of how their feedback was considered to ensure a common understanding of next steps. The detailed process for engaging with stakeholders throughout the design process is captured in the dedicated *Stakeholder Approach, Engagement and Feedback* report.

The options appraisal process and stakeholder feedback determined the recommended offshore network design for the HND. The HND specifies the interface sites, onshore works, and offshore network interconnection, but does not mandate a particular choice of route, use of particular technology or exact locations of required substations. These additional design details will be developed as part of the Detailed Network Design process, which builds on the high-level HND.

The onshore network design was indicatively determined during the development of the recommended offshore network and finalised through the Network Options Assessment (NOA) Refresh process, which used the recommended offshore network design as an input to determine the final onshore network design.

To ensure operability of the recommended design, we assessed the dynamic performance of an appropriately representative part of the design. The East Coast Region was modelled, and its operation simulated. The simulation model used detailed representations of the expected electrical equipment and control systems. The settings used were aligned with the latest Grid Code requirements, but a number of assumptions and simplifications had to be made about information that is not yet known. As development progresses it is expected that further analysis will be required.

A range of onerous operating conditions that could reasonably be expected were tested to ensure the system stayed stable and operational parameters stayed within acceptable NETS Security and Quality of Supply Standards (SQSS) limits.

The testing has found some challenges such as offshore voltage control and short-term overload conditions, but we are confident that these can be resolved with future planned solutions. The analysis suggests that the offshore designs are operable considering dynamic studies, but care will need to be taken during the detailed design stage and procurement to ensure that the control and protection settings are coordinated and specified correctly. Extensive further study and development will be required through the detailed design up to delivery.

3.7 NOA Refresh

The Network Options Assessment (NOA) is a key annual ESO publication. It recommends the major onshore projects that are needed to deliver a transmission system that is fit for purpose to meet Great Britain's net zero and green ambitions, whilst balancing the costs to end consumers. The NOA process is therefore closely aligned with the HND in its objectives and plays a fundamental role in the delivery of a HND, and hence needs to be considered as part of this process.

The recommendations of *NOA 2021/22* provide the optimal level of onshore reinforcement against the FES 2021 without considering offshore coordination. This provides a robust starting point for the HND analysis. All reinforcement options submitted by the TOs and the ESO for *NOA 2021/22* have been considered within the optimisation process that has determined the recommended offshore network design.

Following the finalisation of the offshore design, the onshore reinforcements required to facilitate economic and efficient transfer of power needed to be re-evaluated. This has been carried out by refreshing the *NOA 2021/22* assessment with the offshore network design embedded within the study background. This is referred to as the *NOA 2021/22 Refresh* and informs the TOs which onshore options to develop further.

The inputs to the background for the *NOA 2021/22 Refresh* were the HND recommended offshore design, which was identified in the strategic options appraisal, and a modified version of the FES 2021 Leading the Way scenario (as referred to in the establishment of HND data set section earlier in this report). The recommended offshore network design has changed the location of offshore connection points, thus impacting energy flows around the country. This has an impact on the onshore network reinforcements and hence is reassessed through the NOA process.

Typically, the NOA process follows the previously published and approved NOA methodology. However, to align with the HND and ensure a consistent approach, some adjustments are necessary for the *NOA 2021/22 Refresh*. To facilitate this the *NOA 2021/22 Refresh* follows the existing methodology where practicable but differs in two main ways. Firstly, a single scenario was used for the analysis to align the background with that used to develop the recommended offshore design. Secondly, essential options, determined through the HND connection assessment, were fixed in the background as these reinforcements are fundamentally necessary to connect 50GW to the system by 2030 in a compliant manner. More details on the methodology applied for the NOA refresh can be found in the *NOA 2021/22 Refresh* report. Furthermore, the full *NOA Methodology* can be found on our website[13].

3.7.1 Environmental and community assessment of onshore works

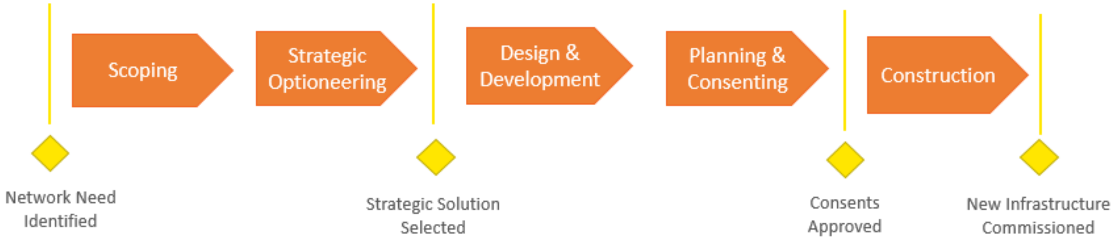
The Environmental and community impact of the onshore works is considered within the HND methodology. The essential onshore works at the interface point sites are included in the strategic appraisal undertaken for the offshore network design.

The onshore reinforcement options are assessed by the TOs. The methodology used by the TOs to appraise options is well established and has been subject to scrutiny through numerous examinations by planning authorities on prior projects. It is broadly similar to the process we used in the appraisal of the radial and coordinated offshore network options, using high-level environmental and socio-economic constraints, which are considered alongside technical factors

[13]https://www.nationalgrideso.com/research-publications/network-options-assessment-noa/methodology

(including capability, operability and deliverability) and cost. *Figure 7* below sets out the multiphase investment process which the TOs broadly follow. This starts with establishing the agreed network need, then selection of a strategic solution, followed by detailed network design and obtaining consent before construction.

Figure 7 - Multiphase investment process



The level of detail included in the assessment by the TOs of community and environmental impacts is dependent on the maturity of the onshore reinforcement project (*Table 4*). This ranges from initial desktop studies to detailed environmental and community assessment considerations. The different environmental and community assessments carried out at each stage of the project inform the strategic option selection and detailed design for the reinforcement works and aim to minimise overall environmental and community impacts.

Table 4 - Project phases

Project Phase	Description of Project Phase
Scoping	Identification of broad Needs Case and consideration of a number of design and reinforcement options to solve boundary constraint issues.
Strategic Optioneering	The Needs Case is firm; a number of design options are developed so that a preferred design solution can be identified.
Design Development and Consenting	Design of the preferred solution into greater levels of detail and preparing for the planning process, including public consultation and stakeholder engagement.
Planning/Consenting	Continuing with public consultation and adjusting the design as required all the way through the planning application process.
Construction	Planning consent has been granted and the solution is under construction.

3.8 Validating the optimiser outputs with the NOA economic analysis

We used the economic optimiser in choosing both the optimal radial and coordinated designs. However, the optimiser is currently limited to a single year (2030). Therefore, we have also used BID3[14] (the economic analysis tool used in the NOA) to simulate both the optimal radial and coordinated designs from the optimiser for the years beyond 2030. The results from BID3 show that the recommended design is the preferred solution, and this recommended design was used as an input to the *NOA 2021/22 Refresh* process. The economic analysis within the *NOA 2021/22 Refresh* also uses the BID3 tool to assess the expected constraints on each boundary, looking at the years beyond 2030.

As BID3 looks at a wider time horizon, we used it to more accurately calculate the differentials in constraint costs which are quoted throughout this report.

[14] https://www.nationalgrid.com/sites/default/files/documents/Long-term%20Market%20and%20Network%20Constraint%20Modelling.pdf

4. Network design guidelines and network overview

Our designs are made up of multiple pieces of equipment, which link together to form a network. The equipment performs one of two broad functions, either to form a junction point for the network at a substation or to provide the long links between substations. Any offshore design will need platforms to carry substation equipment and will use cables to provide the links between them. Our design includes High Voltage Alternating Current (HVAC) and High Voltage Direct Current (HVDC) assets that are proven technology.

Before developing the coordinated offshore designs, we established a set of electrical design guidelines, which we tested with our internal Offshore Coordination Engineering Advisory Group. This group was formed to inform and provide technical challenge and guidance into the offshore transmission planning, coordination and operation elements of the Offshore Coordination Project. It consisted of ESO experts on technical codes, assurance, and connections. The guidelines provide direction on several technical considerations in the design such as technology selection, cable ratings, cable voltages and network redundancy.

A separate code change report is published as part of the Holistic Network Design (HND) package, and code changes will go through the standard processes.

4.1 Assets considered

HVAC assets:

- **Subsea Alternating Current (AC) cables:** Of voltage level up to 275 kV and commercially available from multiple suppliers. They can achieve up to 500 MW of power transfer in a single 3-phase bundle. Higher power transfers can be achieved by using multiple cable bundles laid in parallel, for example a 1.5 GW AC connection could be designed using three parallel 500 MW AC cables. This takes up significant space as the cable bundles need to be spaced apart, potentially increasing environmental impacts.
- **Offshore AC substations of compact gas-insulated switchgear (GIS) design**: Its functionality should allow circuit selection, maintenance access and fault disconnection. These are commonly used onshore and have also been constructed offshore. Considering the current level of experience of suppliers this is expected to be feasible.
- **Onshore AC substations**: Part of the offshore transmission system needed to interface with the existing onshore network and provide the necessary switching and isolation facilities. These are commonly used and commercially available.
- **HVAC circuit breakers**: Of a conventional design and commercially available.
- **Reactive power compensation:** The power transmission capacity of AC submarine cables is limited by capacitive charging currents. To counteract this, reactive power compensation must be added. For short cables less than 100 km this can be kept to the ends of the cable, but longer cables require additional mid-point compensation. Reactive compensation installation onshore is common but less so offshore and extra platforms to host reactive power compensation may be needed on long offshore routes. Multiple suppliers of reactive compensation are available.

HVDC assets:

- **Subsea Direct Current (DC) cables with a voltage level up to 525 kV:** The HVDC circuits need a pair of HVDC cables, a positive and a negative cable. In most instances the pair of cables can be bundled and laid together, which minimises seabed disruption. For some HVDC circuits, larger than 1.8 GW, the cables need to be separated and an extra metallic return conductor (which can be co-axially added to the outer sheath of the power cables), so that a fault will not disconnect the whole HVDC circuit. Due to limitations on the availability of large capacity cables, the largest HVDC circuit used in the designs is 2 GW. A small number of suppliers are available.
- **Offshore DC converters**: Built onto an offshore platform with AC interface at 275 kV for meshed offshore network or AC interface at 66 kV for direct windfarm interface. Dependant on

size and security needs, the converters may be of bipole or symmetric monopole design. A small number of suppliers are available.

- **Onshore DC converters**: To interface with the onshore transmission network. The type needs to be consistent with that used at the other end. A small number of suppliers are available.
- **HVDC isolators**: To allow offline disconnection of DC cable sections following fault or for maintenance. The design does not include HVDC circuit breakers, as we do not believe the technology will be mature enough to use until at least 2035. As a result of using isolators instead of circuit breakers, if there is a fault in a multi-terminal DC link, all ends will go offline.

4.1.1 Technology selection considerations

AC cable circuits will be used as much as possible due to their lower cost. However, for long lengths that would require impractical amounts of reactive compensation or where power flow control is required, HVDC will be used. We have assumed within our economic analysis that AC cable circuits longer than 100 km require midpoint reactive compensation, and cable circuits longer than 200 km should be DC. However, the recommendations of technology type made within the HND do not mandate that this particular technology must be built; the party carrying out the DND will make the final choice of technology type.

Due to technology readiness, live offshore circuit switching will be facilitated by means of conventional AC circuit breakers. HVDC circuit breakers will be not assumed mature for the 2030 designs.

Multi-ended HVDC configurations will be considered, and offline switching will be built-in, such as is already being put into service for the Caithness-Moray system.

HVDC bipole systems with metallic return (which may be built into the power cable sheathing), cable separation and sufficient pole separation will be considered as two separate transmission circuits. This will require a change to the definition of a HVDC converter within the SQSS.

It is recognised that supply chain limitations may impede delivery, particularly with HVDC converters and cables. The designs have not been constrained by supply chain limitations on the basis that all the equipment in the designs proposed should be available from more than one vendor, and the recommended design does not pose a significantly greater challenge than the optimised radial design.

Although, we have made assumptions about the numbers of cables required for each technology type, this does not mandate a particular choice at the DND stage but provides an input to our economic optimisation process.

4.1.2 Cable rating and voltage considerations

275 kV AC cables have been recommended in order to reduce the total number of cables. While still uncommon compared to 220 kV, they are expected to be available within the required timescales, and we are aware of developers who are planning to use them. Suitable reactive compensation will be required to compensate for cable capacitance.

The upper practical limit of HVDC circuit voltage considered for 2030 is 525 kV using XLPE cables.

The maximum HVDC bipole rating considered available for 2030 is 2 GW. This is consistent with European development expectations and is primarily limited by cable ratings.

Symmetrical monopole HVDC circuits will be limited to a rating of 1.8 GW.

4.1.3 Other design considerations

Under intact conditions 100% of the Transmission Entry Capacity (TEC) will be able to able to reach shore. For any credible single offshore outage, at least 50% of the TEC will be able to reach shore. This principle is applied to both the radial and coordinated designs and for the projects which are large enough to require multiple cables.

Offshore, the AC cables should be in a bundled group containing all three phases to permit laying in a single operation and minimise seabed usage. Longer distances may require an additional parallel cable to account for reactive power losses. Onshore the cables can be laid in single phase configuration.

To minimise the amount of switchgear required and to limit the number of available onshore connections bays required, multiple cables may be banked together.

Infeed loss risk will be considered at 1.8 GW, as suggested by the OTNR Phase 1 report. This will require a change to the SQSS.

Infeed loss risk considerations offshore mean that offshore busbar arrangements will extend to double busbars where required to secure against breaker and bar faults.

Some of the complex offshore nodes will require multiple platforms close together to accommodate the HVDC converters, AC switchgear, cable entries and necessary equipment.

Operational control of the offshore systems will require automation, including power flow optimisation to minimise network constraints and post-fault response to onshore and offshore system events.

4.2 Stakeholder engagement

The following section describes, at high-level, how stakeholders were involved in the design process. We have also produced a dedicated *Stakeholder Approach, Engagement and Feedback* report to provide further detail on the stakeholder engagement approach and feedback received during the design process.

The development of a coordinated onshore and offshore NETS impacts a wide range of stakeholders; therefore, stakeholder engagement was critical to the successful delivery of the HND and recorded throughout its development. The stakeholder engagement approach aligns with the HND ToR, that specifies which stakeholders should be engaged throughout the design process.

Although we have led the HND, several partners and stakeholders were engaged at regular touchpoints. The CDG, consisting of representation from key stakeholders including the onshore TOs, was established to support the development of the HND and ensure that stakeholder views are considered in the design. The Department for Business, Energy and Industrial Strategy (BEIS), Ofgem, and the Scottish and Welsh Governments sat on the group as observers. The specific roles of the ESO, CDG, and CDG subgroups are described below.

We have, in consultation with the CDG, delivered a design recommendation that ensures an economic, efficient, operable, sustainable, and coordinated offshore and onshore NETS. The design includes the connections and associated strategic onshore infrastructure necessary to connect offshore generation in order to facilitate the pace and certainty required to deliver the 2030 offshore wind targets and the 2045 and 2050 net zero targets.

The CDG acted as a vehicle for the ESO to consult with TOs on the HND, and to consult with stakeholder groups as the HND was developed. The CDG members met on a periodic basis to discuss key design options and considerations. Four CDG subgroups, that align with the stakeholder engagement requirements set out in the HND ToR, were established to focus on various objectives of the design. The CDG subgroups provided a focused forum to receive expert input and formal advice on specific elements of the design.

4.3 Choice of regions

Network designs are presented in this section of the report by region. Regions were defined based on the opportunity to coordinate between different offshore wind farms within the HND. We have carried out a holistic exercise, which looks across the whole of Great Britain and seeks to deliver the best overall outcome for consumers, communities, and the environment.

We have recommended connection and offshore network designs for four offshore regions of Great Britain that contain the in scope offshore wind projects:

- North West
- North Scotland
- East Coast
- South West

We have also recommended key wider system reinforcements based on a system-wide view, which we describe in the system-wide view section. Whilst some of these system-wide reinforcements sit neatly within one region, the majority solve wider network issues outside of these regions. We have therefore included a system wide view to reflect this.

Wales has been considered in two separate parts, due to the concentration of generation assets at either end of the country: North Wales is included within the North West Region (as there are opportunities for coordination between Irish Sea wind farms), and South Wales is included within the South West Region as there are opportunities for coordination between Celtic Sea wind farms.

Scotland has been considered as part of three separate regions: West Scotland forms part of the North-West Region due to opportunities for coordination with Irish Sea wind farms, North Scotland is treated as its own region due to limited opportunities for coordination with other regions, and the East Coast of Scotland is considered alongside the East Coast of England.

England has been considered as part of three of these regions: North-West (due to coordination opportunities within the Irish Sea), South West (due to coordination opportunities within the Celtic Sea), and the East Coast (due to coordination opportunities within the North Sea).

The South East and South Coast Region does not contain any offshore wind directly covered by the HND due to the well-developed nature of the majority of the projects in this area. The Department for Business, Energy and Industrial Strategy (BEIS) has now announced four initial pathfinder projects. These are well-advanced projects that are leading the way in utilising the regulatory and policy changes being developed through the OTNR to increase transmission network coordination and deliver the OTNR's objectives[15]. Two of these projects are in this region:

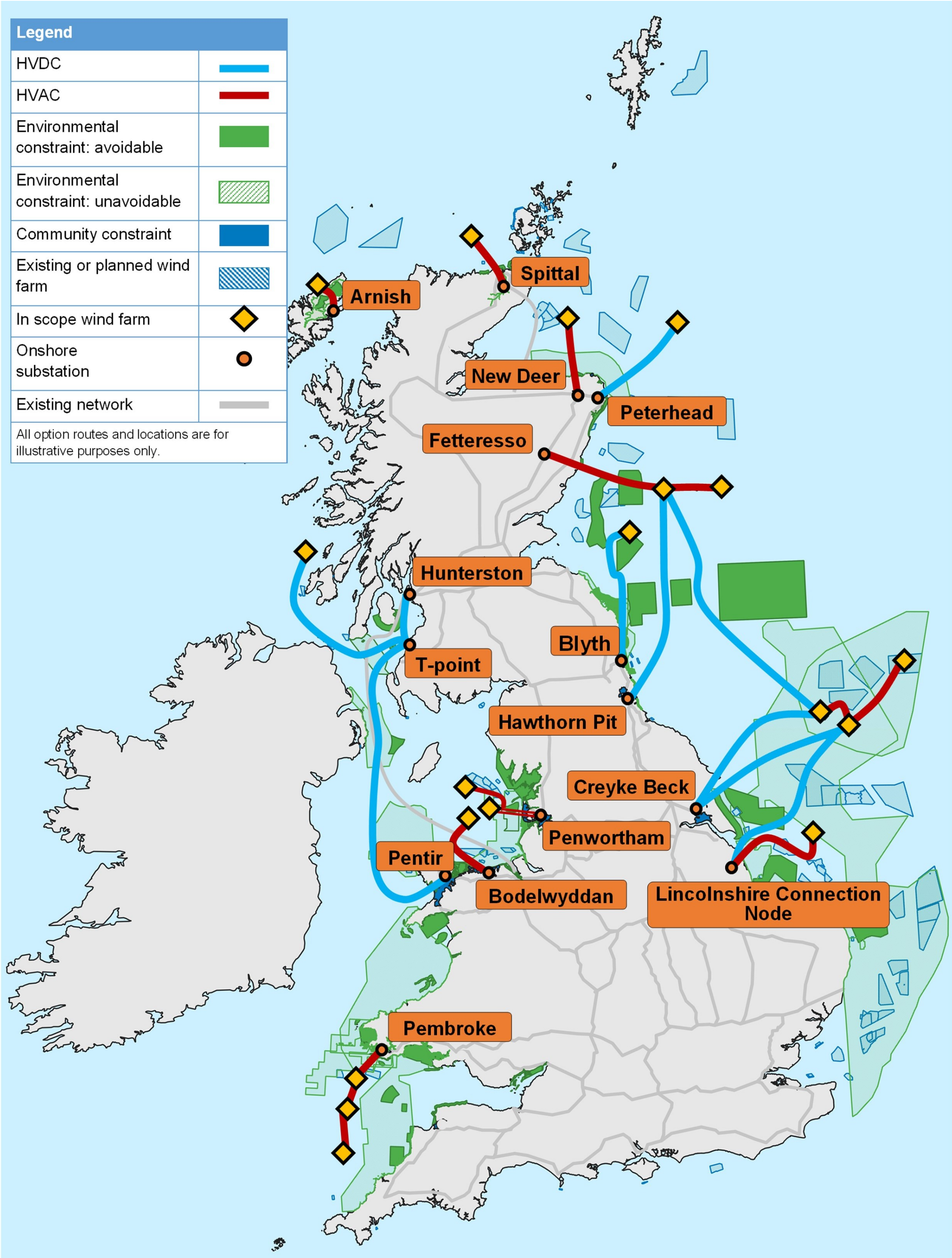
- Equinor's proposal for an integrated transmission system for the Sheringham Shoal and Dudgeon Extensions in Norfolk.
- Orsted's proposal for Boudica, to co-locate a 200MW battery as part of the grid connection in Norwich, Norfolk of Hornsea 3 offshore wind farm.

National Grid Electricity Transmission (Sea Link), National Grid Ventures (Nautilus and EuroLink interconnectors) and the two offshore wind farms North Falls and Five Estuaries have published an update on their work together to explore the potential for offshore coordination as part of the OTNR Early Opportunities workstream too.

[15] link to BEIS press release/OTNR GOV.UK

4.4 Offshore network design

The recommended offshore network design is shown in Figure 8



The HND connects 23 GW of offshore wind capacity to the Great Britain transmission network. When combined with existing offshore wind projects and those already further advanced in their development, the HND should enable the connection of 50 GW of offshore wind in Great Britain by 2030.

The recommended offshore network design connects all 18 in scope offshore wind farms to the onshore network, using 15 different landing points to shore. It includes some regions of strong coordination, and some regions where radial connections are favourable. It establishes new offshore connections between different onshore regions, particularly between west Scotland and north Wales, as well as between east Scotland and the east of England.

In the North West Region, the wind farm in West Scotland connects to a T-point with connections into both Scotland and Wales. The Irish Sea wind farms are connected radially with two sharing a route corridor.

In the North Scotland Region, the recommended design connects the two wind farms radially.

In the East Coast Region, the recommended design is a combination of radial and coordinated connections. The coordinated part of the design provides an offshore network which delivers additional network capacity between Scotland and England, as well as connecting five wind farms.

In the South West Region, the indicative recommended design is a coordinated connection into South Wales, although this is subject to change when the outcome of The Crown Estate's Celtic Sea leasing round is known.

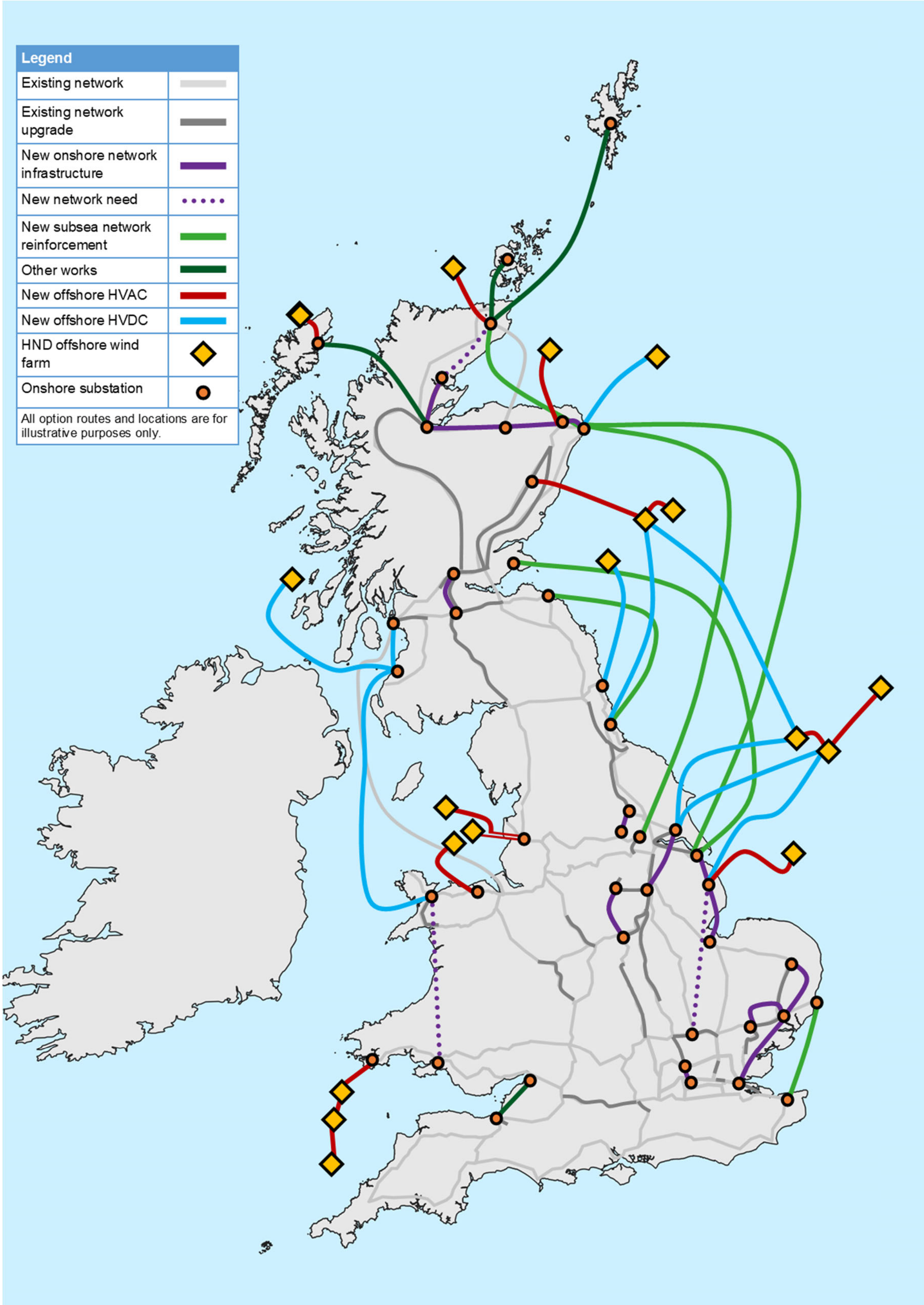
Please note that the design is our best view based on the information available at the time. This and all the maps in this document are illustrative. They highlight an identified need to transmit volumes of energy from point A to point B and do NOT represent specific routes. The next steps involve more detailed network design, which will include specific locations and designs for projects, and as a result the design may change. The detailed network designs will be designed and consulted on in future by the organisations appointed to fulfil the needs identified.

4.5 Onshore network

The major projects required for 2030 to enable the transfer of high volumes of renewable generation to where it will be used across the country is illustrated in *Figure 9*. These reinforcements include upgrades to the existing transmission system in dark grey, new onshore transmission reinforcements and subsea cables previously recommended in NOA in purple and green respectively. New network needs are shown as dotted purple lines and the coordinated offshore network in red and blue representing the type of technology proposed.

This, and all the maps in this document, are illustrative. They highlight an identified need to transmit volumes of energy from point A to point B and do NOT represent specific routes. The next steps involve more detailed network design which will include specific locations and designs for projects and as a result, designs may change. These will be designed and consulted on in future by the organisations appointed to fulfil the needs identified.

Figure 9 - Full HND including major onshore and offshore recommendations



The HND identifies and clearly distinguishes onshore transmission projects that are required to facilitate the 2030 ambitions to allow the power to be transported to where it is needed. It identifies 11 onshore transmission projects that are required for 2030 but where a business as usual approach would result in delivery after 2030.

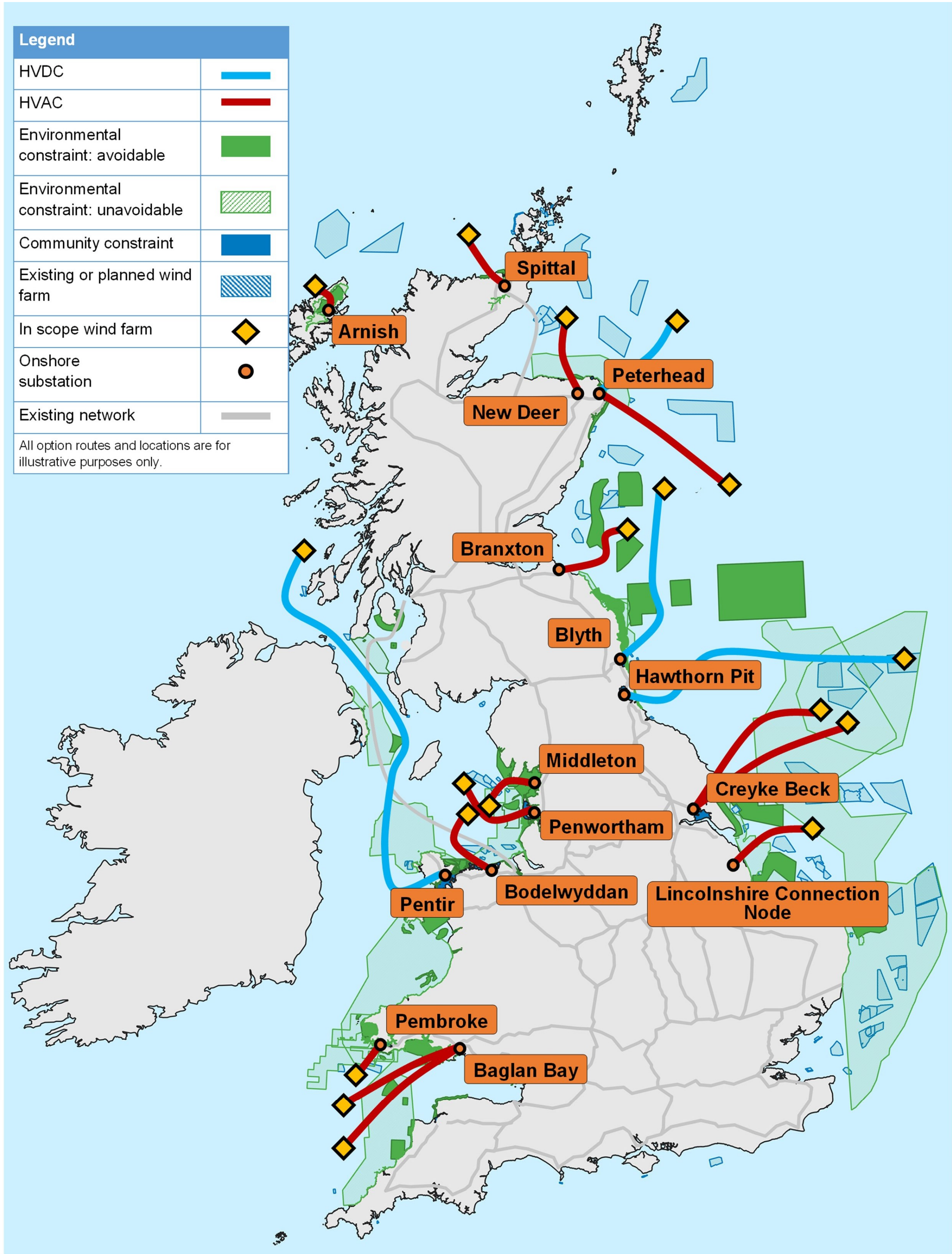
The 2030 onshore transmission network will look very different to the one we see today. To meet the 2030 ambitions and facilitate the delivery of the offshore wind in scope of the HND, 94 reinforcement projects totalling £21.7 billion are required to be delivered by the end of the decade. These range from very small upgrades to large new transmission infrastructure such as new onshore routes or sub-sea cables with the sole purpose of transporting electricity from where it is produced to where there is demand for it. This investment is driven by the increasing level of renewable generation connecting to the system, often in places that have historically seen no requirement for onshore transmission network.

Of the 94 reinforcements required by 2030, many must be delivered earlier to maximise consumer benefit. The NOA process provides this additional insight via an optimal date; ensuring that reinforcements are delivered when they are needed and that the costs of building them outweigh the costs of managing power flows around the network without them in place.

Further detail on the onshore network is included in Appendix 1.

4.6 Optimised radial design

The aim of the optimised radial design is to enable the evaluation of the benefits of a coordinated design relative to an optimised radial design. The optimised radial design is shown in *Figure 10*



The optimised radial design consists of point-to-point connections between offshore wind farms and onshore interface points. The approach used takes into consideration all in scope wind generation, rather than considering each application individually under the current process. This provides a credible counterfactual against which to compare our recommended design.

The optimised radial design connects the 18 wind farms to the onshore network at 15 landing points to shore. It was produced taking into account the four objectives in the HND terms of reference.

4.7 Comparison with recommended design

4.7.1 Economic and Efficient

When the entirety of Great Britain is taken into account, the radial design performs worse than the recommended design from an economic perspective. Although the optimised radial design has lower capital costs (as less offshore infrastructure is needed), it leads to significantly higher constraint costs.

It is also worth noting that the coordinated parts of the recommended design provide redundancy compared to the radial design (which simply provides a minimum-sized connection for each wind farm). This redundancy translates into higher capital costs for the coordinated parts of the design. The economic optimiser used in the design process considers the cost of replacement energy if offshore wind power cannot get to shore.

Based on the assumptions used in our economic modelling, the costs of the offshore network infrastructure required in the recommended design would be around £32 billion. This compares to around £24.4 billion for the optimised radial design (giving the differential of £7.6 billion). These costs are based on high-level assumptions, and we would expect them to change during the Detailed Network Design stage as routing and technology choices are decided.

The economic comparison between the optimised radial design and the recommended design is shown in *table 5* below

Cost Type	Cost Description	Most economic option	Cost differential (£bn)
New offshore/onshore capital and operational costs	The cost of constructing and operating all offshore assets to connect the generators to the system, plus any onshore works essential to connect in a manner compliant with relevant standards that are not NOA works. The costs of new offshore transmission network infrastructure are based on component unit costs derived from data provided by equipment suppliers. The input cost assumptions have been provided to in scope developers and OTNR stakeholders.	Optimised radial	£7.6bn
NOA boundary reinforcement costs	The cost of constructing works that are required for the connection of the generators and/or boundary reinforcement, which have previously been included in a NOA assessment. These costs are broadly comparable between all options considered.	Equivalent[16]	-
Constraint costs	The cost of taking balancing actions to redispatch generation to prevent unacceptable network flows across parts of the network that have limited capacity. These consist of actions to decrease generation output in one part of the country, and	Recommended	£13.1bn

[16] The costs and scope of onshore boundary reinforcements are broadly comparable between the two designs though it should be noted that there is a limit to the amount of boundary reinforcement that can be delivered in the lead up to 2030. This is due to the time taken to deliver large scale infrastructure projects, as well as other factors including supply chain and network access. However, if these delivery constraints were removed and more network reinforcement options were available, the HND would reduce the requirement to invest in onshore infrastructure. This is demonstrated through the significant reductions in constraint costs it provides compared to the optimised radial design.

	actions to increase generation output in a different part of the country.		
Total costs		Recommended	£5.5bn[17]

4.7.2 Deliverable and operable

Both the optimised radial design and the recommended design are deliverable and operable and provide the opportunity for wind farms to be able to connect by 2030. The recommended design is more complex, and the longer, and more complex, HVDC links in the recommended design are unlikely to be complete by 2030 in the absence of major acceleration in the supply chain. However, both designs offer the potential to get generation connected by 2030, and increase capacity progressively, given timely allocation of responsibilities, delivery of the commitments in the *BESS* and a coordinated and concerted effort from all parties. Our analysis has not identified any significant operability challenges with either design, although the DND will explore this further for the recommended design.

4.7.3 Environmental impact

The nature of the infrastructure required means the HND cannot be without impact. However, careful consideration has been given to the design to minimise cumulative environmental impacts.

The recommended design reduces the footprint of the cables being laid to shore by up to a third due to the use of HVDC technology. However, the total length of cable route corridors in the offshore network is slightly higher in the recommended design than in the optimised radial design. This is due to the additional cable needed to provide north to south routes on the east and west coasts. These cable routes are beneficial because they minimise network constraints, enabling more zero carbon wind energy to be utilised and offset the need for less environmentally friendly energy generation. In comparison to the radial design, the recommended design saves 2 million tonnes of CO_2 between just 2030 and 2032. It also reduces the need for future infrastructure, which would be needed to achieve the same emission reductions and does this while minimising environmental impact through designing the offshore network in a coordinated way.

Both designs take account of environmental constraints, and the recommended design seeks to minimise the impact on sensitive habitats through the coordination of wind farm connections to shore. Cable route corridors can avoid many of the identified environmentally sensitive features, however this is not possible in all cases.

For the recommended design, further consideration will need to be given to cable routing in the DND stage to minimise environmental and consenting risks. While the environmental mitigation hierarchy should be followed, it is likely that environmental compensation measures will be required, assuming no viable alternatives are identified in the DND stage. This might include measures at a regional or national level. However, in the first instance measures to alleviate pressures on and protect sensitive habitats both within and outside Marine Protected Areas (MPAs) should be considered, and compensation seen as a last resort.

4.7.4 Community impact

The rapid development of offshore wind is already having an impact on coastal communities. The HND has sought to minimise the impact on communities in balance with the other three design objectives.

The recommended design reduces the impact on local communities, for example, relating to the volume of transmission network infrastructure in some areas, the cumulative impact associated with multiple connections, and onshore transmission reinforcements that are driven by the offshore

[17] The £5.5bn figure is calculated by subtracting £7.6bn from £13.1bn.

network. There is also the potential for the route corridors to avoid many of the identified community constraints; specific route corridors will be defined as part of the DND.

While the HND has tried to reduce community impacts and reduce the number of cable routes to shore, it is not possible to fully eliminate community impacts. At Peterhead and Creyke Beck there is a significant amount of new infrastructure being proposed in addition to the HND which will have a cumulative impact on communities in these regions. There are also new coastal sites being proposed on the West Coast of Scotland and in Lincolnshire which will impact on coastal communities. However, the recommended design provides community benefits by reducing the number of connection locations in North West England (due to the shared cable corridor to Penwortham), and avoiding further connections into East Anglia at this time beyond those already planned, as there is already significant planned and existing offshore transmission infrastructure in this region.

Further detail about the optimised radial design can be found in section 7.

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5.Regional overview

This chapter provides an outline of each of the four geographic regions considered in the Holistic Network Design *(HND)*:

- North West Region (including West Scotland)
- South West Region
- East Coast Region
- North Scotland Region

Finally, this chapter provides a system-wide view of the wider transmission reinforcements required as part of the HND. These include the wider works at interface points determined to be essential to delivering 50GW by 2030, as well as the wider network reinforcements required by 2030 to facilitate economic and efficient power flow across the system.

Each regional section presents the recommended design and alternative coordinated designs, as well as the optimised radial design.

Note that the recommended design for the North Scotland Region uses radial connections only. This is because a coordinated design for the in-scope wind farms in this region did not perform as well against the network design objectives as the radial design.

The benefits of each chosen design are discussed, against the four network design objectives (*Table 6*) which were introduced previously:

Table 6 - the four network design objectives

Objective		Description
	Economic and efficient costs	The network design should be economic and efficient
	Deliverability and operability	The network design should be deliverable by 2030 and the resulting system should be safe, reliable and operable
	Environmental impact	Environmental impacts should be avoided, minimised or mitigated by the network design, and best practice environmental management incorporated in the network design
	Local community impact	Local community impacts are avoided, minimised, or mitigated by the network design

5.1 North West Region

The North West Region includes three Irish Sea projects from Crown Estate Leasing round 4 as well as one project off the West Coast of Scotland.

Spanning the three nations of Great Britain, the region includes large parts of the onshore transmission network.

5.1.1 Projects in scope

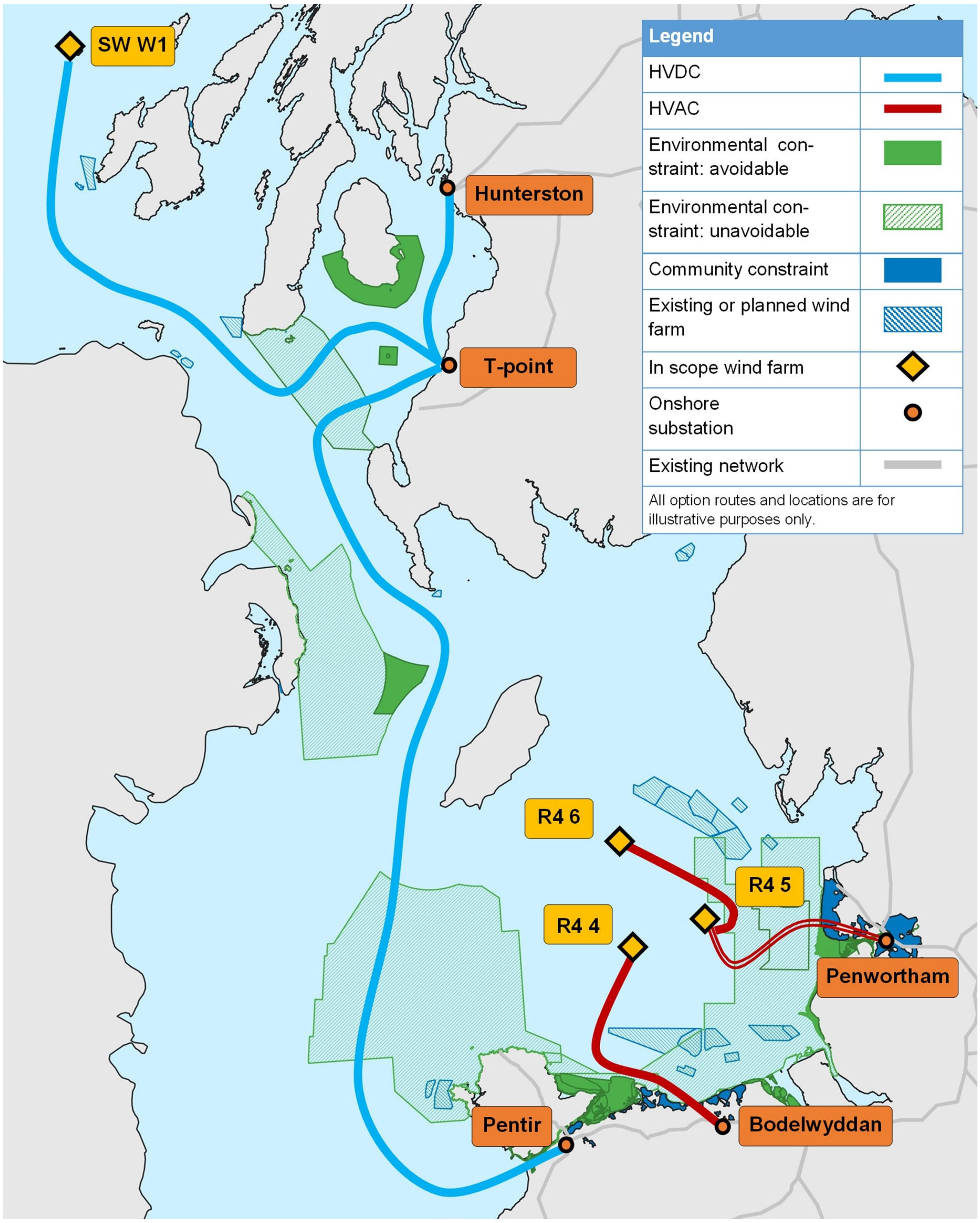
The North West region design connects the following four projects *Table 7*:

Project name	Capacity (MW)
SW_W1	2000
R4_4	1500
R4_5	480
R4_6	1500

There is also a potential opportunity to integrate the planned LirIC interconnector from Scotland to Northern Ireland into the proposed design; more detail about this is provided in section 5.1.9 Coordination with LirLC interconnector.

5.1.2 Offshore design

The recommended offshore design for the North West Region is shown in Figure 11



The recommended design in the North West Region is formed of a connection through offshore waters between Scotland and Wales and connections from the Irish Sea to the North-West of England and North Wales. It includes a High Voltage Direct Current (HVDC) connection from wind farm SW_W1 to a T-point located in the vicinity of South Ayrshire, which further connects to Hunterston and Pentir. This delivers an offshore connection between Scotland and Wales, which bypasses onshore grid constraints and enables transmission of electricity from Scotland to the south, towards areas of higher electricity consumption. HVDC technology needs to be used for this due to the long cable length and large capacity. Due to environmental and deliverability constraints, we have assumed that this cable route approaches Pentir from the south, although route corridors will be determined at the Detailed Network Design stage.

In this design SW_W1 is connected to a T-point, which is assumed to be a location in South Ayrshire on the Scottish mainland. It is possible for the T-point to be offshore or onshore: an offshore T-point would lead to higher capital costs but avoid the environmental impact of cables connecting to shore. An onshore T-point would lead to lower capital costs but there would be an environmental impact of cable landfall. The location of the T-point will be considered further in the Detailed Network Design stage.

When SW_W1 is generating at full output, the link to Pentir will enable this power to be transported south to areas of higher demand, bypassing key constrained boundaries[18] on the England-Scotland boundary (B6) and in the North of England (B7a).

When SW_W1 is not generating at full output, the links from the T-point to Hunterston and Pentir will act as a transmission reinforcement, enabling excess onshore generation output from Scotland to be transported to meet demand further south in Great Britain.

The links to Hunterston and Pentir therefore provide a wider transmission system benefit and avoid the need for an additional north-south link. There is also potential for other projects to connect into the T-point. We would therefore envisage the possibility that the T-point to Hunterston and/or Hunterston-Pentir circuits could form part of the onshore transmission system and would therefore be delivered and operated through the appropriate mechanisms for onshore transmission assets. The SW_W1 developer could therefore only be responsible for the link from SW_W1 to the T-point, with the other circuits being described as TO works within its connection agreement. However, as this situation is not specifically clarified within the Office of Gas and Electricity Market's (Ofgem) May 2022 Minded-to Decision document, further analysis on the primary function of the assets will be needed to confirm this, as envisaged by Ofgem.

The inclusion of a T-point within the design also makes the design more future proof by providing opportunities to accommodate additional connections.

For the R4_5 and R4_6 wind farms, we are recommending radial connections with a shared cable corridor. The shared onshore and offshore cable corridor and landfall minimise the impact of the cables on the environment and local community. This is consistent with the developers' proposal and is expected to limit deliverability risks as a result of a smaller, simpler offshore platform design.

For the R4_4 wind farm, we are recommending a radial connection into Bodelwyddan.

The connections used in the design are described in *table 9*. While these connections represent our current proposal for the design, they may change in further stages of the design process.

Our choice of cable technology (HVDC or High Voltage Alternating Current (HVAC)) in this document has been made in the first instance on the optimal economic design solution based on our assumptions as set out in the Network design guidelines and network overview section. The choice between AC and DC cabling becomes less clear cut in the upper length range for AC cables (150-200 km) and will depend on other project specific factors, including environmental, technical and community constraints. The final choice of technology will be made as part of the Detailed Network Design phase.

[18] Boundaries are explained here: https://www.nationalgrideso.com/research-publications/etys/etys-and-the-network-planning-process

Table 8 – Connections table

Node 1	Node 2	Circuit capacity (MW)	Technology[19]		Distance (km)[20]
SW_W1	T-point	2000	DC	525 kV XLPE pair with co-axial metallic return	180
Hunterston*	T-point	2000	DC	525 kV XLPE pair with co-axial metallic return	55
T-point	Pentir	2000	DC	525 kV XLPE pair with co-axial metallic return	315
R4_4	Bodelwyddan	1500	AC	3-4 cables	75
R4_5	Penwortham	480	AC	1 cable	60
R4_6	Penwortham	1500	AC	3 cables	95

*The termination point location will be finalised at a later stage, see section 6.3 Next Steps

5.1.3 Onshore works

The design requires onshore works at the interface sites (Hunterston, Pentir, Bodelwyddan and Penwortham) as well as wider sites.

Table 9 – Onshore works required

Substation	Work required
Bodelwyddan	Extension of the existing Bodelwyddan 400 kV substation to establish bays for connection to the offshore network.
Penwortham	Extension of the existing Penwortham 400 kV substation to establish bays for connection to the offshore network.
Pentir	Extension of the existing Pentir 400 kV substation to establish bays for connection to the offshore network.
Hunterston	Extension of the existing 400 kV substation building, including additional bays for connection to the offshore network. The extent of the building extension will only be confirmed during the detailed design stage.

The T-point will require design works either onshore or offshore, these will be studied in the Detailed Network Design (DND) phase.

The design requires works at other sites including uprating, reconductoring and reinforcement. Wider onshore works are described in the system-wide view section 5.5.

[19] AC cable numbers assume 500 MW is possible at 275 kV. Longer distances may require an additional parallel cable to account for reactive power losses.
[20] The distances shown relate to an indicative route. Route corridors will be determined as part of the Detailed Network Design process.

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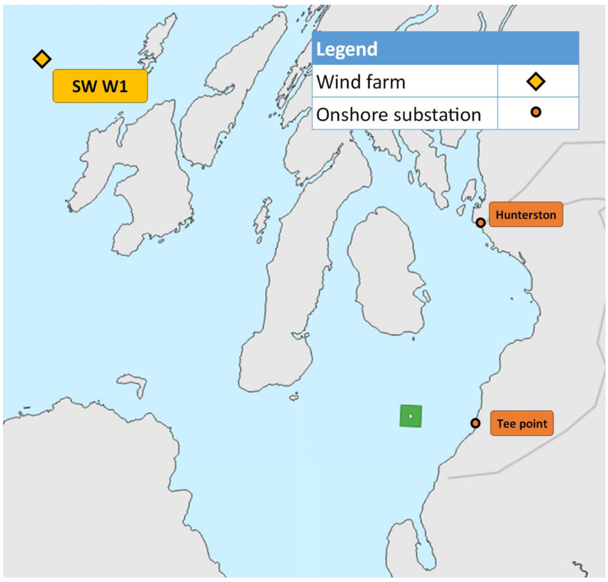
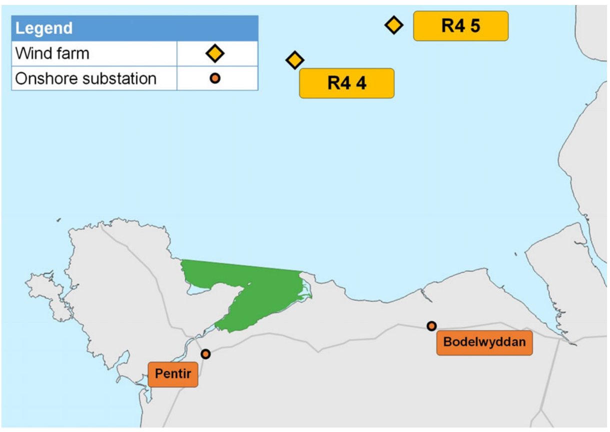
5.1.4 Environment and community constraints

Although route corridors are not defined at this stage of the process, the HND has been developed with a view to avoiding the most significant environmental and community constraints. These include constraints with features expected to be sensitive to impacts from cabling or infrastructure where the risks of cabling would be significant.

We have assumed that Pentir is approached from the south; this reflects feedback we have received from stakeholders that this would be preferable from an environmental and deliverability perspective. However, route corridors will not be defined until the DND stage.

Table 10 lists the significant constraints which it has been possible to avoid in the HND within the region. As in the regional overview, avoidable constraints are shown in solid fill whereas unavoidable constraints are cross hatched.

Table 10 – Significant constraints

Constraint	Map	Description
Constraint 1		**Ailsa Craig** Ailsa Craig Special Protection Area (SPA) is an island in the Firth of Clyde designated for its importance to the European Herring gull, Lesser Black-backed gull, Northern gannet, Black-legged kittiwake and Common murre.
Constraint 2		**Large Shallow Inlets and Bays** The North Wales coast contains submerged or partially submerged sea caves and large shallow inlets and bays. Large shallow inlets and bays are habitat complexes, which comprise an interdependent mosaic of subtidal and intertidal habitats that have been identified as important, sensitive habitats that should be key considerations for cabling activities.

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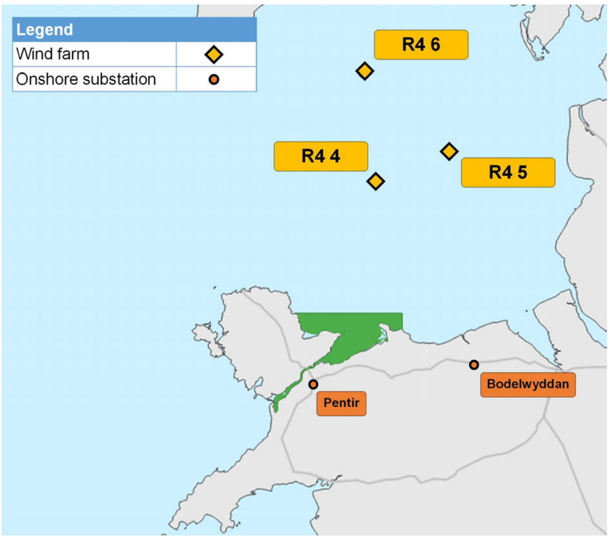
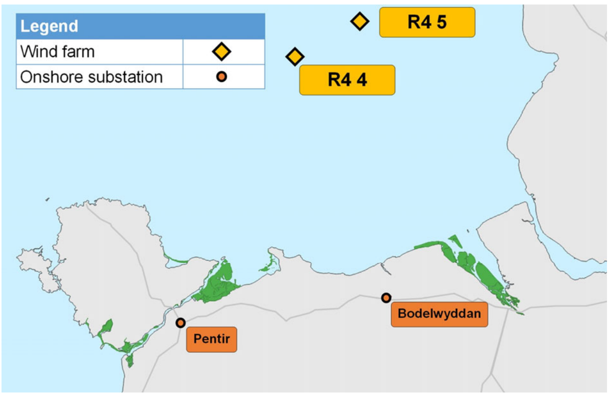
Constraint 3



Menai Strait and Conwy Bay Special Area of Conservation (SAC)

The Menai Strait and Conwy Bay SAC is designated for its marine area, sandbanks, mudflats and sandflats and reefs. The site also contains submerged or partially submerged sea caves and large shallow inlets and bays. The SAC is avoided in the southern approach to Pentir but cannot be avoided in a northern approach.

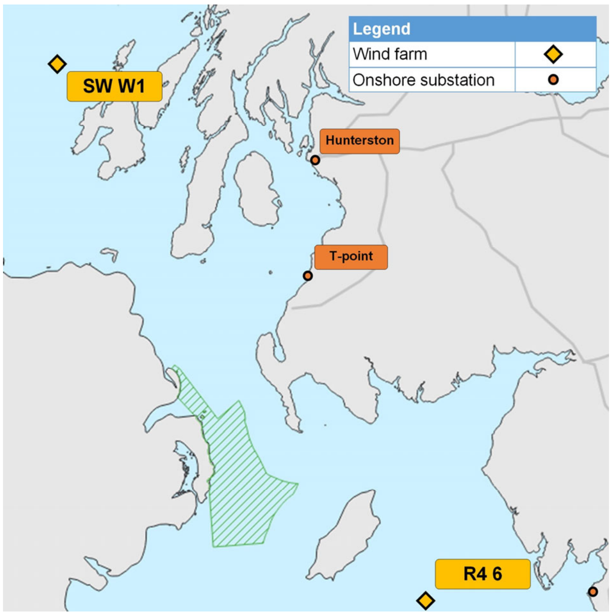
Constraint 4



Mudflats and Sandflats

These intertidal mudflats and sandflats on the North Wales coastline are submerged at high tide and exposed at low tide. These have been identified as important, sensitive, habitats that should be key considerations for cabling activities. Within this habitat, plant and animal communities present vary according to the type of sediment, its stability and the salinity of the water. These are also avoided in the southern approach to Pentir but might be affected by the northern approach.

Constraint 5



North Channel SAC

The North Channel SAC is designated due to its protection for harbour porpoise. Habitats within the site consist mainly of coarse or sandy sediments, with patches of rock and mud.

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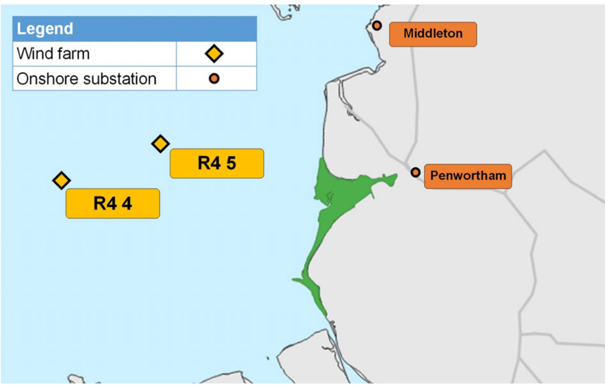
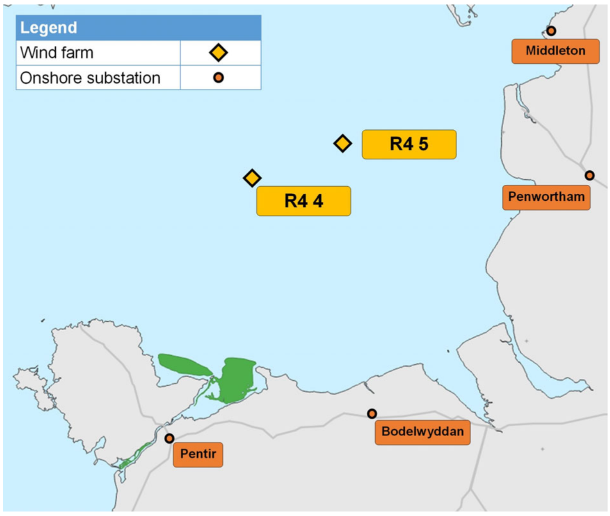
Constraint 6



The Ribble and Alt Estuary SPA

The habitats supporting the Ribble and Alt Estuary SPA are identified by Natural England (NE) and the Joint Nature Conservation Committee (JNCC) as sensitive to cabling. The extensive areas of sandflats, mudflats and saltmarsh of the SPA can be avoided by routing the cable north of the Ribble estuary. The site supports breeding Ruff, Common tern and Lesser Black-backed gull.

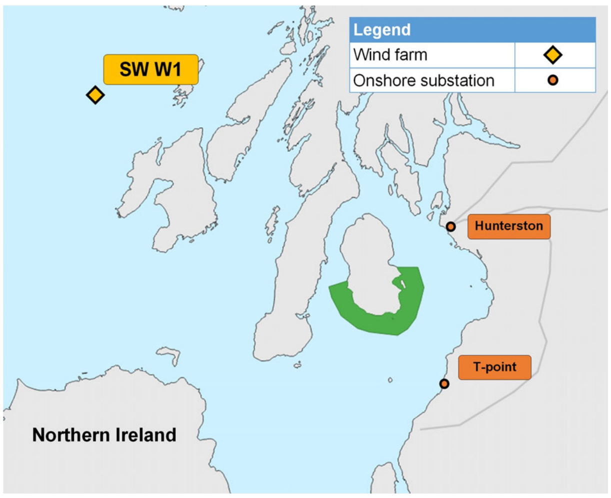
Constraint 7



Sandbanks

The sandbanks of the North Wales coastline, which consist of sandy sediments that are permanently covered by shallow sea water, typically at depths of less than 20m. The diversity and types of community associated with this habitat are determined particularly by sediment type together with a variety of other physical, chemical and hydrographic factors. They have been identified by NRW as key considerations for cabling activities.

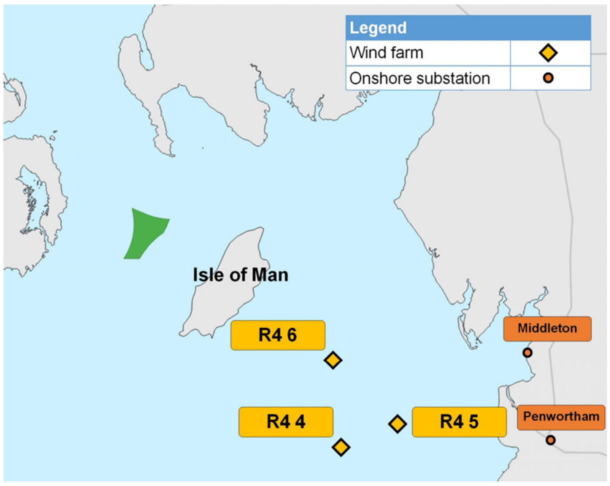
Constraint 8



South Arran

The waters around the southern end of Arran are home to a diversity of habitats and species characteristic of the more exposed areas of the Clyde Sea. The site contains a patchwork of maerl beds, kelp and seaweeds on sediments, burrowed mud, coarse shell gravels with burrowing bivalves, and seagrass beds.

Constraint 9

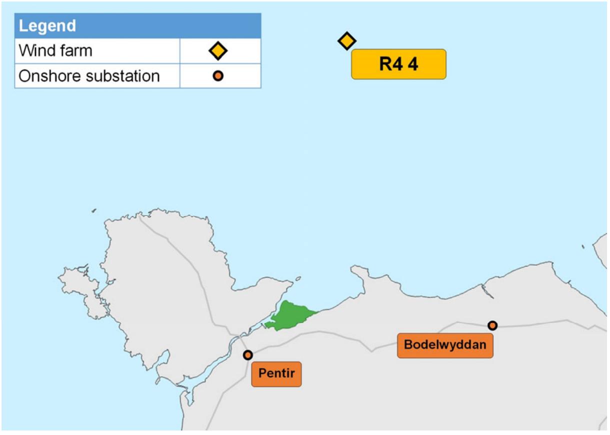


South Rigg MCZ

The South Rigg Marine Conservation Zone (MCZ) contains a variety of habitats (predominately mud and sand with areas of coarse and mixed sediments, as well as rocky habitats) which support a wide range of species.

There is the potential to avoid the MCZ within the route corridors.

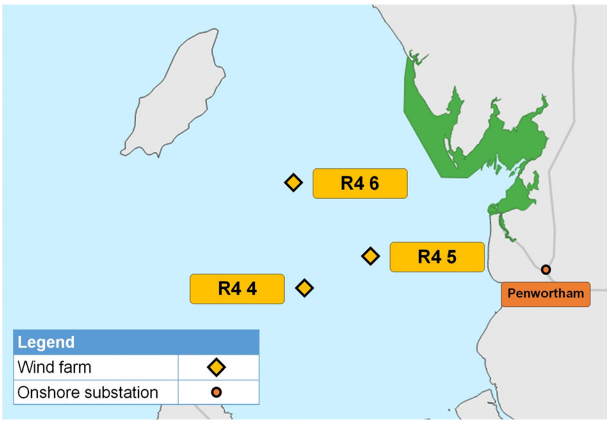
Constraint 10



Lavan Sands, Conway Bay SPA

The Traeth Lafan/ Lavan Sands, Conway Bay SPA is designated for its important wintering area for Eurasian oystercatcher and is a breeding site for Eurasian curlew. It also supports the passage of great crested grebe. The SPA is avoided by a southern approach to Pentir.

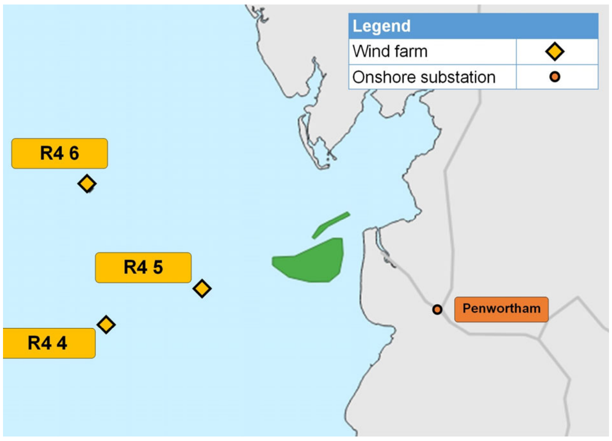
Constraint 11



Morecambe Bay SAC

The Morecambe Bay SAC is designated for its range of marine habitats including coastal sand dunes, estuaries, mudflats and sandflats, and large shallow inlets and bays. Protected species are also present at the site such as the great crested newt.

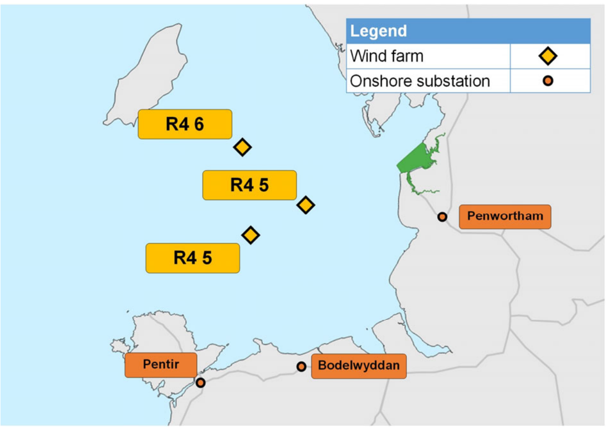
Constraint 12



Shell Flat and Lune Deep SAC

The Shell Flat and Lune Deep SAC is designated for its sandbanks which are covered by seawater all the time and reefs. The bank is an example of a Banner Bank, which are generally only a few kilometres in length with an elongated pear/sickle-shaped form, located in water depths less than 20 m.

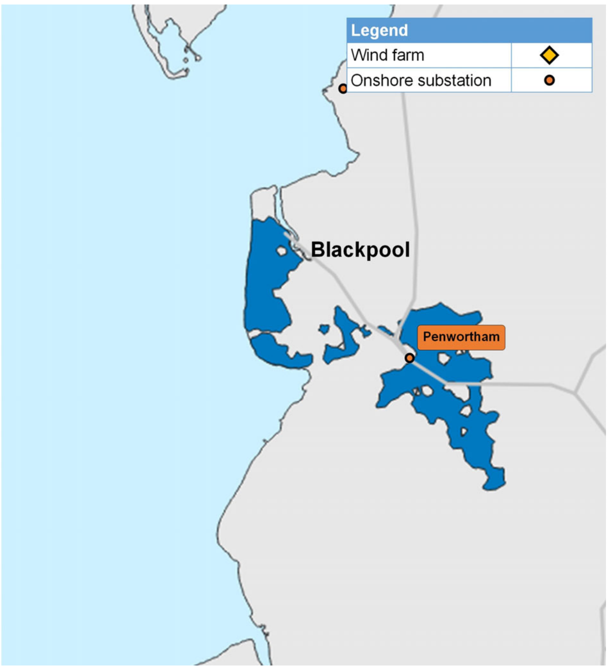
Constraint 13



Wyre-Lune MCZ

Wyre-Lune MCZ is an inshore site that covers an area of approximately 92 km². It is located in the southern part of Morecambe Bay. The site is designated for smelt, which were once widespread in estuaries in the UK but have declined considerably over the past 200 years.

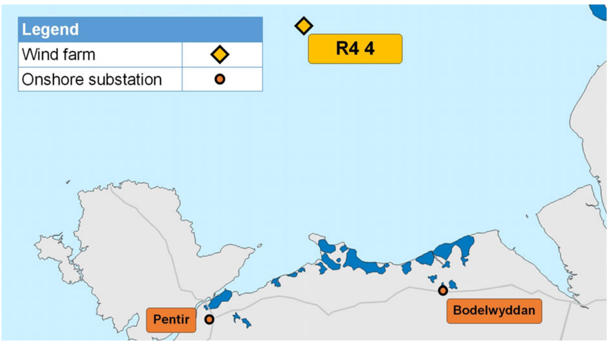
Constraint 14



Major settlements

The major urban areas (Blackpool and Lytham St Annes) can be avoided within the route corridors; however the Penwortham route corridor would require a route through the crossing of Blackpool Airport land area between the settlements after landfall.

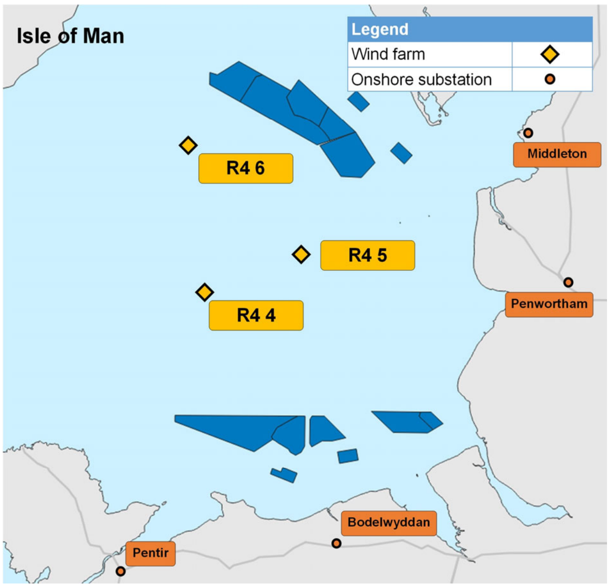
Constraint 15



Major settlements

There are major settlements and urban areas on the north coast of Wales that are likely to be close to landfall for approaches to Bodelwyddan and Pentir. These include Abergele and Llanddulas.

Constraint 16



Existing or proposed wind farms

Potential cable routes from R4_4 to Bodelwyddan extend south west to avoid the Awel y Mor proposed array area. There is also potential to avoid the existing wind farm and Rhyl Flats within route corridors.

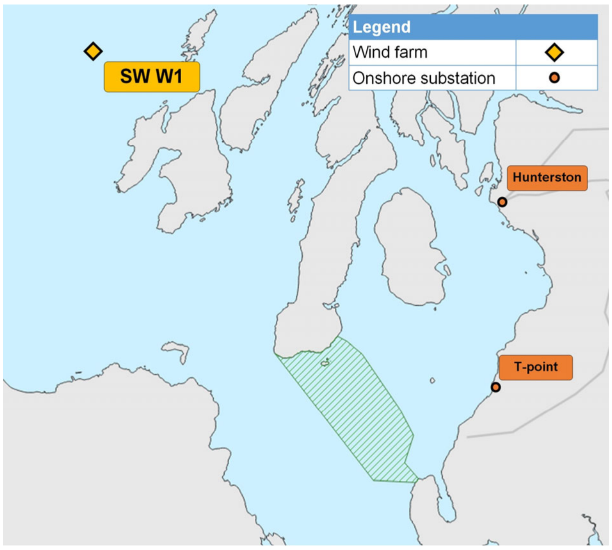
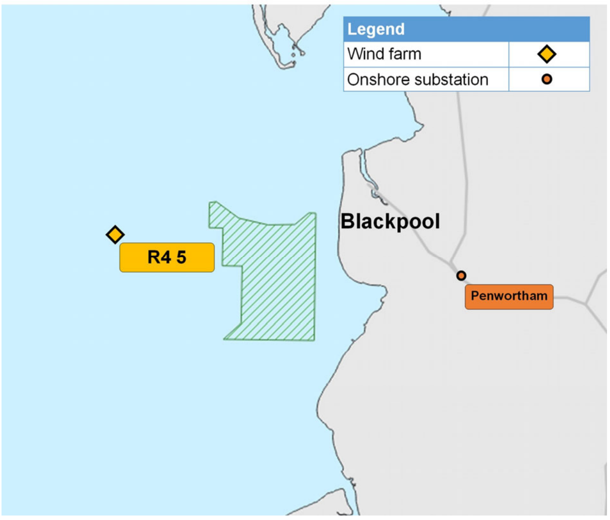
5.1.5 Unavoidable environmental constraints

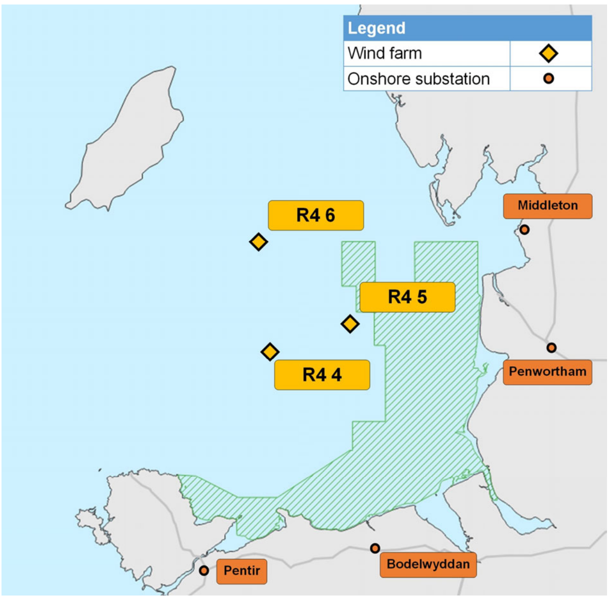
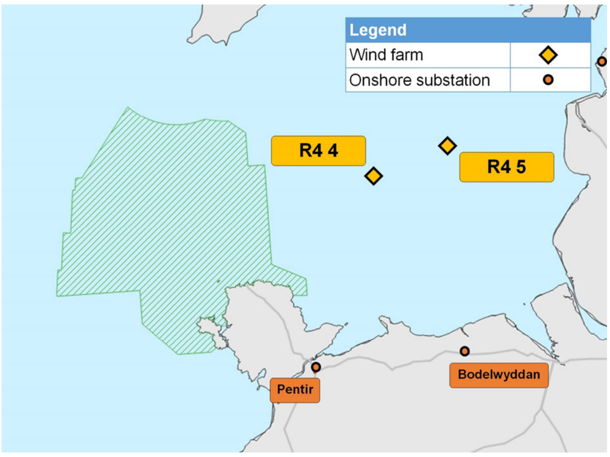
There are some environmental constraints which cover extensive areas or are close to the point of the subsea cables making landfall that are unavoidable due to the locations of wind farms and onshore substations. *Table 11* lists the significant constraints that it has not been possible to avoid in the HND corridors within the region.

At this strategic route selection stage, the primary method of mitigation was to, as far as was possible, avoid features and/or environmental designations that were identified by the relevant statutory bodies as sensitive to cabling operations. In some instances, these environmental or physical features, or infrastructure, formed linear constraints to cable route corridors, that could not be circumvented. In these cases, consideration was given to whether these features could be crossed over (e.g., infrastructure) with physical protection or under, by directional drilling (environmental areas).

More detailed site surveys, routing and consideration of mitigation measures will be required at the detailed network design stage to further avoid identified specific sensitivities or features within designated areas that have not been avoided, and to identify appropriate crossing locations and techniques. At the detailed design stage further mitigation such as limiting the seasonality of working may also be considered to minimise the potential impacts of cable laying operations in areas that are not practical to avoid. Beyond this, compensatory measures may be required at the DND stage to offset identified impacts.

Table 11 – Unavoidable environmental constraints

Constraint	Map	Description
Constraint 17		**Clyde Sea Sill MPA** Clyde Sea Sill MPA is designated for its importance to black guillemots, offshore sand and course sediment communities. It is also of geological interest. The Clyde Sea Sill cannot be avoided for approaches to Hunterston.
Constraint 18		**Fylde MCZ** The site is designated for the extensive areas of subtidal sediment habitats and plant and animal communities present. These sites are good representations of the seabed habitats and communities found on the eastern side of Liverpool Bay. The Fylde MCZ cannot be avoided for approaches to Penwortham. It has not been identified by Natural England (NE) and the Joint Nature Conservation Committee (JNCC) as having habitats with key sensitivities to offshore wind farm cabling.

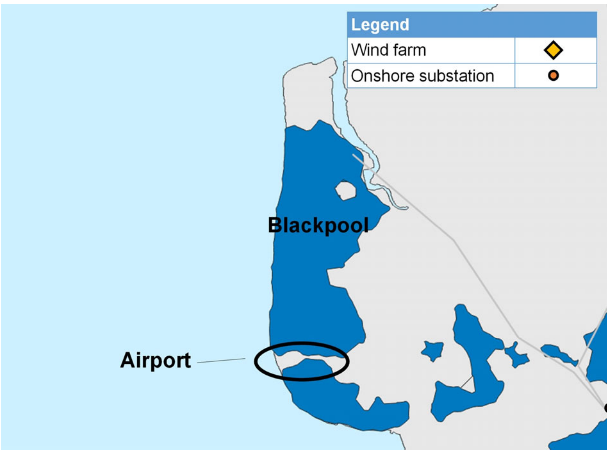
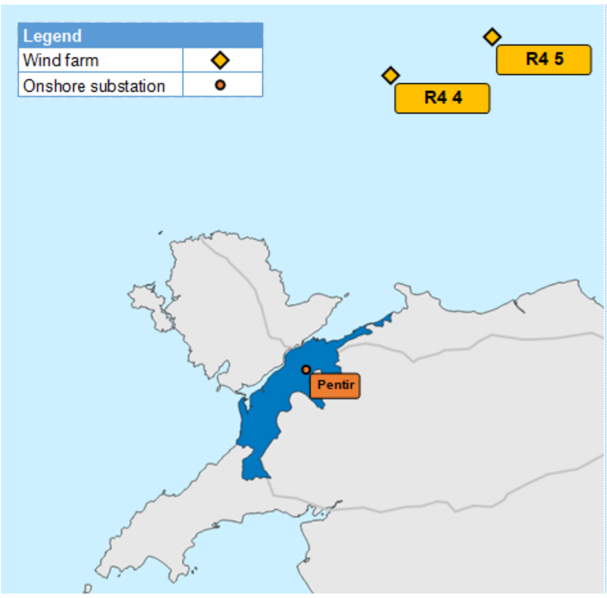
Constraint 19		**Liverpool Bay SPA** Liverpool Bay SPA encompasses marine areas supporting large aggregations of wintering red-throated diver and common scoter as well as important marine foraging areas of little terns breeding within The Dee Estuary SPA, and foraging areas of Common terns breeding at the Mersey Narrows and North Wirral Foreshore SPA.
Constraint 20		**North Anglesey Marine SAC** The North Anglesey Marine SAC is designated due to the area being an important site for Harbour porpoise. The North Anglesey Marine SAC overlaps a range of other habitats, including coarse and sandy sediments, rock, and mud. The SAC is avoided in the Northern approach to Pentir but cannot be avoided in a southern approach.

5.1.6 Unavoidable community constraints

Table 12 lists the significant community constraints that it not expected to be possible to avoid in the region. These include rural areas close to the substations and built-up areas close to Blackpool.

The significant community constraints within this region include wrecks, scheduled monuments and urban areas. Most of these constraints can be avoided however, to avoid the urban areas around Blackpool, landfall will potentially be required near Blackpool Airport. Penwortham substation is located within the Lancashire and Amounderness Plain landscape which, due to existing development in the area, is expected to be less sensitive to planned developments. The Ayrshire coastal path would potentially be difficult to avoid for a T-point in South Ayrshire.

Table 12 – Unavoidable community constraints

Constraint	Map	Description
Constraint 17		**Blackpool Airport** To avoid the urban areas around Blackpool, landfall will be required at Blackpool Airport.
Constraint 18		**Pentir rural areas** Pentir Substation is located within the Arfon area landscape, which is the lowland area bounded on one side by the Menai Strait and on the other by the Snowdonia foothills and adjacent glaciated valleys.

While these tables do not describe all the environmental and community constraints in the North West Region, they provide an overview of the significant constraints that influenced the network design, including constraints that are very close to the interface points and those which have been identified by stakeholders as being particularly sensitive to cabling operations, and thus have significant potential to impact the viability of cable routes through the area. These constraints also highlight the sensitive areas that have been identified as difficult to avoid in designing cable route corridors.

5.1.7 Potential changes to the offshore design

At this stage in the development of the HND it is not possible to detail every aspect of the design. This section outlines the possible alterations that will be considered as part of the DND. For the North West Region there are three possible alterations.

5.1.8 T-point location

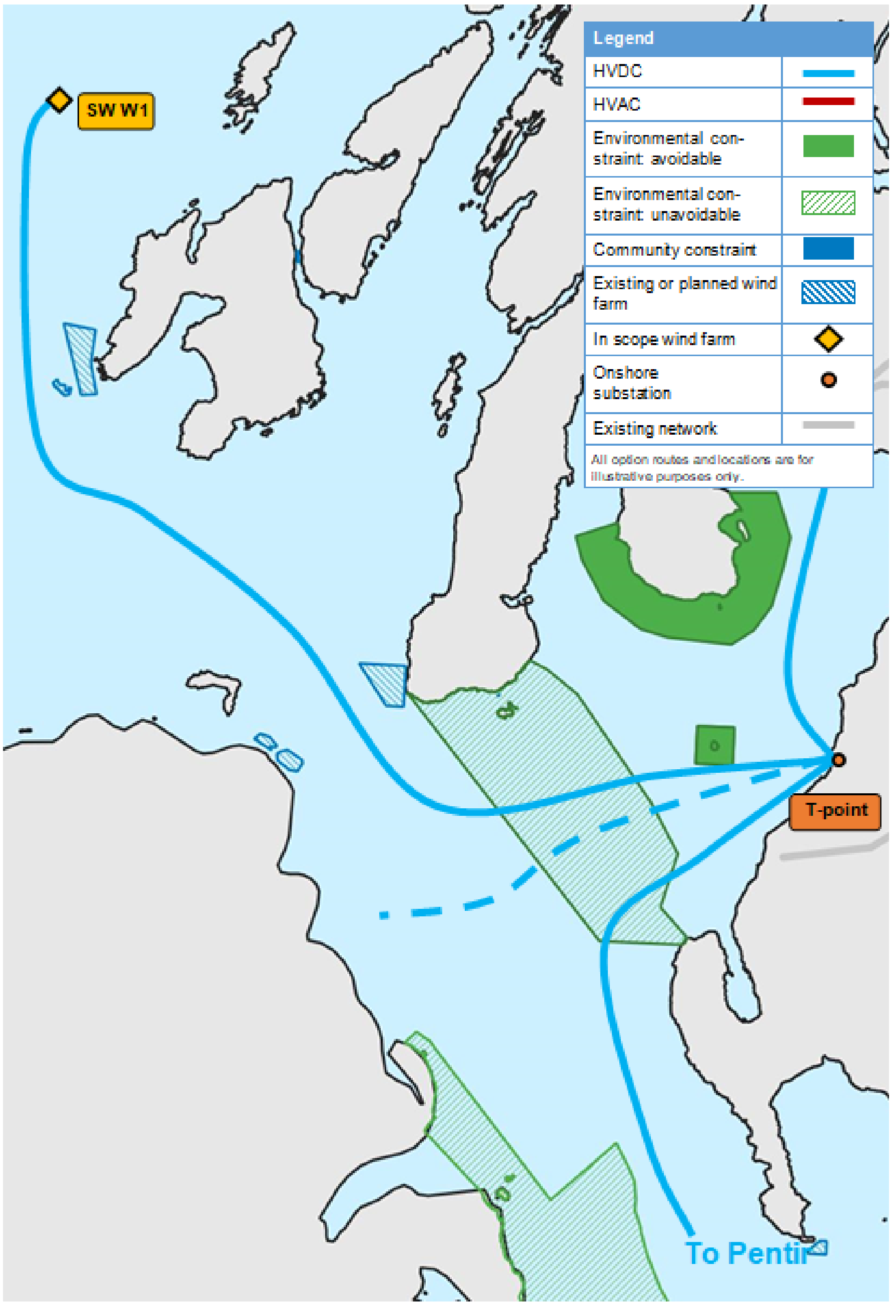
Alternative locations for the T-point/switching station for the multi-terminal HVDC connection between SW_W1, Hunterston and Pentir were considered, including onshore switching stations at various locations in South Ayrshire and offshore platforms.

The high-level initial assessment done for the HND identified a viable location in South Ayrshire. Further work will be required in the DND stage to identify the optimal location for this switching station. Options within South Ayrshire will be considered, as well as offshore locations in the Clyde.

5.1.9 Coordination with LirIC interconnector

The LirIC interconnector is currently planned to be a HVDC connection from Kilroot in Northern Ireland to Kilmarnock South in Scotland. This would intersect with the proposed coordinated design in the North West Region.

Figure 12 - T-Point and LirIC (LirIC shown in dotted line)



It is possible that a favourable economic, environmental and community outcome could be achieved by coordination with the LirIC interconnector. This could be achieved by connecting the LirIC interconnector to the T-point, rather than Kilmarnock South, resulting in one fewer HVDC converter and less cable. For this to be possible, LirIC would need to adopt the same operating voltage and bipole arrangement as the proposed SW_W1 to Hunterston and Pentir HVDC circuit.

This would lead to environmental and community benefits due to fewer landing points and less offshore infrastructure. However, it would introduce additional complexity at the T-point.

For this to be possible, further technical design and economic analysis will need to be carried out; we are currently progressing this work. The regulatory and commercial aspects of this solution would still need to be developed.

5.1.10 Alternative to Hunterston

Kilmarnock South is also under consideration as an alternative to Hunterston. The offshore route corridor and coastal section to Kilmarnock South are moderately constrained environmentally, and lightly constrained onshore. Our analysis showed that a connection to Kilmarnock South would be approximately £25 million more expensive than Hunterston; this differential results from the costs of the offshore infrastructure and works required at each of the substations.

For the purposes of our economic analysis, there are no network boundaries between Hunterston and Kilmarnock South. From a Great Britain wide perspective, there is therefore not expected to be a significant difference in system constraint costs or boundary reinforcement costs associated with connections to each of these substations.

In order to facilitate power flows on the multi-terminal HVDC link south from the SP Transmission area during periods when the SW_W1 generation is at less than full load, a connection at Hunterston relative to Kilmarnock South may advance (in time) the requirement for onshore reinforcement work and potentially increase its scope. Further analysis will need to be undertaken to confirm which is the preferred site.

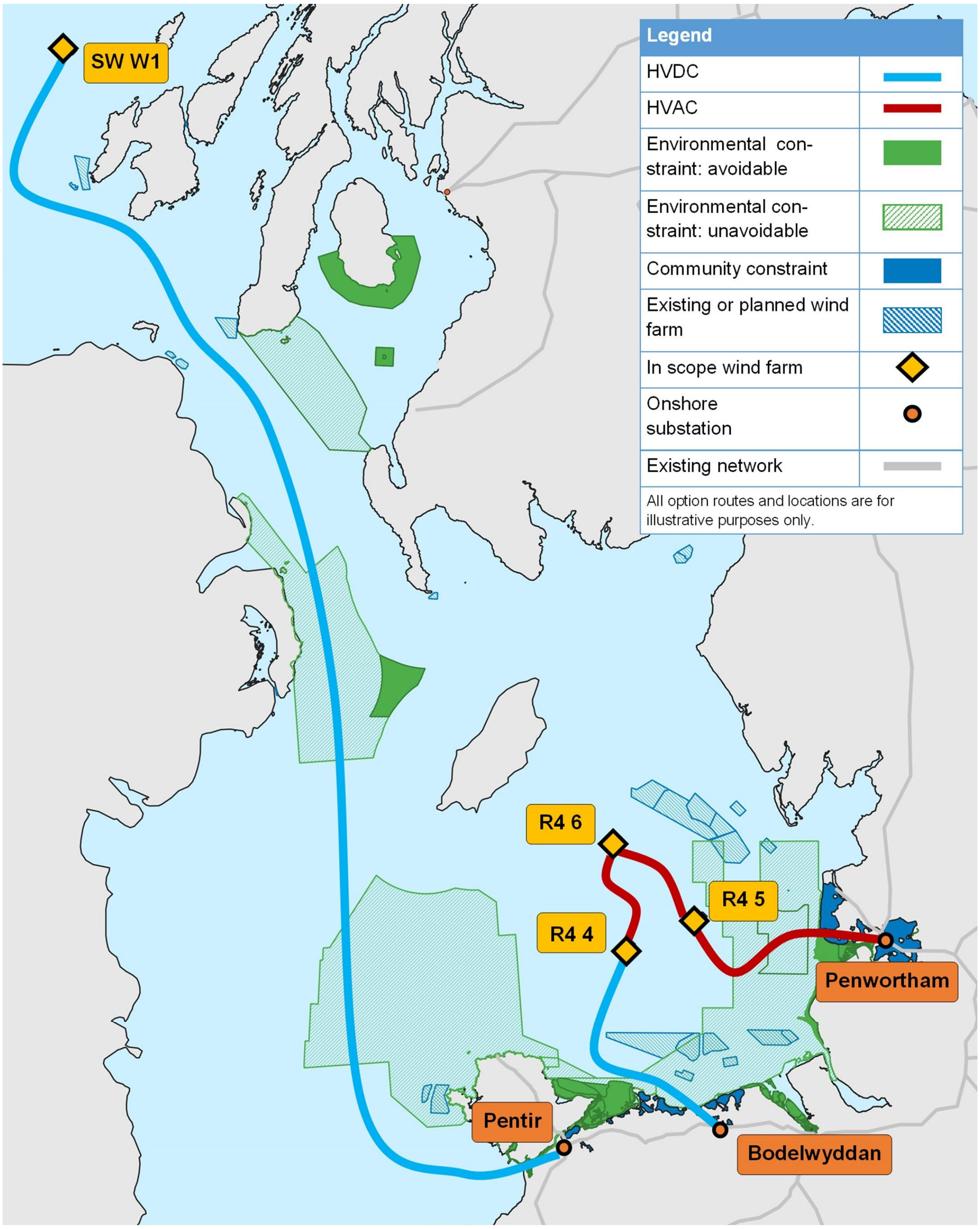
5.1.11 Other offshore designs and variations we considered

As part of the HND process, several design options were considered. This section summarises alternative designs that were not selected for the HND. For the North West Region, two alternative options were considered in detail. The chosen design was considered against an alternative coordinated design and the optimised radial design. Several variations of the chosen design were also considered.

5.1.11.1 North West alternative coordinated design

The alternative coordinated design for the North West Region is shown in *Figure 13* below:

Figure 13 - North West alternative design



The alternative coordinated design for the North West is £1080 million more expensive overall than the recommended design. This is mainly due to higher capital costs due to additional infrastructure in the Irish Sea. The costs and scope of onshore boundary reinforcements are broadly comparable between the two designs. These figures were calculated by changing the recommended design in the North West to the alternative coordinated design, but keeping the rest of the offshore design the same as the recommended design.

The alternative coordinated design does not have the link to Hunterston. This would result in higher constraint costs, as the design does not provide additional capacity between mainland Scotland and North Wales to be utilised in the event of low output from SW_W1. However, the alternative coordinated design provides a connection between North Wales and the North West, which would lead to a reduction in constraint costs.

To maintain full controllability of the coordinated arrangement in the Irish Sea, at least one of the links in the ring configuration would need to be HVDC; in this design this is the link from R4_4 to Bodelwyddan. The alternative coordinated design would therefore include more infrastructure in the Irish Sea, which would lead to a significant increase in capital costs, which would only be partly offset by the removal of the T-point and link to Hunterston.

From a deliverability perspective, this option is similar to the chosen design. The deliverability concern is the extremely long HVDC cable from SW_W1 to Pentir. There is also a moderate level of design complexity with the additional connections between offshore wind farms.

The environmental considerations are equivalent to the chosen option. The Liverpool Bay SPA, the Menai Strait and Colwyn Bay SAC and the Ribble and Alt Estuary SPA are all significant constraints. It is not expected to be possible to define route corridors which avoid the Liverpool Bay SPA. Minimising impacts on the Ribble and Alt Estuary SPA will require landfall at Blackpool Airport. Overall, this option is considered heavily constrained in terms of environmental features. Landfall at Blackpool Airport can help avoid significant constraints in the Ribble Estuary. The Menai Strait and Colwyn Bay SAC can be avoided with the southern approach to Pentir.

The community considerations are also equivalent to the chosen option. The significant community constraints include wrecks, scheduled monuments and urban areas. Most of these constraints can be avoided. However, to avoid the urban areas around Blackpool, landfall would be required at Blackpool Airport. The same substations are used as in the chosen design (Penwortham, Pentir and Bodelwyddan) but without Hunterston and the T-point connections from SW_W1.

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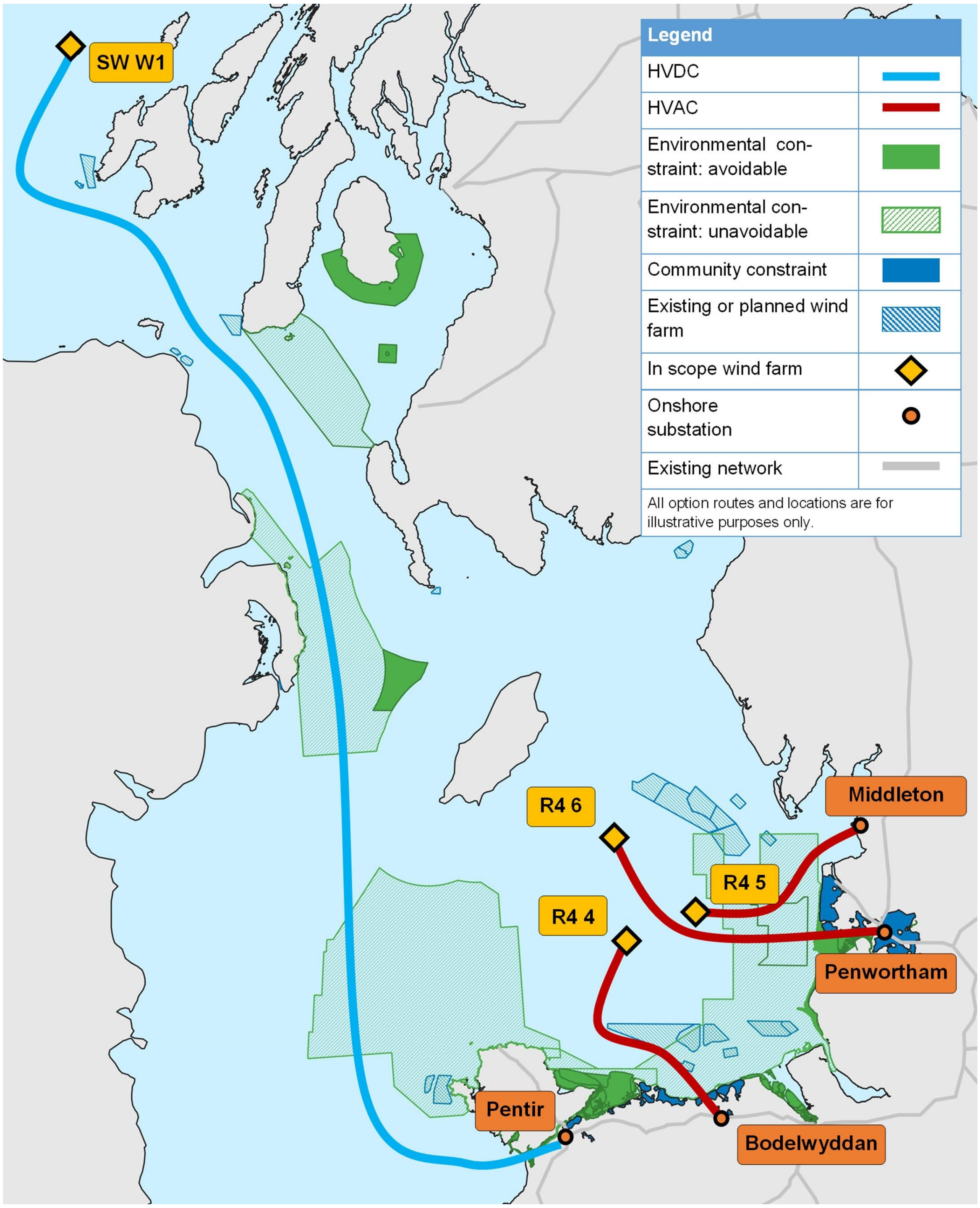
5.1.11.2 North West radial design

The optimised radial design is shown in Figure 14



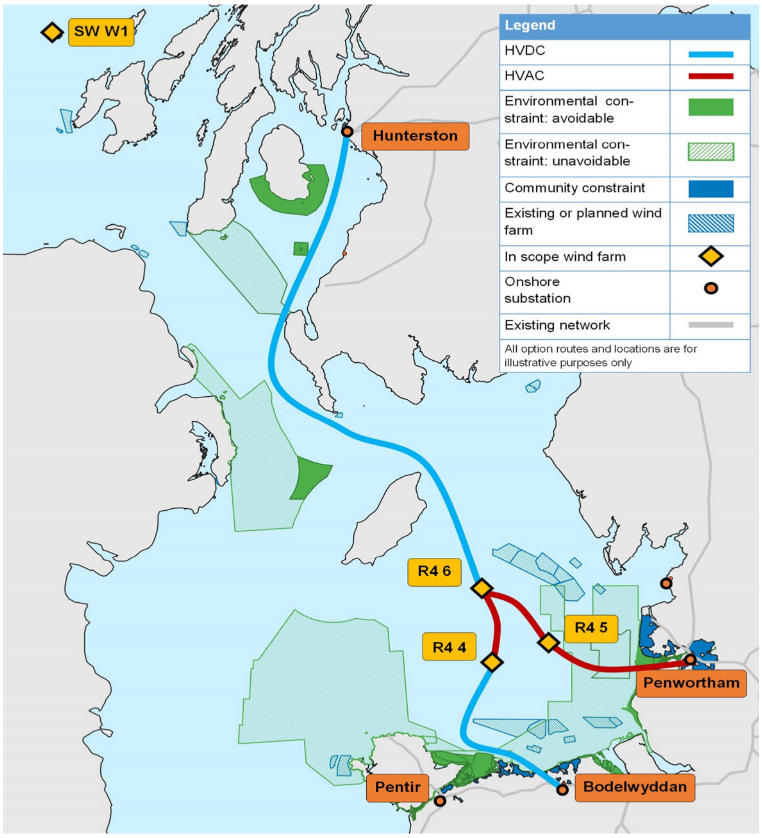
As discussed in section 4.6 Optimised radial design, when all of Great Britain is taken into account, the recommended design performs better than the optimised radial design option from an economic perspective.

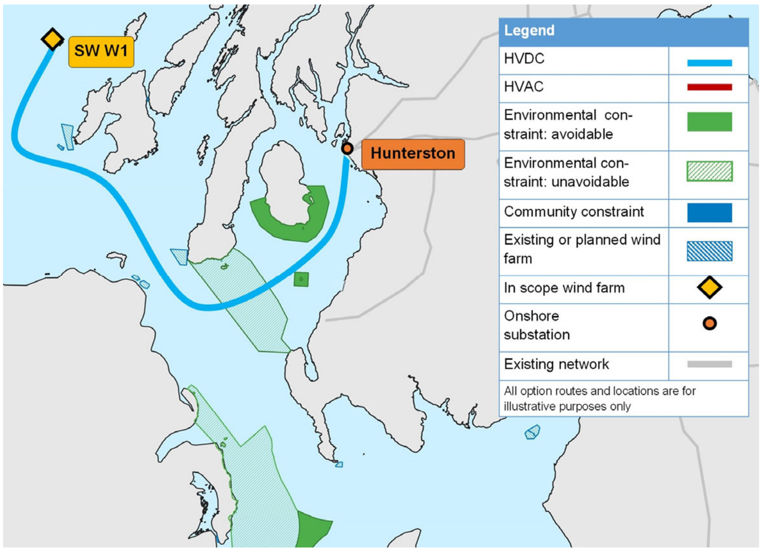
Deliverability, environmental and community considerations for the radial design for each region are discussed further in section 7 Optimised radial design.

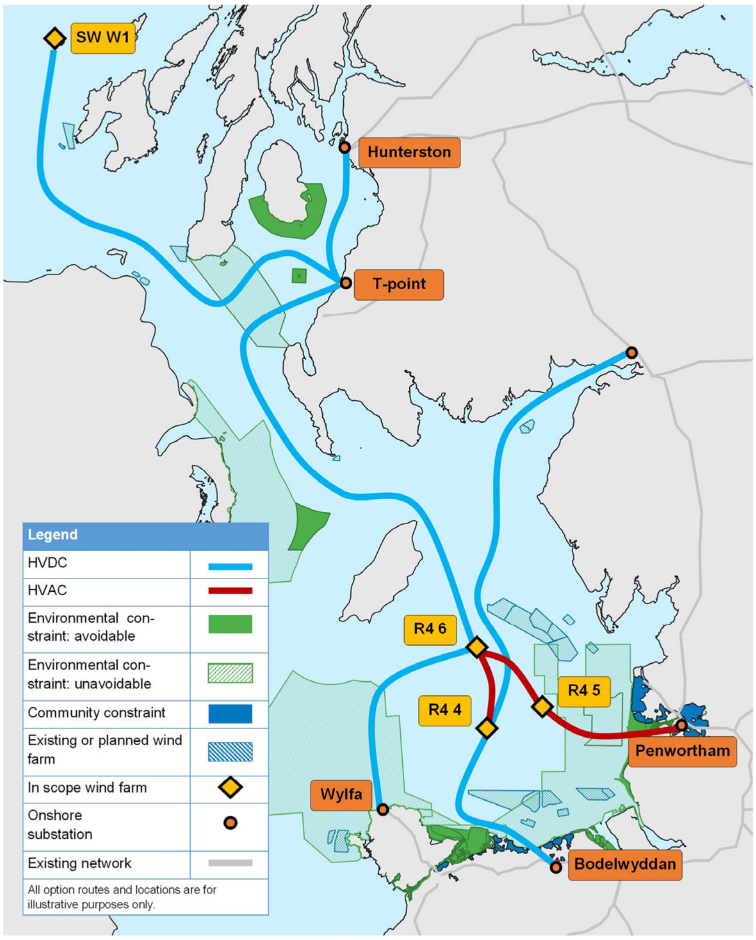
5.1.11.3 Other design options

These options were considered as part of the design process but were not taken forward for detailed consideration. They are included here to demonstrate the range of designs that were assessed.

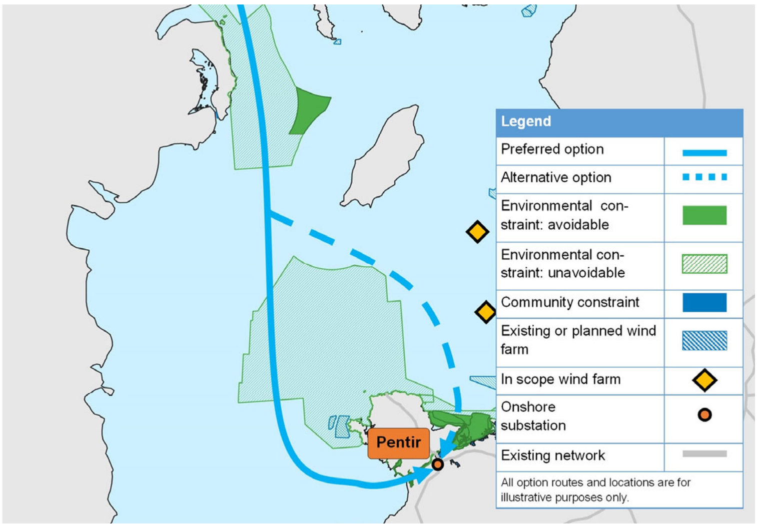
Table 13 - Other options

HVDC link to Irish Sea Ring	
Variation	In this configuration, the Irish Sea wind farms would be interconnected in a ring. R4_4 would be connected to Bodelwyddan via a DC link, and R4_5 to Penwortham via an AC link. R4_6 would be connected to the R4_4 and R4_5 platforms via AC circuits to each platform, and to Hunterston via an HVDC link. To maintain full controllability of the coordinated arrangement, at least one of the links in the ring configuration needs to be HVDC; in this design this is the link to Bodelwyddan. 
Comparison with chosen design	This option was tested to set out a comparison between environment and economic design objectives. By establishing most of the connections offshore, constrained sites such as Pentir could be avoided. However, the additional HVDC infrastructure would lead to a significant increase in capital costs, which would not be outweighed by savings in constraints.
Reason for disregarding	This design was not taken forward as a result of its high capital costs, due to the considerable number of DC circuits. Although DC circuits are needed to maintain full controllability of the coordinated arrangement, they also increase costs and complexity (due to the requirement for additional control systems and converter stations).

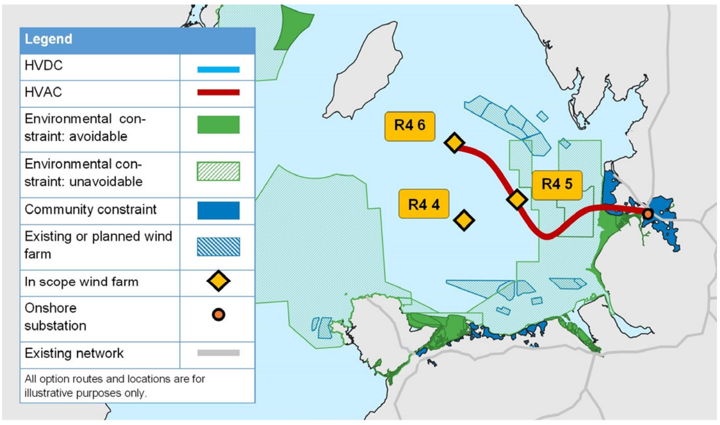
Connecting SW_W1 to Hunterston	
Variation	Within the radial design, a connection of SW_W1 into Hunterston (rather than Pentir) was considered. 
Comparison with chosen design	A connection into Hunterston would lead to higher constraint costs, which would be incurred on the England - Scotland boundary and in the North of England. Within the radial design, the constraint costs associated with a connection to Hunterston would be £8995 million higher than those associated with a connection to Pentir. However, the connection to Hunterston would be significantly shorter, leading to a £1070 million saving in capital costs. From an environmental perspective, both routes would be given an Amber RAG rating if a southerly approach to Pentir is taken, however it is noted that the connection to Pentir is significantly longer. The economic analysis assumes that a southerly approach to Pentir is taken.
Reason for disregarding	This option was not taken forward as it performed less well than the preferred radial design from an economic perspective (it would lead to additional costs of £7925 million).

Double bipole links to Scotland	
Variation	This is a very complex and ambitious coordinated arrangement. The design considers R4_5 connected to Penwortham. R4_4 would be connected via HVDC bipoles to both Bodelwyddan and to Scotland. R4_6 has four connections: to Wylfa via a HVDC bipole, to R4_4 via two AC circuits, to R4_5 via two AC circuits and to SW_W1 as well as Hunterston in Scotland via a multi-terminal HVDC bipole.
	
Comparison with chosen design	This configuration would bring in significant amounts of power to North Wales and would almost certainly require very significant onshore reinforcement.
Reason for disregarding	This design was not taken forward due to its high cost and additional complexity.

Approach to Pentir	
Variation	The recommended design uses an indicative route approaching Pentir from the south. We also considered an alternative route which approaches Pentir from the north. Although route corridors are not defined within the HND, we have sought to use realistic route corridors within our economic analysis.



Comparison with chosen design	For a connection from the T-point to Pentir, an approach from the north would be approximately £50 million less expensive. This is because the route would be approximately 20 km shorter, with 295 km of cable from the T-point to Pentir. However, this route would involve cabling through environmentally sensitive areas around the Menai Strait.
Reason for disregarding	This option would align with some highly constrained areas, including the Menai Strait, which are sensitive to cabling operations. After feedback from stakeholders, this option was deemed to be unsuitable. We have therefore used routes approaching Pentir from the south within our economic analysis (for both radial and coordinated designs).

R4 5 to R4 6 Coordination	
Variation	As part of the design process, we considered electrical coordination between R4_5 and R4_6. 
Comparison with chosen design	This design would include more coordination than the recommended design. In the recommended design the two wind farms share a cable route corridor but there is no electrical connection between them offshore. In this design R4_6 connects directly to an offshore platform at the R4_5 site. The two wind farms would then use a shared export cable to export power to shore, connecting at Penwortham.
Reason for disregarding	This option was proposed as part of the Options Appraisal Summary Tables shared with stakeholders. The R4_5 and R4_6 developers jointly proposed the recommended solution as an alternative to our original proposal. As the developers' proposal performs better from an economic perspective, due to the smaller, simpler offshore platform design, our original proposal was not taken forward. The total number of cables to shore is the same in both designs, and both designs allow for all the cables to use the same corridor.

Connection to Wylfa	
Variation	A connection to Wylfa was considered instead of connecting to Pentir.
Comparison with chosen design	This interface point is technically feasible and has fewer environmental constraints than other sites in the North West.
Reason for disregarding	A connection here would require a new double circuit between Wylfa and Pentir including a new cable tunnel across the Menai Strait. An approach to Pentir from the south was chosen instead to avoid the environmental constraint of the Menai Strait.

5.1.12 Economic and efficient considerations

We have sought to use realistic route lengths within our economic analysis. Within our optimisation, the costs of the links to Pentir (across all options) assume that Pentir is approached from the south as explained in the Environment and Community considerations section below.

The recommended design performs better from an economic perspective than the alternative designs considered. When compared to the alternative coordinated design, section 5.1.10, the recommended design is £1080 million less expensive overall. This is mainly due to lower capital costs as a result of less infrastructure in the Irish Sea. The costs and scope of onshore boundary reinforcements are broadly comparable between the two designs. These figures were calculated by changing the recommended design in the North West to the alternative coordinated design, but keeping the rest of the offshore design the same as the recommended design.

As described in section 4.7, the recommended design also performs better than the optimised radial design from an economic perspective.

5.1.13 Deliverability and operability

The design is partly deliverable by 2030 under current regulatory and consenting frameworks. Although firm connections will not be available until later years in some cases without delivery of the commitments in the *BESS*, the design could be built using a phased approach.

5.1.13.01 HVDC

The design includes a significant volume of HVDC infrastructure and a T-point connection from SW_W1. These connections, and the length of cable required, will take several years to design, manufacture, and commission.

It is estimated that construction of the three-ended HVDC link could take approximately eight to ten years, making delivery before 2030 challenging. The link could be built in stages to enable progressive access to the system ahead of the full link being completed. The responsibility for each section of the link is discussed in an earlier section of this chapter.

5.1.13.02 Overall Complexity

The overall complexity of the recommended design is higher than the radial design, with the three ended HVDC link and the coordinated cable corridor for R4_5 and R4_6. However, the design is partly deliverable by 2030.

Offshore infrastructure for R4_4, R4_5 and R4_6 is expected to be deliverable by 2030.

5.1.13.03 Technical and environmental

There are a number of technical challenges that would need to be overcome as part of this design. There are long HVDC links and offshore cable crossings, pipelines and offshore rock that will likely need to be crossed in several of the route corridors. The landfall areas around Bodelwyddan and Penwortham are constrained due to the large number of cable and offshore rock crossings required in this option, along with landfall constraints.

Avoiding environmental constraints in the Ribble and Alt Estuaries could require cable routing close to Blackpool Airport. Whilst cable routing on or close to the airport should be technically feasible, the impact on airport operations and the feasibility of using the airport land remain to be established.

5.1.14. Onshore works

For this option, all interface point site works can be completed by 2030.

However, some of the works listed for this connection at wider sites have an Earliest In Service Date (EISD) beyond 2030 which include a new onshore transmission circuit. We are working with the TOs to review the programme for these works to understand if they can be accelerated.

5.1.15 Operability

The radial connections of R4_4, R4_5 and R4_6 are not expected to raise any unusual operability issues.

The connection of SW_W1 into to a three-ended HVDC system poses some operability challenges but is like the Shetland connection to the Caithness-Moray HVDC system currently in construction[21].

With the SW_W1 project being larger than the infrequent infeed loss limitation, the HVDC system needs to respect that limit. The design has employed bipole HVDC with metallic return and cable separation to maintain credible infeed to loss to half of the SW_W1 capacity.

The HVDC control system should be set so that under moderate to high wind output, most of the power transfer should be fed into North Wales to reduce north to south power flow limitations on the wider transmission network. Under outage or fault conditions, power flows may need to be directed towards Hunterston instead.

5.1.16 Stakeholder feedback

Stakeholders noted that successful delivery of the coordinated design may depend on which party is responsible for building each part of the design, the date by which each part of the design can be constructed, and the timescales by which this responsibility is known.

Stakeholders raised concerns that the coordinated HND designs required large platforms, leading to complex builds and significant anticipatory investment for some parties (those building additional infrastructure to facilitate a coordinated design), and dependency and risk for other parties (those dependent on this infrastructure to connect).

Stakeholders raised concerns about the northern approach to Pentir that affected the sensitive habitats of the Menai Strait and Colwyn Bay SAC. Taking this into account, an approach to Pentir from the south was developed which was preferable from an environmental and deliverability perspective. Although route corridors will not be defined until the DND stage, we have updated our economic analysis to reflect costs associated with offshore routes which approach Pentir from the south. This does not change our overall recommendation but represents a more feasible route corridor.

Stakeholders felt that the links from Hunterston and Pentir to the T-point provide a wider transmission system benefit, and therefore should be delivered and operated under the appropriate mechanisms for onshore transmission assets. Our assessments to date support this logic. However, this is subject to further analysis by Ofgem.

Following stakeholder feedback, the design for R4_5 and R4_6 was changed from a coordinated design with electrical integration offshore, to radial connections with a shared cable corridor. The connections would share a land substation site, landfall, and cable corridors. The developers had proposed this solution as an alternative to our proposed coordinated design. We evaluated the developers' proposal in comparison to our original proposal and found that it performs better from an economic perspective, as the simpler offshore platform designs reduce the infrastructure costs.

[21] https://www.ssen-transmission.co.uk/projects/shetland/

5.1.17 Conclusions and next steps

The recommended design connects the four in scope generators to the transmission network.

As envisaged by Ofgem, further analysis on the primary function of each asset will be needed to confirm who is responsible for each part of the coordinated design.

The recommended design is **economic and efficient**, offering savings of £1080 million compared with the alternative coordinated design due to lower capital costs. When looking at the whole of Great Britain, the recommended design is also more economic and efficient than the optimised radial design. In comparison to the optimised radial design, the recommended design has higher costs for connecting and operating the transmission network infrastructure needed to connect the wind farms. However, the design of the SW_W1 connection and T-point will provide a wider network benefit, delivering savings in constraint costs by transferring additional power from north to south and bypassing onshore boundary constraints.

The design is **partly deliverable by 2030** under current regulatory and consenting frameworks. Firm connections will not be available until later years in some cases without delivery of the commitments in the British Energy Security Strategy (*BESS*). However, the design could be built using a phased approach.

The design includes a significant volume of HVDC cables, and it will be challenging to deliver the full three-ended HVDC link by 2030. Additionally, some of the required reinforcement works currently have dates which extend beyond 2030. We are working with the relevant TOs to review the programme for these works in light of the commitments in the *BESS*. The timings and required works for each connection will be determined as part of the connection offer update programme.

The design minimises **the impact on the environment**. It is expected to be possible to define route corridors which avoid many important environmental constraints. Whilst it is not expected to be possible to avoid all environmental constraints, this design performs better than the alternative radial design by introducing a shared cable corridor to Penwortham and avoiding the Morecambe Bay SAC.

The **design minimises local community impact**. The community sensitivities in the region can either be avoided or mitigated successfully. It is expected to be possible to define route corridors that avoids key community sensitivities in the region. The recommended design for the Irish Sea provides community benefits over the radial design by reducing the number of cable corridors, which will reduce community impact from construction activities.

On all four of the design objectives this design performs as well, if not better than, the alternative designs considered. It balances the design objectives successfully to provide an efficient holistic design.

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5.2 South West Region

For the South West Region, it would be premature to propose a finalised design before more certainty of the Celtic Sea leasing round is known. For the purposes of this study, 1 GW of Celtic Sea floating wind has been assumed, split into three wind farms. This assumption was based on the ambitions for the region at the time that the scope for the HND was defined, as well as the size of projects that were being developed.

The design presented here is not the final design for the Celtic Sea. The design will be updated once more detail is known about the capacity and location of seabed leases in the Celtic Sea.

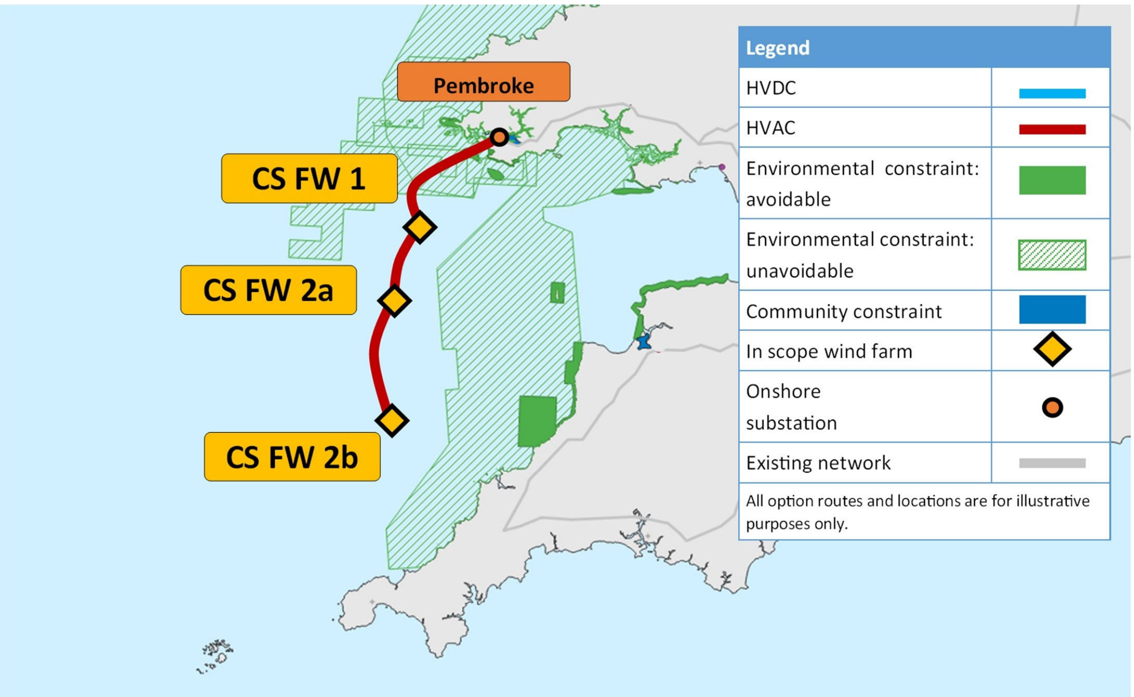
5.2.1 Projects in scope

The South West Region design connects the following three projects *Table 14*:

Project name	Capacity (MW)	Notes
CS_FW_1	300	The Celtic Sea projects included here do not relate to specific projects but are assumed based on the ambitions for the region.
CS_FW_2a	300	
CS_FW_2b	400	

5.2.2 Offshore design

Based on the locations assumed for those wind farms, the indicative recommended design connects all three Celtic Sea wind farms in a double circuit AC chain to Pembroke. This is shown in *Figure 15:*



This is our indicative recommended design for the region based on these assumed wind farm locations and sizes.

Due to the uncertain locations of the wind farms, as well as the likelihood that there will now be much more than 1 GW of wind in the area, these results are largely given for information and interest, and it is our intention to not give a firm recommendation on the best overall solution until a more accurate view of the wind farms in the area can be agreed upon and studied in a future process.

The design connects all three Celtic Sea wind farms in an AC chain to Pembroke. Each link in the chain would consist of two electrically separable circuits, with each circuit being capable of carrying half of the overall capacity needed on that link.

Our choice of cable technology (HVDC or High Voltage Alternating Current (HVAC)) in this document has been made in the first instance on the optimal economic design solution based on our assumptions as set out in the Network design guideline and network overview section. The choice between AC and DC cabling becomes less clear cut in the upper length range for AC cables (150-200 km) and will depend on other project specific factors, including environmental, technical and community constraints. The final choice of technology will be made as part of the DND phase.

The connections used in the design are described in *Table 15*:

Node 1	Node 2	Circuit capacity (MW)	Technology[22]	Distance (km)[23]
CS_FW_1	Pembroke	1000	**AC** 2-3 cables	45
CS_FW_2a	CS_FW_1	700	**AC** 2 cables	35
CS_FW_2b	CS_FW_2a	400	**AC** 1-2 cables	45

5.2.3 Onshore works

The onshore works required at Pembroke include extending the substation and replacing the circuit breakers *Table 16*.

Substation	Work required
Pembroke	Extension of the current Pembroke 400 kV substation to create a new Gas Insulated Switchgear (GIS) compound including bays for connection to the offshore network.

Further onshore works include turning in circuits, uprating circuits and installing Static Synchronous Series Compensators (SSSC) to manage power flow.

The design requires works at other sites including uprating, reconductoring and reinforcement. Wider onshore works are described in the system-wide view section 5.5

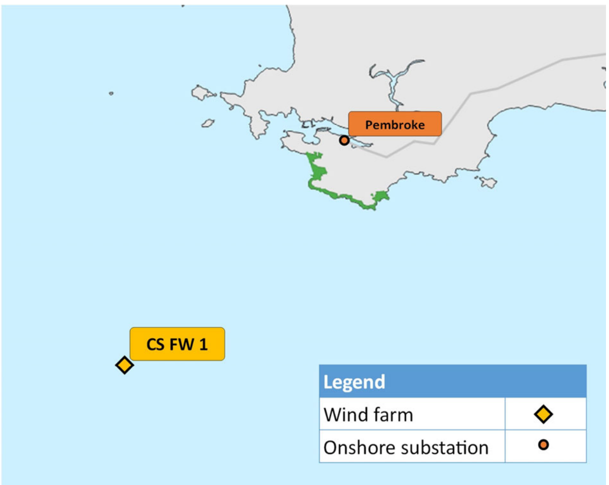
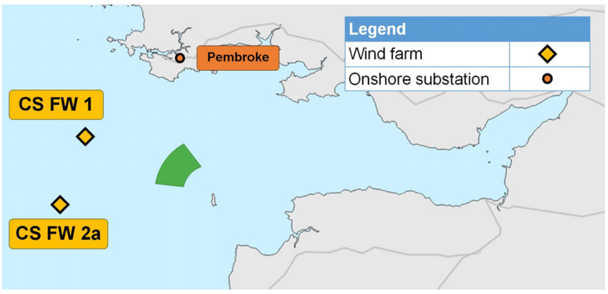
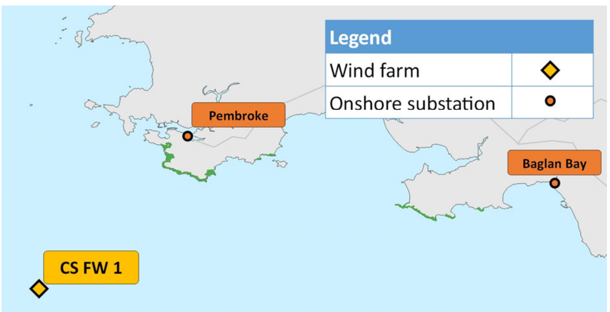
Pembroke, the proposed interface point for the South West region coordinated design, has been identified as a very constrained site, and not all constraints can be avoided. However, given the geographical location of the wind farms considered in the HND, it lends itself to being a good connection point against the other design criteria. In further iterations of the HND, consideration will be required as to whether on balance this site remains a good connection location.

Although route corridors are not defined at this stage of the process, the HND has been developed with a view to avoiding the most significant environmental and community constraints. These include constraints with features expected to be sensitive to impacts from cabling or infrastructure where the risks of cabling would be significant.

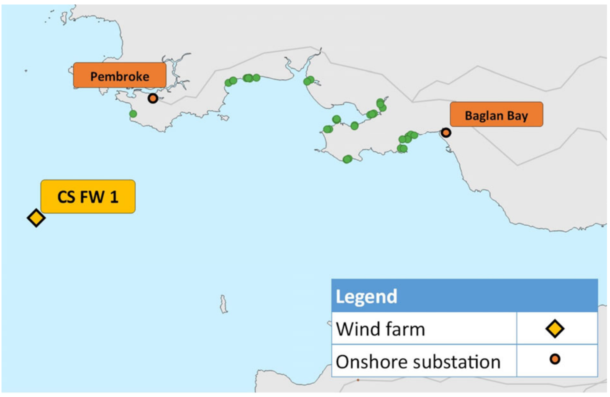
[22] AC cable numbers assume 500 MW is possible at 275 kV. Longer distances may require an additional parallel cable to account for reactive power losses.
[23] The distances shown relate to an indicative route. Route corridors will be determined as part of the DND process.

Table 17 lists the significant constraints which it has been possible to avoid in the HND within the region. As in the regional overview, avoidable constraints are shown in solid fill whereas unavoidable constraints are cross hatched.

Table 17 - Environment and community constraints:

Constraint	Map	Description
Constraint 2		**Castlemartin Coast SPA** The SPA is designated for its breeding population of red-billed chough which makes up 3.5% of the Great Britain breeding population. There is potential to avoid the SPA in approaches to Pembroke.
Constraint 3		**Northwest of Lundy MCZ** The northwest of Lundy MCZ is an inshore site that covers an area of 173 km^2, 15 km northwest of Lundy. It is located in the Western Channel and Celtic Sea Region. The northwest of Lundy site contains a large area of subtidal coarse sediment which provides habitat that supports a variety of species, for example Segmented Bristle worms, Venus clams and small crustaceans (such as crabs and barnacles) living within and on top of the sediment.
Constraint 4		**Limestone coast of Southwest Wales** The Limestone Coast of Southwest Wales is designated for its vegetated sea cliffs and fixed coastal dunes with herbaceous vegetation.

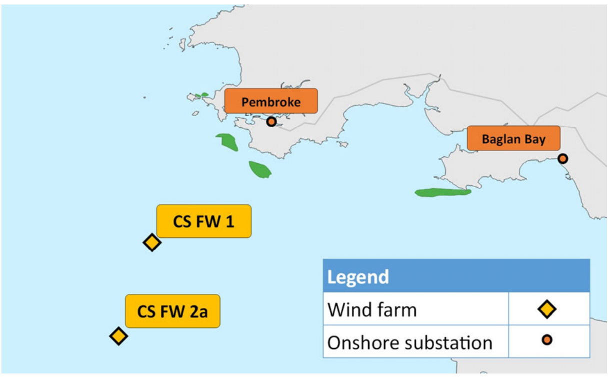
Constraint 6



Peat and clay exposures

This habitat on the South Wales coastline includes littoral and sublittoral examples of peat and clay exposures, both of which are soft enough to allow them to be bored by a variety of piddocks. It has been identified by NRW as key considerations for cabling activities.

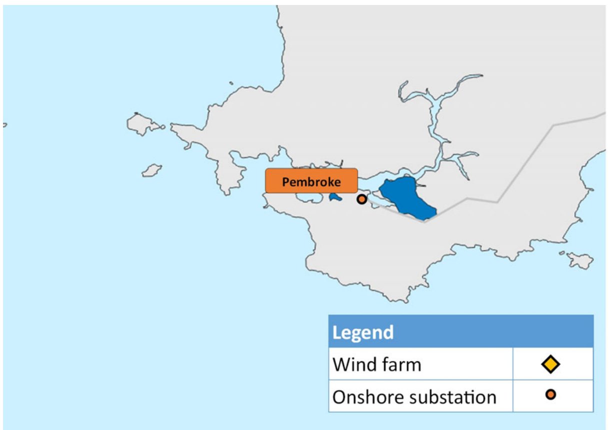
Constraint 7



Sandbanks

Sandbanks of South Wales, which are slightly covered by sea water all the time, consist of sandy sediments that are permanently covered by shallow sea water, typically at depths of less than 20 m. The diversity and types of community associated with this habitat are determined particularly by sediment type together with a variety of other physical, chemical and hydrographic factors. They have been identified by NRW as key considerations for cabling activities.

Constraint 9



Rhoscrowther and Milford Haven

The urban areas of Rhoscrowther and Milford Haven are located within the vicinity of Pembroke substation.

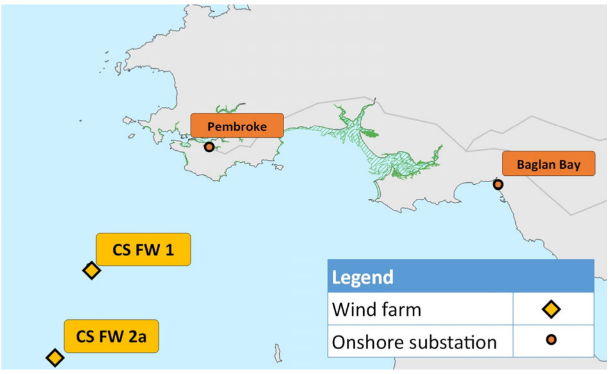
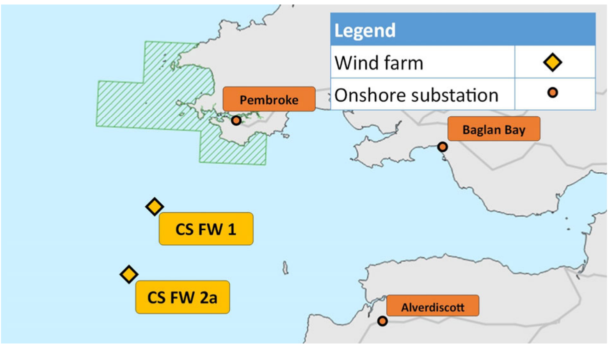
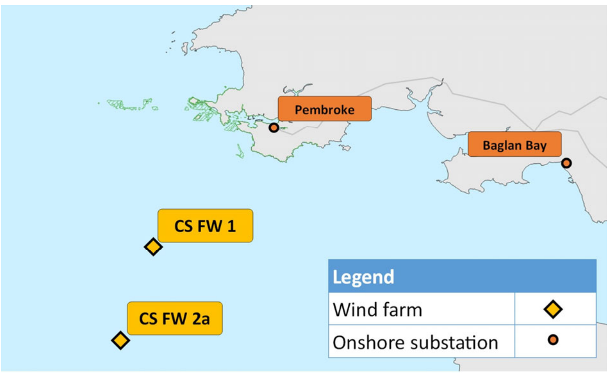
5.2.4.01 Unavoidable environmental constraints

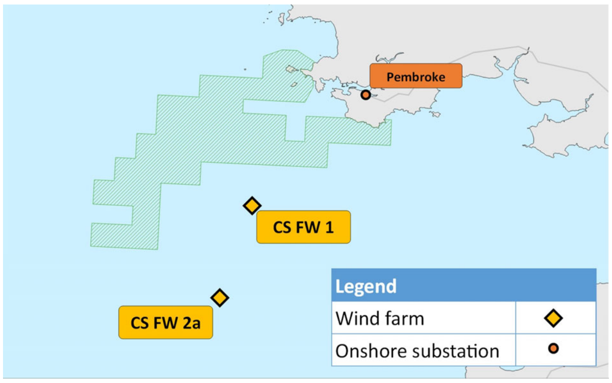
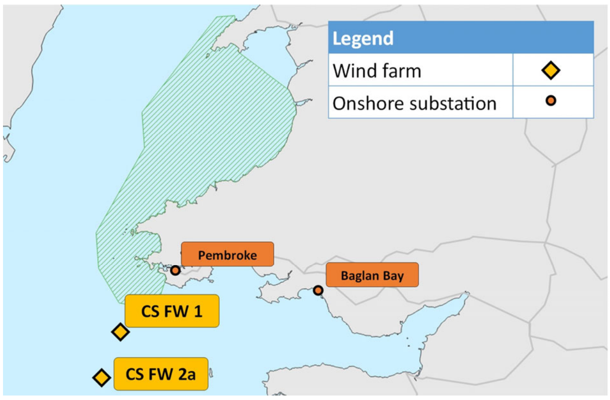
There are some environmental constraints which cover extensive areas or are close to the point of the subsea cables making landfall that are unavoidable due to the locations of wind farms and onshore substations. *Table 18* lists the significant constraints that it is not possible to avoid in the region.

At this strategic route selection stage, the primary method of mitigation was to, as far as was possible, avoid features and/or environmental designations that were identified by the relevant statutory bodies as sensitive to cabling operations. In some instances, these environmental or physical features, or infrastructure, formed linear constraints to cable route corridors, that could not feasibly be circumvented. In these cases, consideration was given as to whether these features could be feasibly crossed over (e.g., infrastructure) with physical protection or under by directional drilling (environmental areas).

More detailed site surveys, routing and consideration of mitigation measures will be required at the DND stage to further avoid identified specific sensitivities or features within designated areas that have not been avoided, and to identify appropriate crossing locations and techniques. At the DND stage further mitigation such as limiting the seasonality of working may also be considered to minimise the potential impacts of cable laying operations in areas that are not practical to avoid. Beyond this, compensatory measures may be required at the detailed network design stage to offset identified impacts.

Table 18 - Unavoidable environmental constraints

Constraint	Map	Description
Constraint 10		**Mudflats and sandflats** Intertidal mudflats and sandflats of the South Wales coast are submerged at high tide and exposed at low tide**.** Within this habitat the plant and animal communities present vary according to the type of sediment, its stability and the salinity of the water. They have been identified by NRW as key considerations for cabling activities.
Constraint 12		**Pembrokeshire Marine SAC** The SAC is a multiple interest site that has been selected for the presence of eight marine habitat features and seven species features.
Constraint 13		**Reefs** Reefs are rocky marine habitats or biological concretions that rise from the seabed. They are generally subtidal but may extend as an unbroken transition into the intertidal zone, where they are exposed to the air at low tide. Two main types of reef can be recognised: those where animal and plant communities develop on rock or stable

		boulders and cobbles, and those where structure is created by the animals themselves (biogenic reefs).
Constraint 14		**Skomer, Skokholm and the seas off Pembrokeshire SPA** The SPA is classified for the protection of: European storm-petrel, manx Shearwater, Atlantic puffin, and Lesser Black-backed gull, as well as Red-billed chough, Short-eared owl and breeding seabird assemblage.
Constraint 15		**West Wales Marine SAC** The SAC is identified as an area of importance for Harbour porpoise. This SAC overlaps a number of other SACs including parts of the Pembrokeshire Marine SAC and the Pen Llŷn a'r Sarnau SAC, and encompasses the entire Cardigan Bay SAC.

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5.2.4.02 Unavoidable community constraints

Table 19 lists the significant community constraints that it not expected to be possible to avoid in the region.

The community constraints include offshore wrecks and the Pembrokeshire Coast National Park and National Trails. It is not possible to avoid the National Park and National Trails.

Table 19 - Unavoidable community constraints

Constraint	Map	Description
Constraint 16		**Pembrokeshire National Park** The Pembrokeshire Coast National Park is located along the coastline.

While these tables do not describe all the environmental and community constraints in the South West Region, they provide an overview of the significant constraints that influenced the network design, including constraints that are very close to the interface points and those which have been identified by stakeholders as being particularly sensitive to cabling operations, and thus have significant potential to impact the viability of cable routes through the area. These constraints also highlight the sensitive areas that have been identified as difficult to avoid in designing cable route corridors.

5.2.5 Potential changes to the offshore design

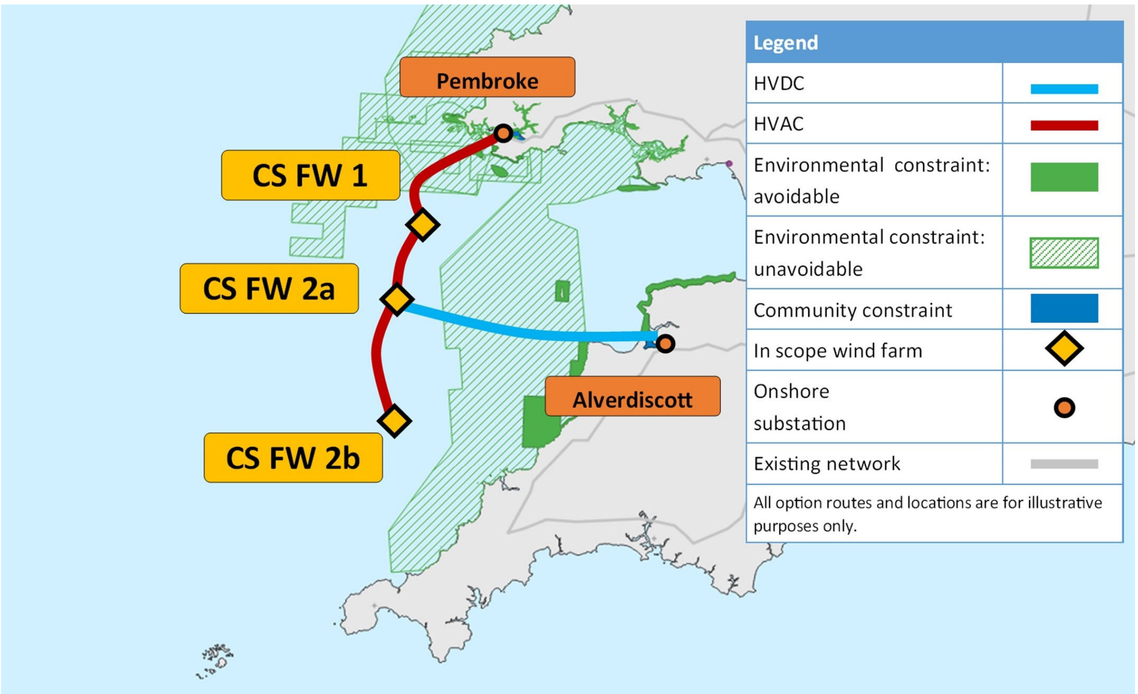
It is important to note that the design shown here for the Celtic Sea is only indicative and will be updated once more detail is known on the capacity and location of seabed leases in the Celtic Sea. A large range of alterations are therefore possible.

5.2.6 Other offshore designs and variations we considered

As part of the HND process, several design options were considered. This section summarises alternative designs that were not selected for the HND. For the South West Region, two alternative options were considered in detail, as well as further design options.

5.2.7 Alternative coordinated design

Figure 16 Alternative coordinated design



This option connects all three wind farms in an AC chain to Pembroke (similarly to the recommended design) and includes a HVDC link from CS_FW_2a to Alverdiscott.

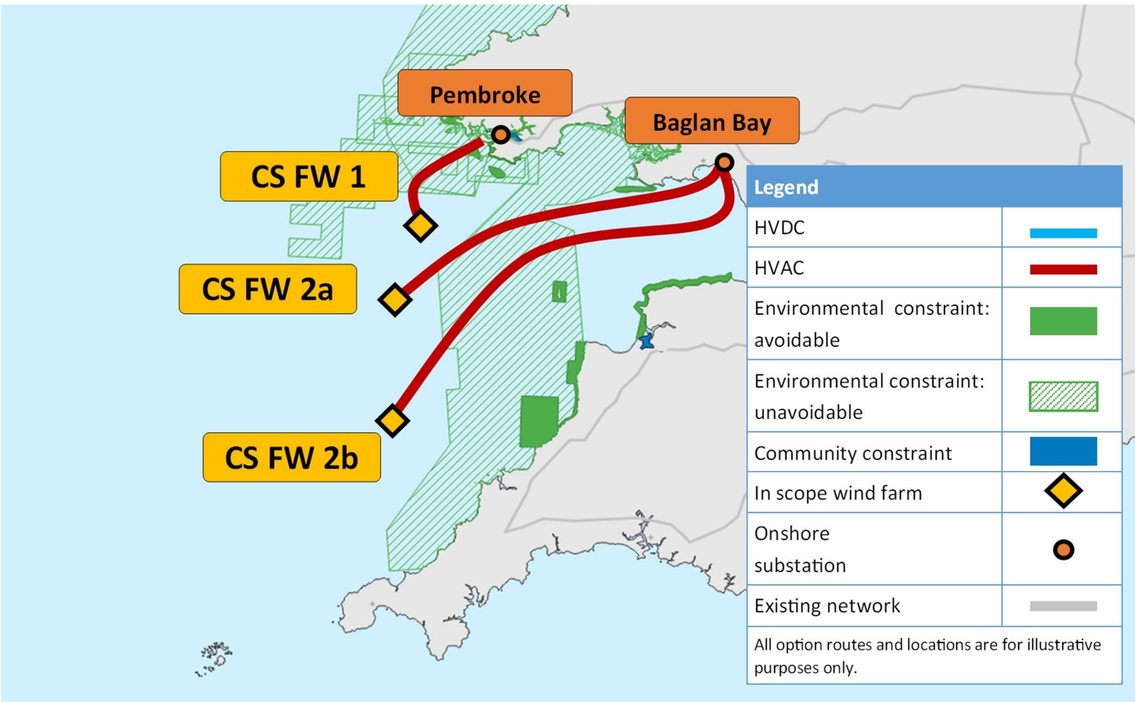
This option would be £735 million more expensive overall. This is due to the £1100 million increase in capital costs, which is larger than the £365 million decrease in constraint costs. The costs and scope of onshore boundary reinforcements are broadly comparable between the two designs. These figures were calculated by changing the recommended design in the South West Region to the alternative coordinated design, but keeping the rest of the offshore design the same as the recommended design.

The alternative design would introduce an extra interface point at Alverdiscott, which would involve crossing areas sensitive to cabling including the Bristol Channel Approaches SAC. There are also Site of Special Scientific Interest (SSSI) designations close to Alverdiscott which it would be difficult to avoid at landfall. There is also potential for cumulative impacts from a converter station due to recent solar farm development in the vicinity of the Alverdiscott substation and other proposed projects. However, the search area for a converter station site can be relatively wide.

The inclusion of a HVDC link within this design would also make it more complex and more challenging to deliver in full by 2030.

5.2.6.2 South West radial design

The optimised radial design is shown in Figure 17



As discussed in section 4.6 Optimised radial design, when all of Great Britain is taken into account, the recommended design performs better than the optimised radial design option from an economic perspective.

Deliverability, environmental and community considerations for the radial design for each region are discussed further in section 7 Optimised radial design.

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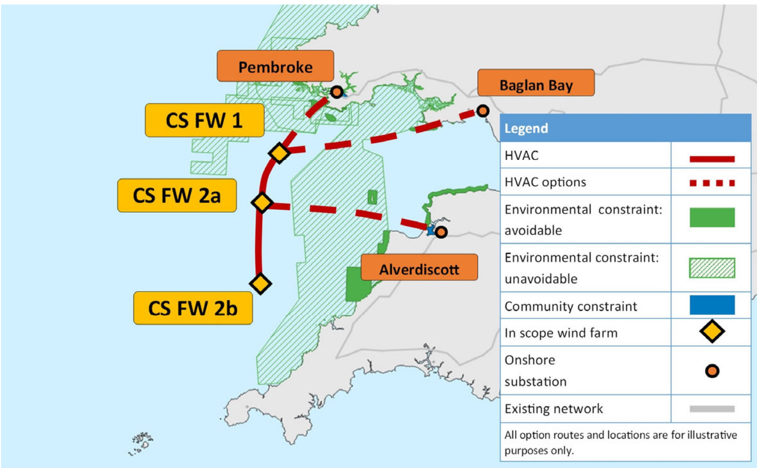
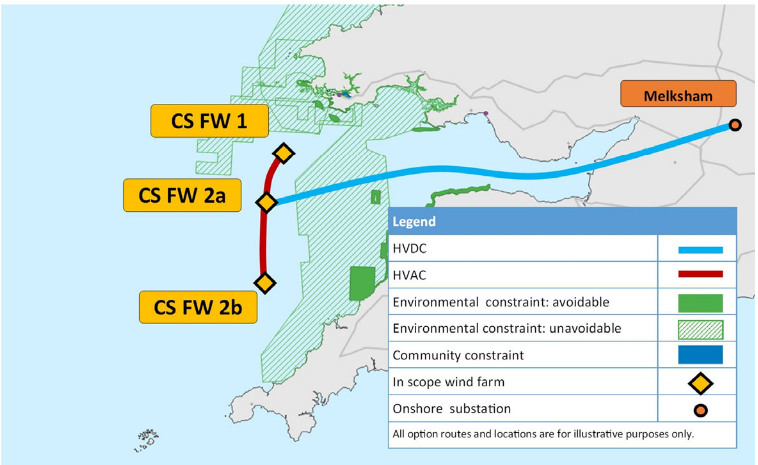
5.2.6.3 Other design options

These options were considered as part of the design process but were not taken forward for detailed consideration. They are included here to demonstrate the range of designs that were assessed.

Table 20 - Other design options

Single Circuit Chain to Pembroke, Alverdiscott or Baglan Bay	
Variation	Similar to the recommended design, but these designs consist of only a single circuit connecting all three wind farms. Each option includes a single connection to shore, either from CS_FW_1 to Pembroke, CS_FW_1 to Baglan Bay or CS_FW_2a to Alverdiscott. 
Comparison with chosen design	These options were considered as likely to be the lowest capital cost way to connect all parties in scope to each onshore substation.
Reason for disregarding	Rejected due to lack of redundancy for the single outage of any circuit.
Double Circuit Chain to Alverdiscott or Baglan Bay	
Variation	These options connect all three wind farms together via double circuits. A double circuit connection is used either from CS_FW_1 to Baglan Bay or from CS_FW_2a to Alverdiscott. The layout of these options is the same as the previous options.
Comparison with chosen design	This was considered as a way to connect all power either to Alverdiscott or Baglan Bay with 50% n-1 redundancy (i.e., maintaining 50% of capacity if one cable fails).
Reason for disregarding	Rejected due to performing less well economically compared to the other options considered, without enough other reasons to promote it.

Single circuit grouping with HVDC link to Melksham	
Variation	Three wind farms connected with a single circuit. HVDC link from CS_FW_2a to Melksham. 
Comparison with chosen design	A HVDC link to Melksham was considered to analyse the impact on constraint costs of taking power out of the South West Region.
Reason for disregarding	Rejected due to lack of redundancy for a single outage of any circuit, and the cost and complexity of introducing a HVDC link which was not outweighed by the savings it delivered.

5.2.7 Economic and Efficient considerations

This design, while only provisional, is recommended based on the assumptions in the South West Region because it has lower total costs than the alternative designs considered.

Compared to the alternative coordinated design, the total costs of the recommended design are £735 million lower. This is due to the recommended design having £1100 million lower capital costs, but £365 million higher constraint costs. The difference in capital costs is due to the HVDC link from CS_FW_2a to Alverdiscott, which is present in the alternative coordinated design but not in the recommended design. The difference in constraint costs is because the alternative coordinated design introduces an offshore connection from South West England to South Wales, which is not present in the recommended design. The costs and scope of onshore boundary reinforcements are broadly comparable between the two designs. These figures were calculated by changing the recommended design in the South West to the alternative coordinated design, but keeping the rest of the offshore design the same as the recommended design.

As described in section 4.7, the recommended design also performs better than the optimised radial design from an economic perspective.

5.2.8 Deliverability and operability

It is expected that the full indicative recommended design for the South West could be constructed by 2030.

5.2.8.1 HVDC

No HVDC technology is included in the indicative recommended design for the South West.

5.2.8.2 Overall complexity

The design is relatively simple, but the additional connections between wind farms would introduce a degree of complexity over the radial design.

5.2.8.3 Technical and environmental

One deliverability risk is the connection into Pembroke. It may not be possible to accommodate the offshore connections into Pembroke as well as other future generation opportunities.

Further deliverability and operability questions will be considered when the Celtic Sea wind projects have been awarded. For example, technical differences with the potential for floating substations will impact the overall deliverability of the offshore network in the region.

5.2.8.4 Onshore works

The design does not trigger requirements for any new circuits beyond those already being considered by the transmission owner, and all the works necessary for this option are deliverable by 2030.

5.2.8.5 Operability

With the offshore wind farms sharing connection assets, the operational planning and management of outages will require additional coordination compared to direct radial connections.

5.2.9 Stakeholder feedback

Since sharing our indicative design recommendations with stakeholders, we have updated our economic analysis to take account of constraint costs in years beyond 2030. This meant that the economically optimal design became the coordinated link to Pembroke, whereas it had previously been the design with a HVDC link from CS_FW_2a to Alverdiscott (now described as the alternative coordinated design).

As this design also performed better from an environmental and community perspective due to the removal of the additional cable route, we updated our indicative recommendation.

5.2.10 Conclusions and next steps

For this iteration of the HND, 1 GW of floating wind has been assumed in the Celtic Sea, split into three windfarms. The indicative recommended design will be updated once further information is known about locations and capacities of wind farms in the Celtic Sea.

The indicative recommended design is **economic and efficient** and offers savings of £735 million over the alternative coordinated design due to lower capital costs. When looking at the whole of Great Britain, the recommended design is also more economic and efficient than the optimised radial design.

The design is expected to be **fully deliverable by 2030**. The recommended design does not trigger any new transmission circuits onshore, and all onshore works are expected to be in service by 2028.

The design **minimises environmental impact** by avoiding constraints where possible, and only using a single interface point. It results in fewer landing points and is expected to result in fewer crossings of environmentally constrained areas compared to the radial counterfactual. Our analysis has identified significant onshore and offshore constraints around the Pembroke site; careful consideration will need to be given to future developments in this location.

The **design seeks to minimise local community impact** as there is potential to define a route which avoids urban areas and other community and heritage features. There are some national parks and trails that cannot be fully avoided: mitigation measures will be considered as part of the DND stage. The coordinated design would lead to fewer interface points than the radial alternative.

5.3 East Coast Region

The East Coast Region covers both the East of England and the East of Scotland.

The significant number of wind farms to connect on the east coast of Great Britain and the requirement to add additional connection capacity between the north and the south, means that the design for this region is complex and involves significant infrastructure.

Our assessment indicates there is clear value in transferring power south through the offshore network from the eastern ScotWind zone, via the developments off the east coast of England. The benefit this provides offsets the additional network costs involved and additional future infrastructure.

5.3.1 Projects in scope

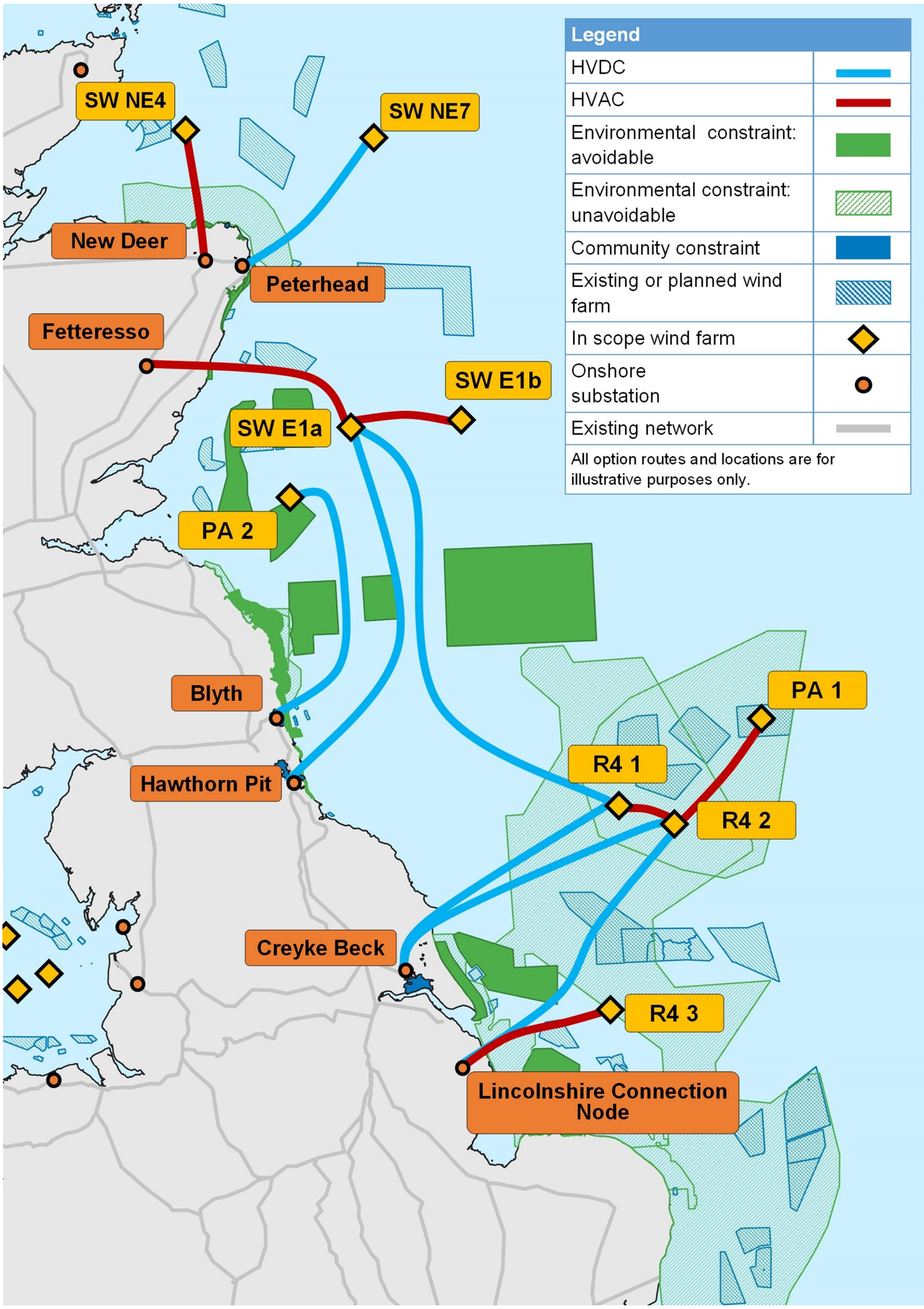
The East Coast Region design connects the following nine projects *Table 21*:

Project name	Capacity (MW)[24]	Notes
R4_1	1500	
R4_2	1500	
R4_3	1500	
PA_1	1320	PA_1 has been included as it is spatially and temporally relevant to the HND process
PA_2	1800	
SW_E1a	1500	This generator has connection contracts for 3000 MW. A capacity of 1500 MW is included in this phase of the HND due to limitations on the total amount of ScotWind generation, but we expect to include its full capacity in the follow up exercise.
SW_E1b	1200	
SW_NE4	1500	This generator has a connection contract for 2000 MW. A capacity of 1500 MW is included in this phase of the HND due to limitations on the total amount of ScotWind generation, but we expect to include its full capacity in the follow up exercise.
SW_NE7	1500	This generator has a connection contract for 3000 MW, currently divided into two stages (1000 MW followed by 2000 MW). The capacity of 1500 MW reflects an alternative staging arrangement which takes account of the developer's intention to use HVDC technology. Only 1500 MW is included in this phase of the HND due to limitations on the total amount of ScotWind generation considered in this phase, but we expect to include its full capacity in the follow up exercise.

[24] The capacities listed here are the capacities that were modelled in the HND. They may not reflect the capacities currently listed in connection contracts or in the ScotWind leasing round.

5.3.2 Offshore design

Our recommended design is shown in Figure 18



The design includes four radial connections:

- SW_NE4 to New Deer
- SW_NE7 to Peterhead

- PA_2 to Blyth
- R4_3 to Lincolnshire Connection Node

The remaining wind farms are connected through a coordinated design. The ScotWind projects, SW_E1b and SW_E1a, have a coordinated connection to Fetteresso with further connections south to Hawthorn Pit and Creyke Beck via R4_1.

PA_1 connects to R4_2 offshore. R4_2 then connects via HVDC links to Creyke Beck and to the Lincolnshire Connection Node via an AC link to R4_1.

Our choice of cable technology (HVDC or High Voltage Alternating Current (HVAC)) in this document has been made in the first instance on the optimal economic design solution based on our assumptions as set out in the Network design guidelines and network overview section. The choice between AC and DC cabling becomes less clear cut in the upper length range for AC cables (150-200 km) and will depend on other project specific factors, including environmental, technical and community constraints. The final choice of technology will be made as part of the DND phase.

The connections used in the design are described in table 22. While these connections represent our current proposal for the design, they may change in further stages of the design process.

Table 22 - Connections table

Node 1	Node 2	Circuit capacity (MW)	Technology[25]		Distance (km)[26]
R4_1	SW_E1a	1800	DC	525 kV XLPE bundled pair	285
R4_1	R4_2	1500	AC	3-4 cables	30
R4_1	Creyke Beck	1800	DC	525 kV XLPE bundled pair	160
R4_2	Creyke Beck	1800	DC	525 kV XLPE bundled pair	180
R4_2	Lincolnshire Connection Node	1800	DC	525 kV XLPE bundled pair	210
R4_2	PA_1	1320	AC	3-4 cables	85
R4_3	Lincolnshire Connection Node*	1500	AC	3-4 cables	105
PA_2	Blyth	1800	DC	525 kV XLPE pair with metallic return	145
SW_E1a	SW_E1b	1200	AC	3-4 cables	80
SW_E1a	Hawthorn Pit	1800	DC	525 kV XLPE bundled pair	225
SW_E1a	Fetteresso	2000	AC	4-5 cables	115

[25] AC cable numbers assume 500 MW is possible at 275 kV. Longer distances may require an additional parallel cable to account for reactive power losses.
[26] The distances shown relate to an indicative route. Route corridors will be determined as part of the DND process.

SW_NE7	Peterhead	1500	**DC**	525 kV XLPE pair with metallic return	135
SW_NE4	New Deer	1500	**AC**	3-4 cables	90

* Note that the choice of the Lincolnshire Connection Node site is not finalised and will be decided after further analysis.

5.3.3 Onshore works

The design requires onshore works at the interface sites (Peterhead, Fetteresso, New Deer, Blyth, Creyke Beck, Lincolnshire Connection Node, Hawthorn Pit) as well as wider sites.

Table 23 – Onshore works

Substation	Work required
Peterhead	Establish a new substation site in the vicinity of the existing Peterhead 400 kV substation including bays for connection to the offshore network and works to connect the new site to the existing substation. The location of the new site is still to be confirmed.
Fetteresso	Establish bays for connection to the offshore network at the existing Fetteresso 400 kV substation.
New Deer	Establish bays for connection to the offshore network at the existing New Deer 400 kV substation.
Blyth	Extension of Blyth 400 kV substation, beyond existing substation boundary to accommodate additional bays and new interbus transformers.
Creyke Beck	Extension of the new Creyke Beck 400 kV substation which is already being planned for other customer connections to provide additional bays for the offshore network.
Lincolnshire Connection Node	Extension of the new Lincolnshire Connection Node 400 kV substation which is already being planned for other customer connections to provide additional bays for the offshore network.
Hawthorn Pit	Extension of the new Hawthorn Pit 400 kV substation which is already being planned for the Eastern Link project to provide additional bay for the offshore network.

The design requires works at other sites including uprating, reconductoring and reinforcement. Wider onshore works are described the system-wide view section 5.5

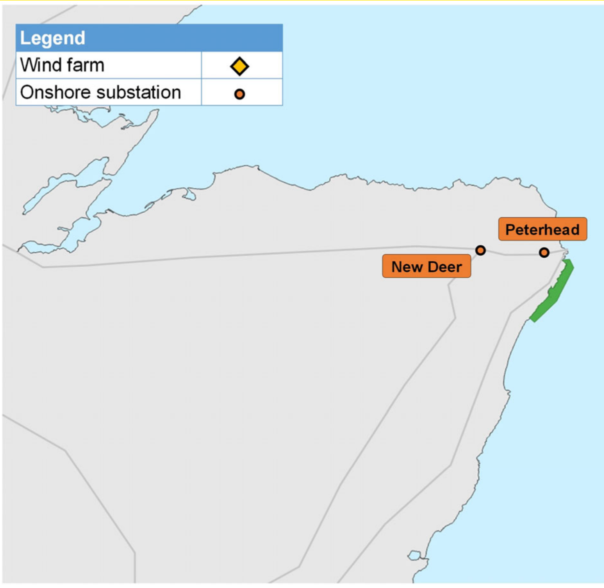
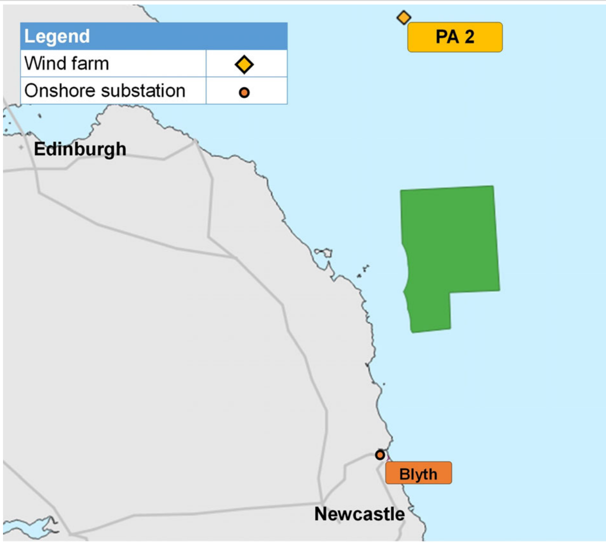
5.3.4 Environment and Community considerations

Both the recommended and radial design options increase the cable route length in the Dogger Bank Special Area of Conservation (SAC), which is unavoidable due to the location of three of the windfarms within the SAC. The recommended design, however, performs worse than the radial design in this aspect. The current layout of the recommended design reduces the number of cables to shore by connecting PA_1 into an offshore hub at R4_2, however, it increases the cable route length in the Dogger Bank SAC. The impact on the SAC could be reduced in the DND stage through careful siting of infrastructure and consideration of cable routing to minimise the impact.

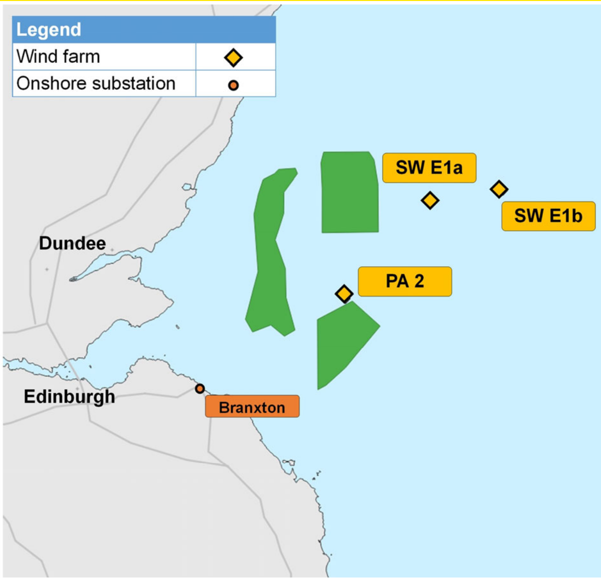
Although route corridors are not defined at this stage of the process, the HND has been developed with a view to avoiding the most significant environmental and community constraints. These include constraints with features expected to be sensitive to impacts from cabling or infrastructure where the risks would be significant.

Table 24 lists the significant constraints which it has been possible to avoid in the HND within the region. As in the regional overview, avoidable constraints are shown in solid fill whereas unavoidable constraints are cross hatched.

Table 24 - Environment and community constraints:

Constraint	Map	Description
Constraint 1		**Buchan Ness to Collieston coast MPA and SPA** The Buchan Ness to Collieston SPA is designated for its vegetated cliff slopes with an abundance of local species such as Scots lovage and roseroot. In several places the cliff edge retains semi-natural plant communities. The indicative route corridors in the design avoid the site but conflicts between cable routing projects to Peterhead might require routes to the south that might affect this SPA.
Constraint 2		**Farnes East MCZ and MPA** The site is designated for its subtidal coarse sediment seabed, subtidal sand and subtidal mixed sediments, with a scattering of small patches of moderate energy circalittoral rock. A glacial trench, which forms the deepest part of the MCZ, contains subtidal mud. There is the potential to avoid the MCZ within the cable route corridors, but avoidance would affect the Berwickshire and North Northumberland coast SAC and/or Northumberland Marine SPA.

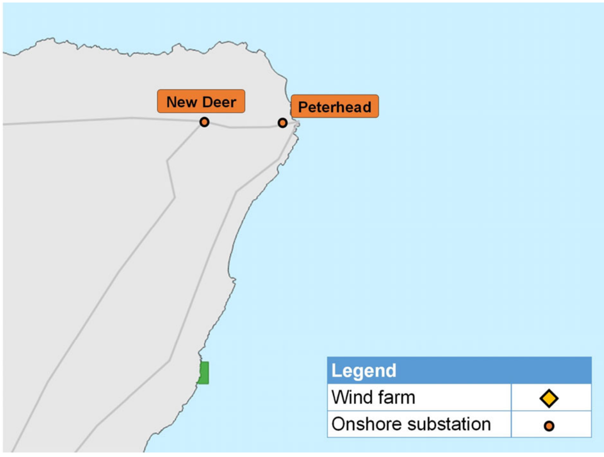
Constraint 3



Firth of Forth Banks Complex MPA

Firth of Forth Banks Complex MPA is designated for its unique mixture of habitats that overlie the underwater banks and for its role in improving our understanding of the history of glaciation. Whilst affected by the radial design, the recommended design has the potential to avoid this MPA.

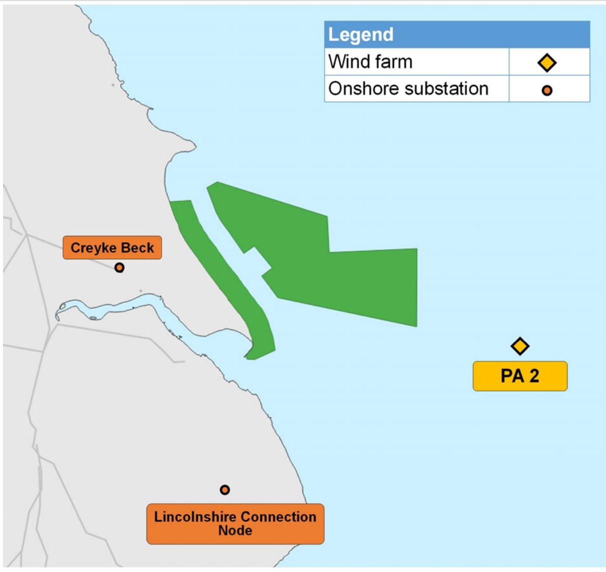
Constraint 4



Fowlsheugh SPA

The Fowlsheugh SPA regularly supports 145,000 seabirds. The site regularly supports populations of European importance of the migratory species: Common guillemot and Black-legged kittiwake and nationally important populations of razorbill, Northern fulmar and Herring gull.

Constraint 5

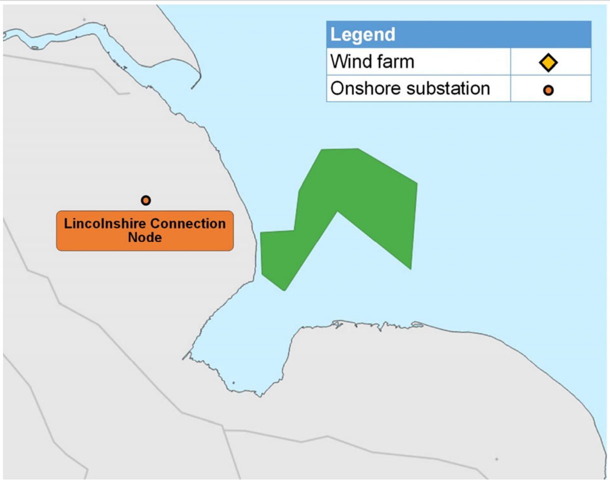


Holderness Inshore and Offshore MCZs

The Holderness Inshore MCZ is designated to protect muds, sands, rock and coarse and mixed sediments to help preserve habitats of various fish species and crustaceans. The site is also designated to protect a geological feature, Spurn Head, which is a unique example of an active split system.

The Holderness Offshore MCZ is designated for the protection of subtidal coarse and mixed sediment, subtidal sand, North Sea glacial tunnel valleys and ocean quahog environments. Both MCZs can be avoided within the approach to Creyke Beck although to do so encroaches on an area of concern to the north known as Smithic Bank. All options for cable routing in this area and the Holderness MCZs will need to be reviewed in the DND.

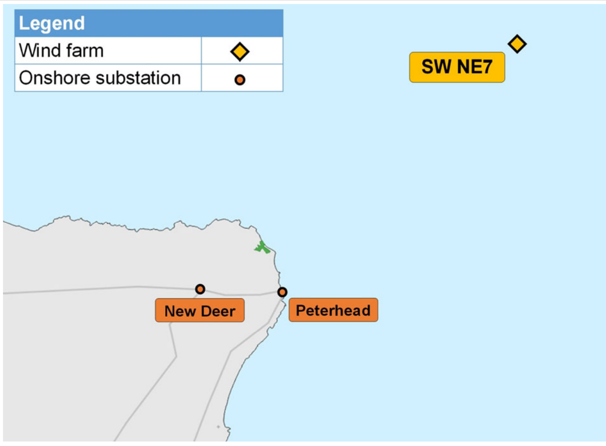
Constraint 6



Inner Dowsing, Race Bank and North Ridge SAC

The Inner Dowsing, Race Bank and North Ridge SAC is designated for its sandbank feature (including subtidal coarse sediment, subtidal mixed sediment, subtidal sand) and subtidal biogenic reefs. Although avoided by the northern route corridor in this part of the HND, this is a long diversion. We acknowledge that routes potentially affecting this SAC will need to be reviewed in the DND.

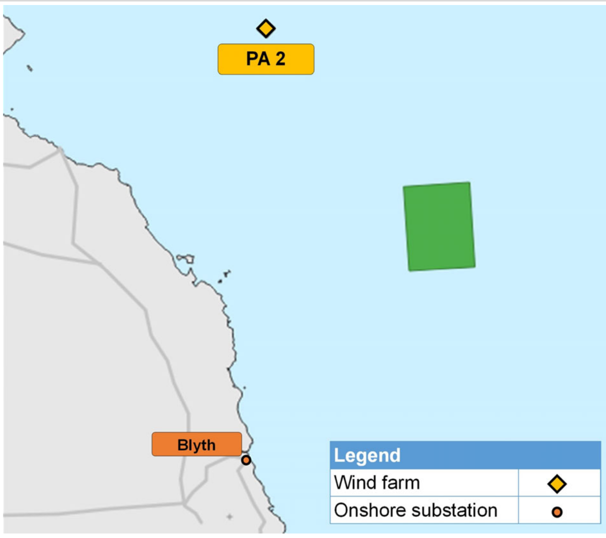
Constraint 7



Loch of Strathbeg SPA

Loch of Strathbeg SPA is composed of a shallow freshwater loch with surrounding wetland, dune and grassland communities. It provides wintering habitat for a number of important wetland bird species, particularly wildfowl.

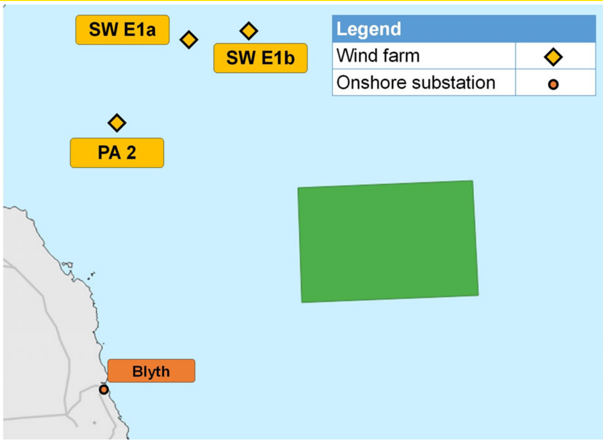
Constraint 8



North east of Farnes Deep MCZ

The site is designated for its habitats. The habitats within the MCZ are relatively stable and support a diverse range of marine flora and fauna such as anemones, worms, molluscs, echinoderms, and fish species.

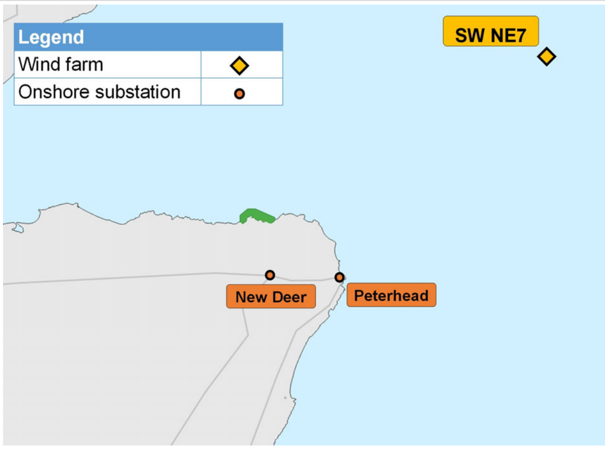
Constraint 9



Swallow Sand MCZ

The Swallow Sand site is low energy, providing a stable sediment habitat supporting a diverse range of marine species including worms, brittlestars, bivalves and gastropods.

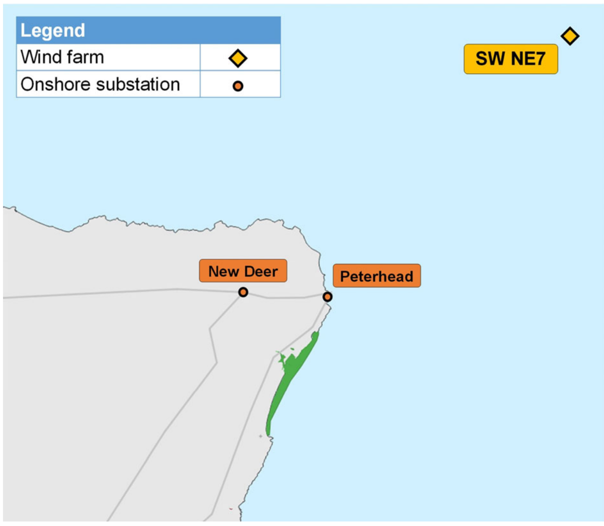
Constraint 10



Troup, Pennan and Lion's Heads SPA

The Troup, Pennan and Lion’s Heads SPA is a 9 km stretch of sea cliffs along the Aberdeenshire coast. The cliffs support large colonies of breeding seabirds, including Fulmar, guillemot, Herring gull, and kittiwake.

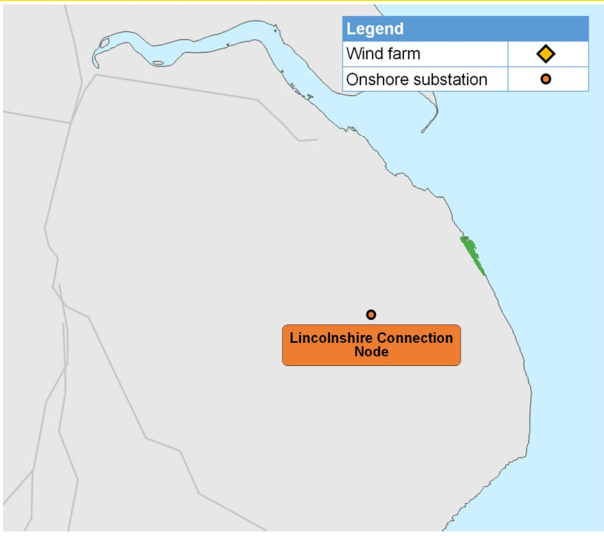
Constraint 11



Ythan Estuary, Sands of Forvie and Meikle Loch SPA

Ythan Estuary, Sands of Forvie and Meikle Loch SPA covers a complex area in the north east of Scotland that contains the long, narrow estuary of the River Ythan, the Sands of Forvie on the east bank of the estuary; the eutrophic Meikle Loch and a marine component covering the area between Aberdeen and Cruden Bay to the north. Ythan Estuary, Sands of Forvie and Meikle Loch SPA is designated for regularly supporting populations of European importance including terns, lapwings, Eider and Redshank.

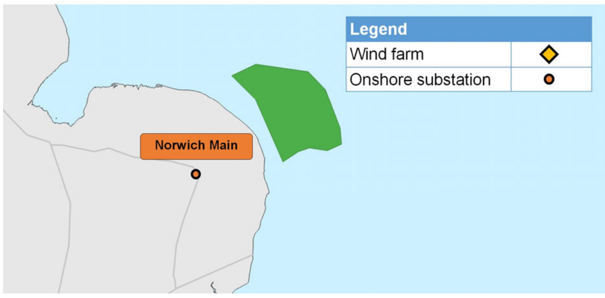
Constraint 12



Saltfleetby- Theddlethorpe Dunes and Gibraltar Point SAC

The site has been designated for its range of dune systems present. These include shifting dunes, fixed dunes, dunes with sea-buckthorn and humid dune slacks.

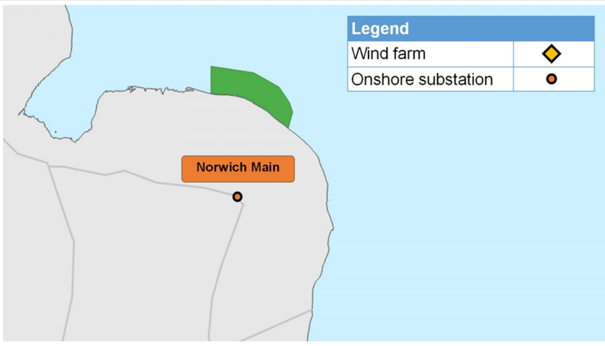
Constraint 13



Haisborough, Hammond and Winterton SAC

The Haisborough, Hammond and Winterton SAC is designated for its sandbanks, which are slightly covered by sea water all the time, for which this is considered to be one of the best areas in the United Kingdom.

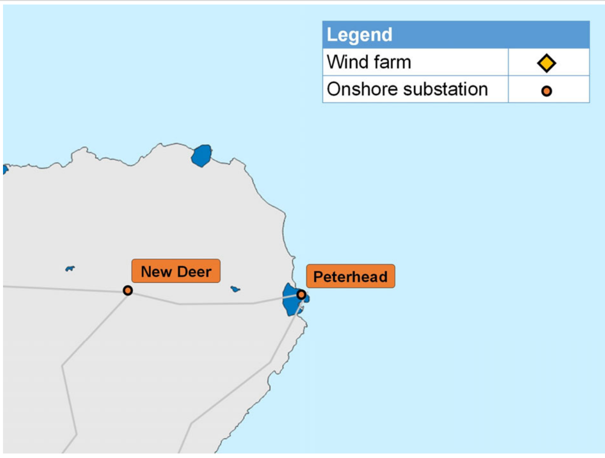
Constraint 14



Cromer Shoal Chalk Beds MCZ

The MCZ protects seaweed dominated infralittoral rock, these rocks in shallow water are an important habitat, providing a home for a variety of small creatures which shelter and feed amongst seaweeds.

Constraint 15



Peterhead and New Deer

Moderate constraints were identified at Peterhead due to the high number of residential properties around the substation. The constraints identified also include potential effects upon the landscape and cultural heritage features (such as Boddam Castle and the designated conservation Area). There are also a number of other cable routing projects proposed that require access to Peterhead.

		Moderate constraints were identified at New Deer and Fetteresso potentially impacting residential areas.
Constraint 15		**East England Settlements** There are settlements in the vicinity of the Blyth, Hawthorn Pit and Creyke Beck substations.

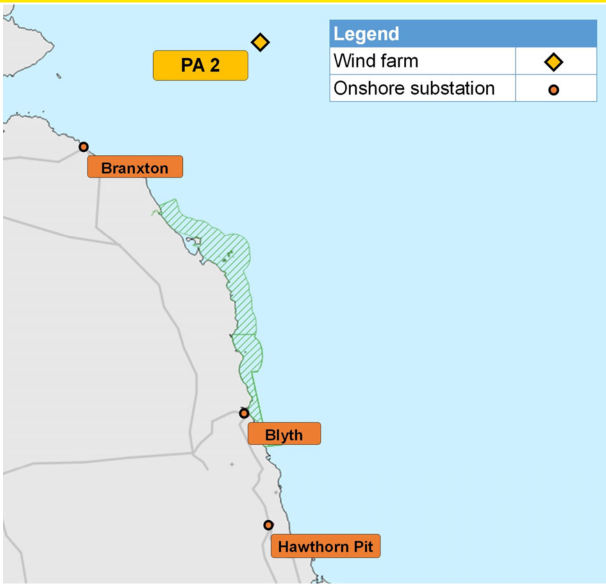
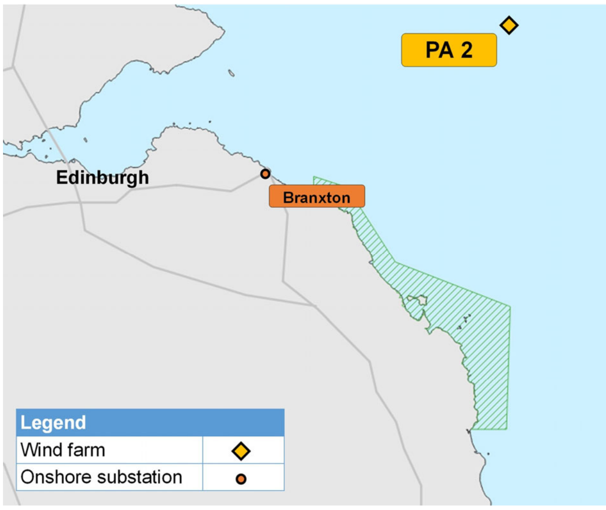
5.3.4.1 Unavoidable environmental constraints

There are some environmental constraints which cover extensive areas or are close to the point of the subsea cables making landfall, which are unavoidable due to the locations of wind farms and onshore substations. *Table 25* lists the significant constraints that it is not possible to avoid in the region.

At this strategic route selection stage, the primary method of mitigation was to, as far as was possible, avoid features and/or environmental designations that were identified by the relevant statutory bodies as sensitive to cabling operations. In some instances, these environmental or physical features, or infrastructure, formed linear constraints to cable route corridors, that could not feasibly be circumvented. In these cases, consideration was given as to whether these features could be feasibly crossed over (e.g., infrastructure) with physical protection, or under by directional drilling (environmental areas).

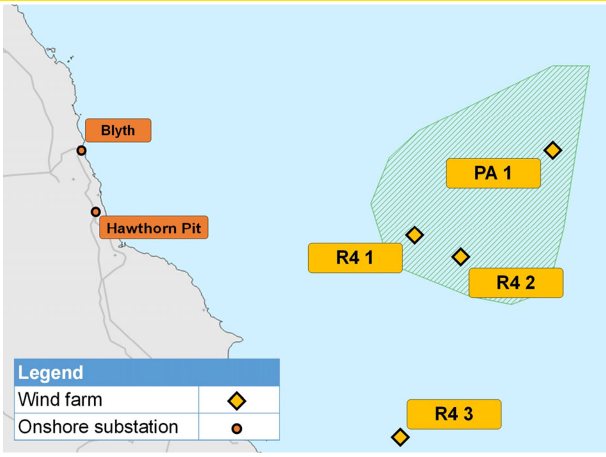
More detailed site surveys, routing and consideration of mitigation measures will be required at the DND stage to further avoid identified specific sensitivities or features within designated areas that have not been avoided, and to identify appropriate crossing locations and techniques. At the detailed design stage further mitigation such as limiting the seasonality of working may also be considered to minimise the potential impacts of cable laying operations in areas that are not practical to avoid. Beyond this, compensatory measures may be required at the DND stage to offset identified impacts.

Table 25 - Unavoidable environmental constraints

Constraint	Map	Description
Constraint 16		**Berwick to St Mary's and Coquet to St Mary's MCZ** The Berwick to St Mary's site is designated for its nationally important numbers of breeding common eider. The area also supports regionally and nationally (England) important numbers of common eider in the non-breeding season. The Coquet to St Mary's site is designated for its several different types of rock and sediment on the shoreline and on the seabed. These habitats and communities support mobile species such as starfish, sea urchins, crabs, and lobsters. The MCZs are directly east of the landfall at Blyth and so cannot be avoided.
Constraint 17		**Berwickshire and North Northumberland Coast SAC** This site is designated for its large shallow inlets and bays; mudflats and sandflats not covered by seawater at low tide (intertidal mudflats and sandflats); reefs; and submerged or partially submerged sea caves. Breeding colonies of grey seals are located in the site.

nationalgridESO

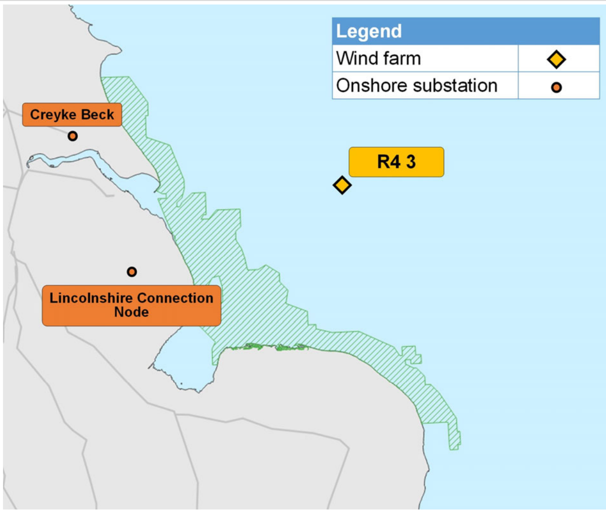
Constraint 18



Dogger Bank SAC

The Dogger Bank is the largest sandbank in UK waters and extends into both Dutch and German waters. It is home to a variety of species which live both on and within the sandy sediment. Potentially affected by a number of route corridors of the recommended design and the features of the SAC are sensitive to cabling operations. As the R4_1, R4_2 and PA_1 offshore generation sites are proposed within the designated area, it is assumed that export cabling would also be required. The locations of offshore platforms and cable routes in the recommended design will need to be reviewed in the DND to minimise cable route lengths in the SAC and/or effects on sensitive features of the SAC.

Constraint 19

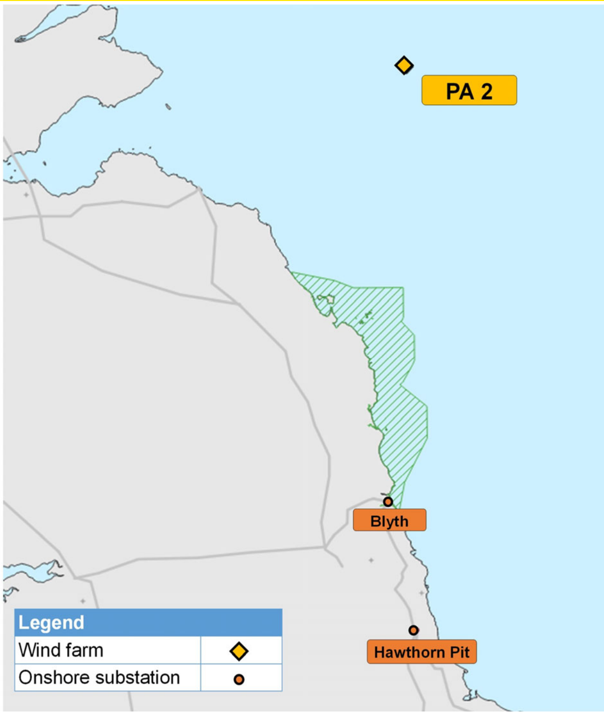


Greater Wash SPA

The Greater Wash SPA is designated for the protection of Red-throated Diver, Common scoter, and Little gull during the non-breeding season, and for breeding Sandwich tern, Common tern and Little tern.

nationalgridESO

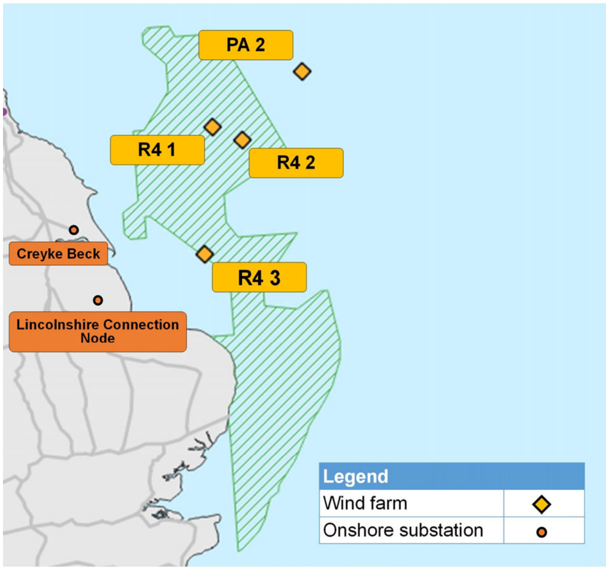
Constraint 20



Northumberland Marine SPA

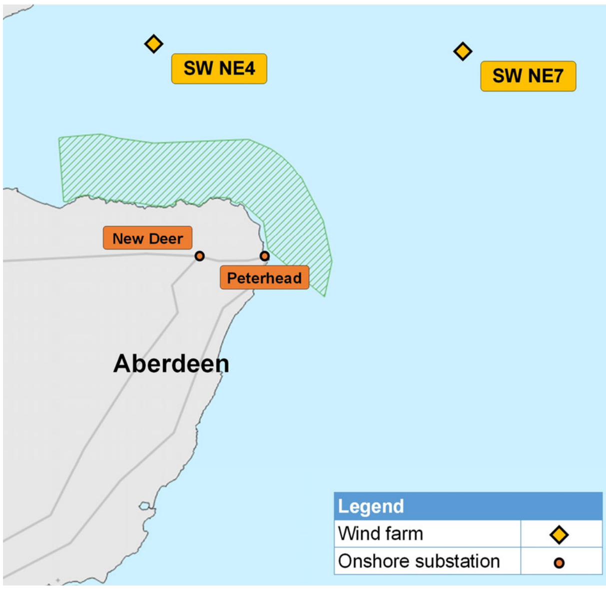
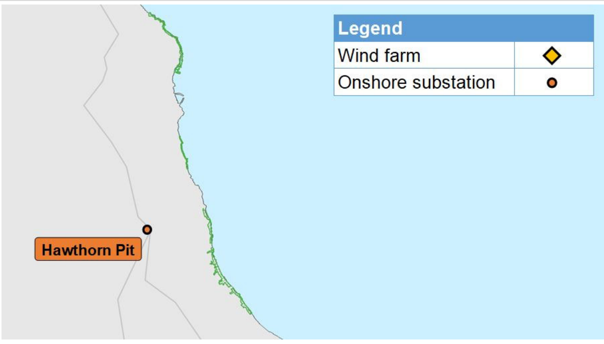
The site is designated for its importance to breeding populations of five species listed in Annex I of the EC Birds Directive.

Constraint 21



Southern North Sea SAC

The Southern North Sea SAC is identified as an area of importance for Harbour porpoise. This site includes key winter and summer habitats for this species. The SAC cannot be avoided. A mix of habitats, such as sandbanks and gravel beds, are included in the site, which overlaps with Dogger Bank SAC.

Constraint 22		**Southern Trench MPA** Cable approaches to New Deer and Peterhead would have to cross this MPA, though the southern trench itself can be avoided.
Constraint 23		**Durham Coast SAC** This site is designated for its unique vegetated sea cliffs on magnesian limestone exposures and is the only example in the UK. The SAC stretches along the coastline for approximately 3 km.

5.3.4.2 Unavoidable community constraints

In addition to the community constraints identified above, the cumulative impact of the continued development of energy infrastructure on coastal communities on the east coast has been identified. This is particularly applicable to Creyke Beck, Peterhead and the Lincolnshire Connection Node.

While these tables do not describe all the environmental and community constraints in the East Coast Region, they provide an overview of the significant constraints that influenced the network design, including constraints that are very close to the interface points and those which have been identified by stakeholders as being particularly sensitive to cabling operations, and thus have significant potential to impact the viability of cable routes through the area. These constraints also highlight the sensitive areas that have been identified as difficult to avoid in designing cable route corridors.

5.3.5 Potential changes to the offshore design

At this stage in the development of the HND it is not possible to detail every aspect of the design. This section outlines the possible alterations that will be considered as part of the detailed network design. For the East Coast Region there is one possible alteration:

One option considered that we will continue to develop, is the design variation where R4_3 connects further in land to a site near Spalding. This removes the dependency on the development of the Lincolnshire Connection Node substation site and the new circuit between south Humber and south Lincolnshire (GWNC[27]). This may provide an opportunity for an earlier connection date and makes connection of R4_3 less dependent on the delivery of GWNC.

The longer cable route in this variation has a higher cost and has an environmental and community impact which needs to be taken into consideration.

However, if an earlier connection can be achieved, there is a potential overall benefit to the consumer. There is therefore an economic case for incurring the additional investment needed for a longer cable route if a connection date can be sufficiently brought forward.

We envisage that a modular approach to offshore platforms in the coordinated East Coast design will aid deliverability and make the design more expandable for future requirements. Deliverability for the East Coast design and possible design variations to aid this is discussed later in this section. This should be considered further as by those undertaking the DND stage.

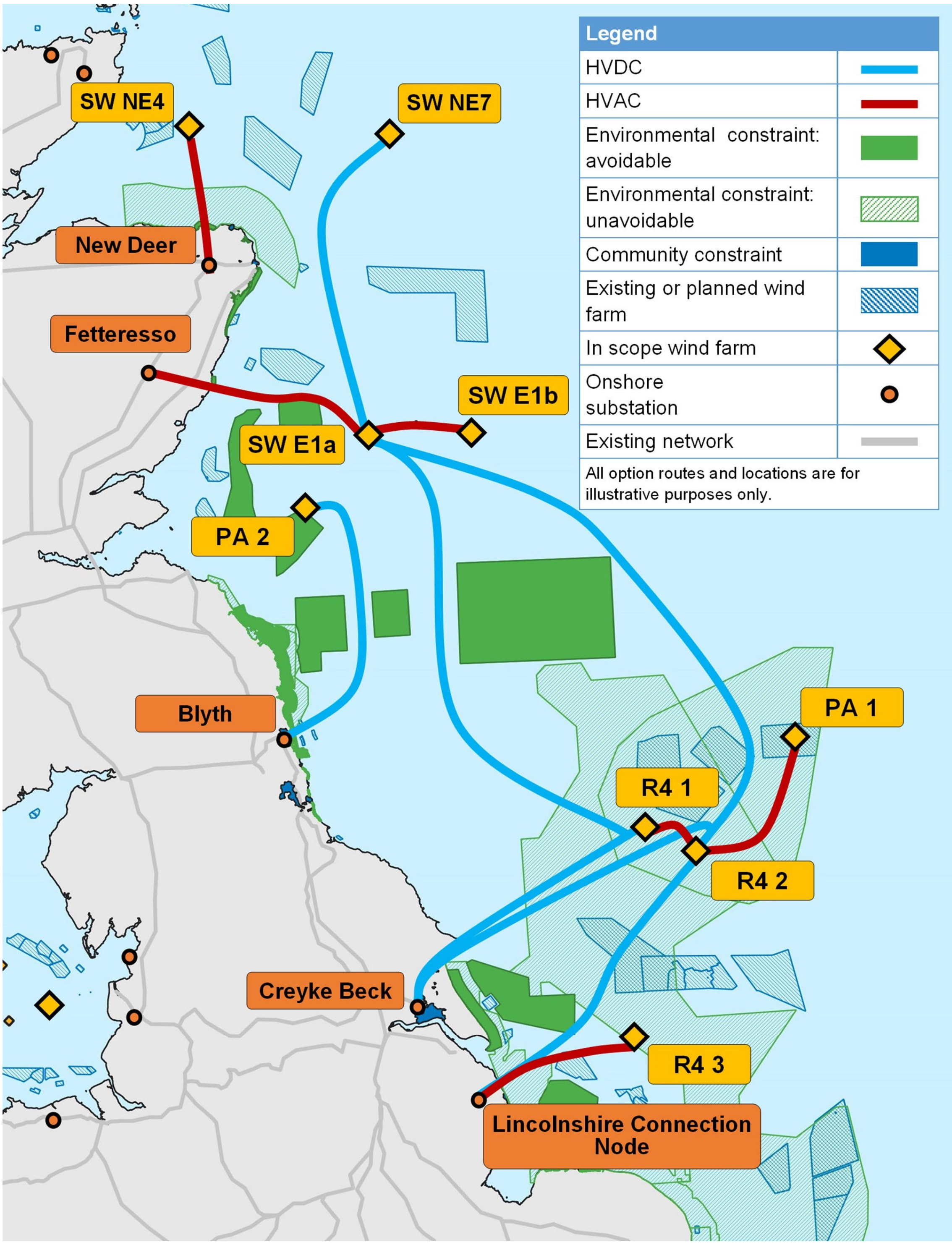
[27] Option GWNC is a new 400 kV double circuit between the south Humber and Lincolnshire areas that has been previously assessed by the NOA process. For further detail please see the *NOA 2021/22 Refresh* publication.

5.3.6 Other offshore designs and variations we considered

As part of the HND process, several design options were considered. This section summarises alternative designs that were not selected for the HND. For the East Coast Region, two alternative options are described in detail: an alternative coordinated design and an optimised radial design.

5.3.7 Alternative coordinated design

The alternative coordinated design is shown in Figure 19



This design uses three radial connections: SW_NE4 to New Deer, PA_2 to Blyth and R4_3 to the Lincolnshire Connection Node.

The other wind farms are connected through a coordinated design. SW_E1b, SW_NE7 and SW_E1a connect to an offshore platform and PA_1 to the R4_2 offshore platform.

The offshore platform(s) in the vicinity of SW_E1a connects to an interface point at Fetteresso. It also connects to R4_1, R4_2 offshore platforms and Creyke Beck through two multi-terminal HVDC links.

Finally, R4_2 connects to the Lincolnshire Connection Node, and also to the to R4_1 offshore platform.

The alternative coordinated design reduces the number of landfall sites but performs worse in terms of economic impact and deliverability.

The alternative coordinated design is less economic and efficient than the recommended design. The alternative coordinated design is £5780 million more expensive overall, with higher capital costs (£3960 million higher) which are mainly due to its additional offshore converter stations. It also has higher constraint costs (£1820 million higher) than the recommended design. The costs and scope of onshore boundary reinforcements are broadly comparable between the two designs. These figures were calculated by changing the recommended design for the East Coast to the alternative coordinated design but keeping the rest of the offshore design the same as the recommended design.

This design also has an additional three-ended HVDC link when compared with the recommended design. This adds complexity and increases the difficulty of delivering the design by 2030.

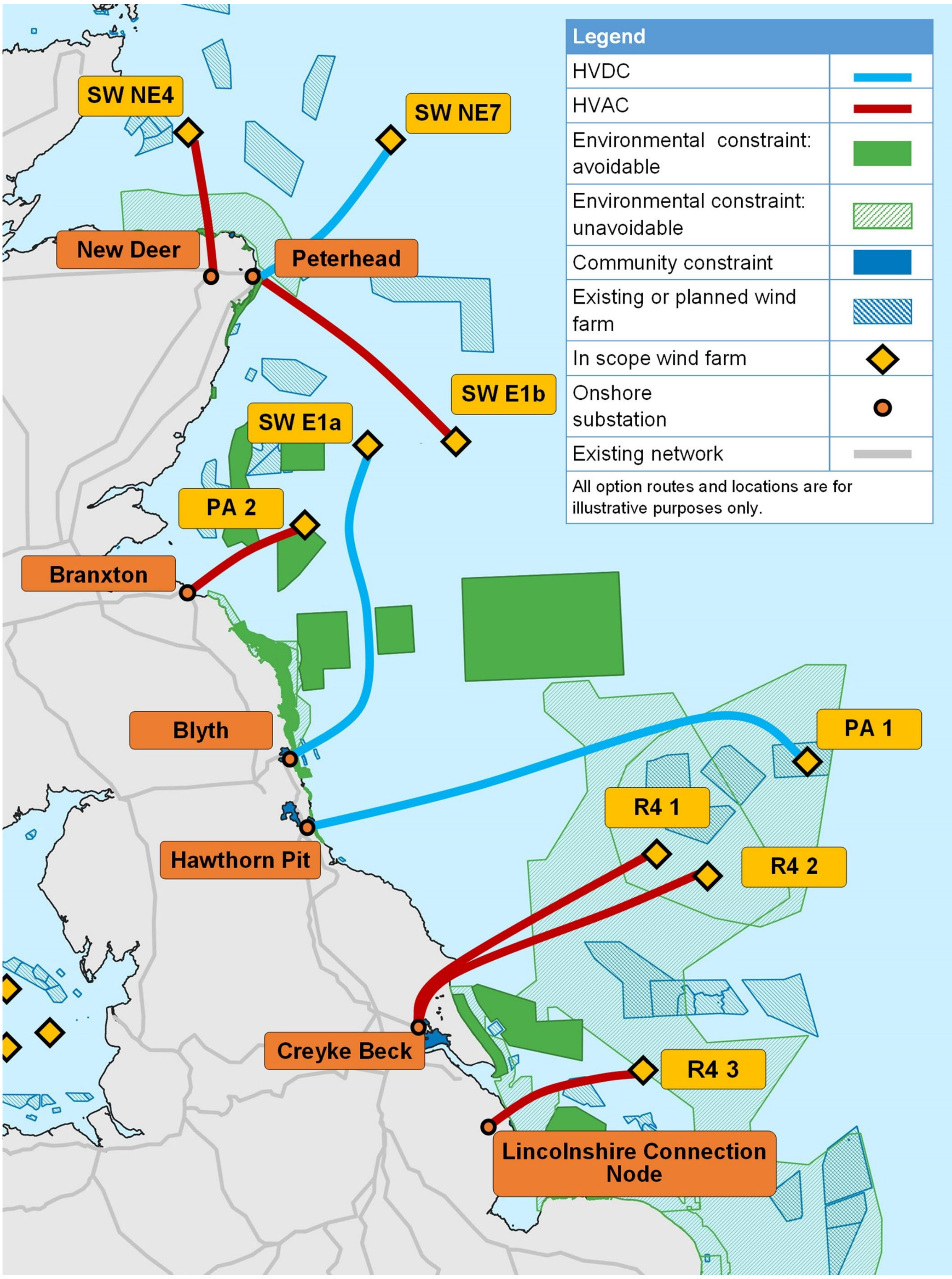
This alternative coordinated design uses fewer connections to shore, with only five onshore interface points compared with seven in the recommended design. This is because there is no interface point at Peterhead or Hawthorn Pit in the alternative coordinated design. The alternative coordinated design therefore performs better from an environmental and community perspective.

The additional multi-terminal HVDC converter station adds additional complexity and cost. Therefore, this option performs worse on economic and deliverability criteria. Although the alternative coordinated design would connect wind from the north east ScotWind Zone into the coordinated network, this does not take account of the full ScotWind capacity which is planned to connect. The option of connecting together the north east and east ScotWind zones will be considered further as part of the follow up design exercise, providing the opportunity to reduce future environmental and community impacts.

Noting the considerations above, the recommended design performs worse from an environmental and community perspective, but better from a deliverability and economic perspective. However, there are future opportunities to improve the recommended design from an environmental and community perspective.

5.3.8 East coast radial design

The optimised radial design is shown in Figure 20



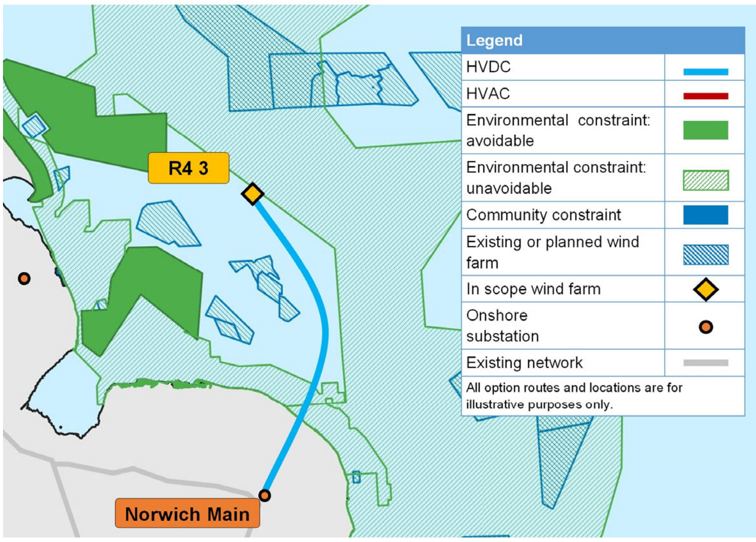
As discussed in section 4.6 Optimised radial design, when all of Great Britain is taken into account, the recommended design performs better than the optimised radial design option from an economic perspective.

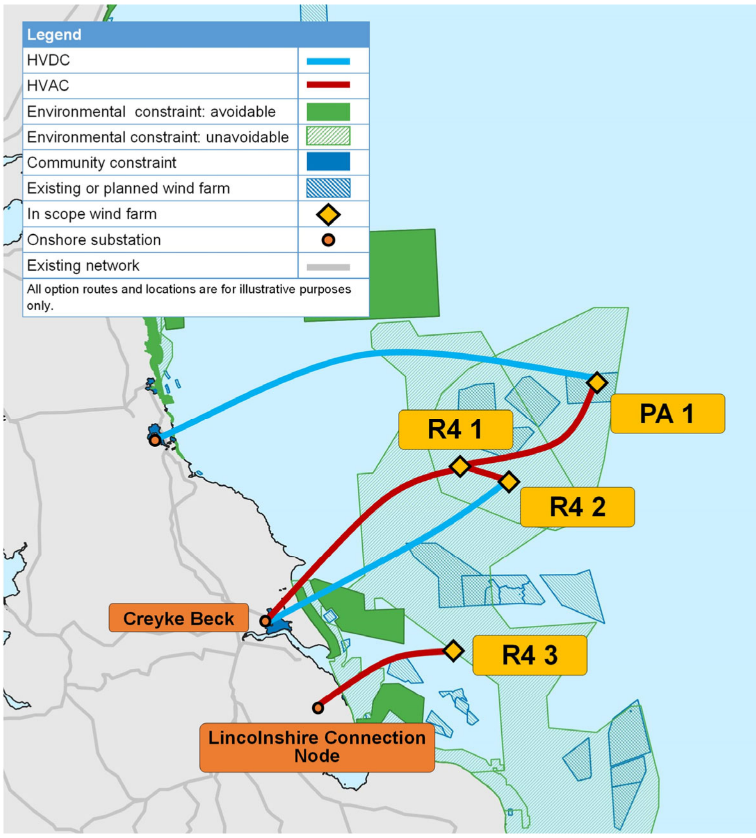
Deliverability, environmental and community considerations for the radial design for each region are discussed further in section 7 Optimised radial design.

5.3.9 Other design options

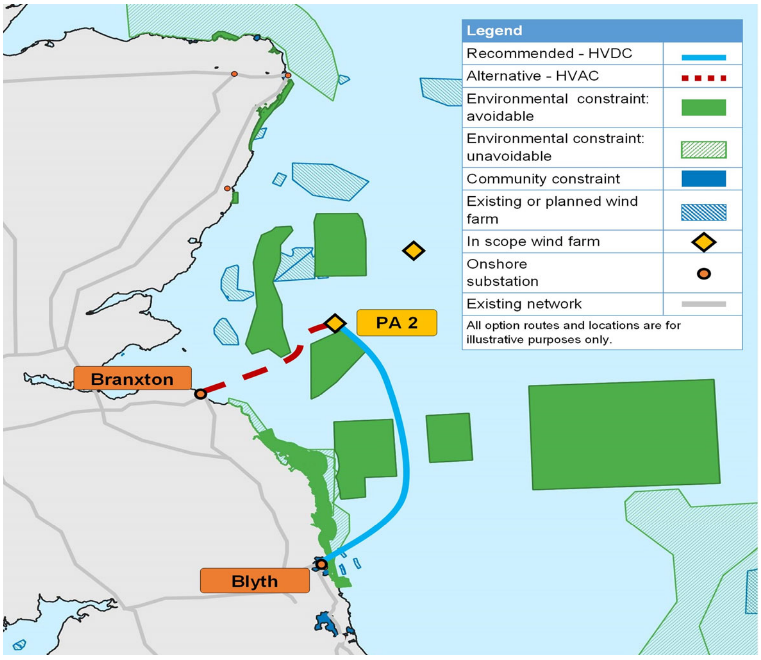
These options were considered as part of the design process but were not taken forward for detailed consideration. They are included here to demonstrate the range of designs that were assessed.

Table 26 – Other design options

Radial connection to Norwich Main	
Variation	Within the radial options appraisal, a connection into East Anglia at Norwich Main substation was considered. This would have enabled several of the wind farms on the east coast to connect to interface sites further south. This would have led to lower costs overall, due to the reduction in constraint costs associated with connecting generation closer to areas of higher demand (London and the South East of England). 
Comparison with chosen design	The recommended design does not include any new connections from offshore wind farms into East Anglia beyond those currently planned at this time. This is due to the technical, environmental and community impacts of adding this connection on top of those already in place and planned. Particular challenges include the likelihood that the environmental constraints at Cromer Shoals MCZ and Haisborough, Hammond and Winterton SAC could not be avoided without taking an alternative route, which has previously been dismissed due to technical and cable safety concerns. Although the location performed well from an economic point of view, it is unlikely to be feasible in the timescales the HND is considering to find a route that is acceptable from an environmental or technical perspective beyond those already in place and in development.
Reason for disregarding	For the reasons set out above, the connection into Norwich Main is considered high risk of being undeliverable within the timescales required. As a result, Norwich Main is not considered to be a suitable connection site in the HND, even though it performs better from an economic perspective.

Greater number of offshore assets	
Variation	Some alternative options considered a much higher number of offshore assets, for example increasing the capacity between Scotland and England, to determine whether this would provide an economic benefit.
Comparison with chosen design	These options did not perform well against our assessment criteria: they introduced additional cost and complexity offshore, which was not outweighed by savings in constraint costs. Due to constraints associated with Norwich at this time (as above) there were limited landfall sites in England to connect the additional offshore infrastructure.
Reason for disregarding	These options were not taken forward as the increase in costs due to the additional infrastructure was greater than the savings in constraint costs that these assets would deliver.
Teesside to Humber region ring	
Variation	This option considered a ring between Teesside and the Humber region for just the English wind farms. 
Comparison with chosen design	The option has lower capital costs than the chosen design due to a lower number of offshore assets, but it led to higher constraint costs because less power could be transferred from Scotland to England.
Reason for disregarding	This option was disregarded because it limits the options for coordination with Scotland as it only enables a single offshore link to connect to Teesside from further north. This would lead to higher constraint costs than the recommended design, which would outweigh the savings in capital costs.

Coordination with Eastern Links (eastern Scotland to England transmission reinforcements)	
Variation	The NOA process recommends that several offshore HVDC links are constructed between eastern Scotland and England. Consideration was given to coordination with the 3rd and 4th Eastern Links due to their route and potential landing point coinciding with the coordinated designs.
Comparison with chosen design	Connecting wind farms directly to these links reduces the available transfer capacity from Scotland to England. The recommended design therefore requires the 3rd and 4th Eastern Links in addition to the offshore network proposed in the recommended design.
Reason for disregarding	Limiting the available transfer capacity from Scotland is not preferable as this would lead to higher constraint costs.
Using AC technology for more offshore routes	
Variation	AC technology could have been used to construct more of the offshore routes.
Comparison with chosen design	Using AC technology would have reduced capital costs by reducing the requirements for converter stations. However, in some situations this would have created an AC route in parallel to the onshore network. Compared to the onshore 275 kV and 400 kV double circuits to which the offshore network would be parallel, the offshore cable circuits would be relatively weak. This would make them prone to overloading and may actually reduce network power transfer capability. To avoid this, fast responding power control systems would need to be put into place which introduces additional complexity, cost and operability risk.
Reason for disregarding	All options which would introduce a parallel AC route were not taken forward in favour of a DC link which provides controllability.

Connecting PA_2 into Branxton rather than Blyth	
Variation	We considered connecting PA_2 into Branxton, as this would require less offshore infrastructure than a connection to Blyth. The optimised radial design shows PA_2 connecting into Branxton. 
Comparison with chosen design	Connecting PA_2 into Branxton would lead to a reduction in capital costs as it is a shorter link. However, when considering constraint costs beyond 2030 in the recommended design, the constraint costs associated with a connection into Branxton are significantly higher than those associated with a connection into Blyth. The total costs of a connection into Blyth are therefore lower than the total costs of a connection into Branxton. A connection into Blyth would also avoid environmental constraints at Branxton. A connection into Branxton would perform worse from a deliverability perspective as it is not consistent with development work carried out to date and clashes with other planned offshore connections at Branxton.
Reason for disregarding	A connection into Branxton performs worse from an economic, environmental and deliverability perspective.

5.3.10 Economic and Efficient considerations

The recommended design performs better from an economic perspective than the alternative designs considered. When compared to the alternative coordinated design in *Section 5.3.7,* the recommended design is £5780 million less expensive overall. The recommended design has lower capital costs (£3960 million lower): this is mainly because the recommended design includes fewer offshore converter stations. The recommended design also has lower constraint costs (£1820 million lower): this is mainly because the recommended design has more capacity to transfer power from Scotland to England. In the alternative coordinated design, one of the circuits going south from SW_E1a goes to R4_2 (effectively meaning that its capacity is shared), whereas in the recommended design this circuit goes directly into Hawthorn Pit. The costs and scope of onshore boundary reinforcements are broadly comparable between the two designs. These figures were calculated by changing the recommended design for the East Coast to the alternative coordinated design, but keeping the rest of the offshore design the same as the recommended design.

As described in section 4.7, the recommended design also performs better than the optimised radial design from an economic perspective.

5.3.11 Deliverability and operability

The design provides the opportunity for in scope wind farms to be able to connect by 2030 under the current regulatory and planning frameworks. The longer, and more complex, HVDC links in the design are unlikely to be complete by 2030 in the absence of major acceleration in the supply chain. However, the design offers the potential to get generation connected by 2030, and increase capacity progressively, given timely allocation of responsibilities, delivery of the commitments in the *BESS* and a coordinated and concerted effort from all parties. During this interim phase, the network would have reduced redundancy.

5.3.11.01 HVDC

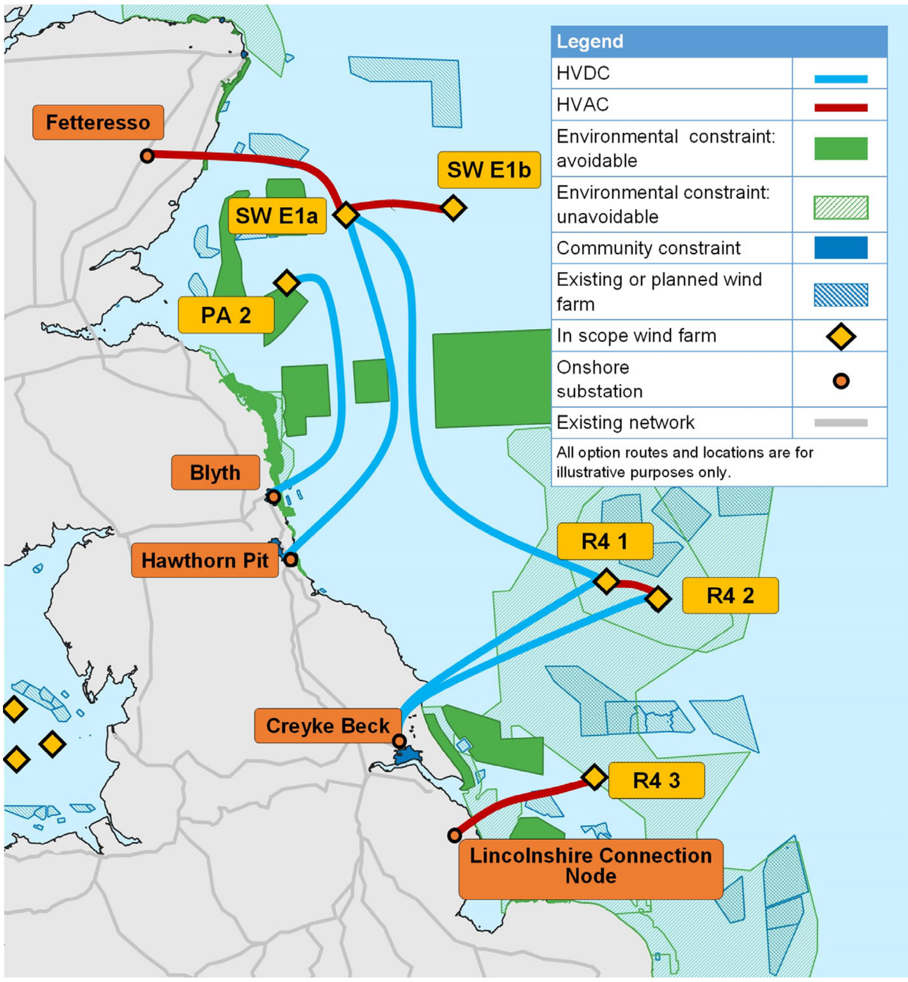
This East Coast design includes five point-to-point HVDC links and a three-ended HVDC circuit. This represents a deliverability risk in terms of cable supply and installation. Some of these are unlikely to be complete by 2030 as set out above, although the design offers the potential to connect generation ahead of this.

5.3.11.02 Overall complexity

The design is complex with several offshore connections between wind farms and HVDC/HVAC connections to the same points. These potentially increase the technical difficulty and the timeframes required for construction and commissioning. They also increase the level of interaction and interdependence between different elements of the design which are likely to become the responsibility of different parties in planning, consenting and construction.

It is not possible at this time to create a fully staged construction timeline for the recommended design for the East Coast Region and not possible to look at all plausible variations, particularly at the northern group of the coordinated section in the ScotWind area. However, we have tested the outcome for a mismatch in the development timelines for the PA_1 and R4_2 sites in the southern group, by examining a design for 2030 in the absence of PA_1. Under this scenario, our optimal design is the same as our recommended design, with the only differences being that the link from PA_1 to R4_2 is not required and the link from R4_2 to the Lincolnshire Connection Node is of less value. This scenario is illustrated in Figure 21.

Figure 21 - Design for 2030 in the absence of PA_1



One conclusion that can be drawn from this assessment is that the links from PA_1 to the R4_2 locations and onwards to Lincolnshire Connection Node can be thought of as a single self-contained package with a linkage to the rest of the design close to R4_2. This approach would also avoid the need to build a single large platform when multiple smaller platforms are more deliverable and entail a lot less work in anticipation of future links. Generally, we envisage that a modular approach to offshore platform design will aid deliverability and make the design more expandable. The most appropriate approach will be informed by Ofgem's asset classification process. The practical implications should be considered further by those undertaking the DND stage.

5.3.11.03 Technical and environmental

The principal offshore technical constraints include ports, dredge spoil dumping sites and offshore infrastructure including pipelines and cable crossings.

5.3.11.04 Onshore works

The design requires several onshore works that are either not included in NOA or currently on "Hold". Most works have an EISD on or before 2030 apart from 11 options which have EISDs later than 2030.

The Lincolnshire Connection Node requires a new onshore circuit which is currently not anticipated to be delivered until 2031; an alternative site further in land remains under consideration as a connection point for R4_3. The timings and required works for each connection will be determined as part of the connection offer update process.

5.3.11.05 Operability

The complex nature of the East Coast design, with its mixture of HVAC and HVDC circuits, gives some operational challenges. The power flows in the offshore network need to be actively managed by means of the HVDC circuits to provide greatest power transfer capability, avoid potential overload conditions and adverse interactions with the onshore network.

For moderate to high wind conditions, it is expected that most power flows will be directed towards the southerly connection points. Under outage or fault conditions, the next available circuits should pick up their loading to maintain power balance.

Dynamic studies have found that the proposed design is stable but the offshore voltage control of both the HVAC and HVDC systems needs to be carefully configured using resource from the wind farms, HVDC converters and reactive compensation equipment.

5.3.12 Stakeholder feedback

Stakeholders noted that successful delivery of the coordinated design may depend on which party is responsible for building each part of the design, the date by which each part of the design can be constructed, and the timescales by which this responsibility is known.

Stakeholders raised concerns that the coordinated HND designs required large platforms, leading to complex builds and significant anticipatory investment for some parties (those building additional infrastructure to facilitate a coordinated design), and dependency and risk for other parties (those dependent on this infrastructure to connect).

Stakeholders also provided feedback about the deliverability of some of our recommendations. We had originally proposed a solution where SW_NE7's connection was split into two phases, with 1000 MW in the first phase and 2000 MW in the second phase (total 3000 MW). Our original design (as shared with developers) proposed a 1000 MW HVAC connection to Peterhead for the first phase of SW_NE7. For SW_NE4, we had proposed a 2000 MW HVAC connection to New Deer (reflecting the capacity in its connection agreement), although this is higher than the published capacity associated with the option agreement with Crown Estate Scotland[28].

Feedback from the SW_NE7 developer indicated that the staging originally assumed for SW_NE7 was not consistent with their needs and preferred technology choice (HVDC). We agree that it could be challenging to deliver a HVAC connection of this length, particularly given landfall constraints around Peterhead. An HVDC connection could have a reduced environmental impact, allowing for cables to be laid closer (for example in a single trench onshore), and with each cable carrying a higher capacity. We have therefore recommended a 1500 MW HVDC connection to Peterhead for SW_NE7.

We note that the HND can only include a limited capacity of ScotWind generation, as described in section 2.3 ScotWind projects in scope. As the two sites are proposed to connect to the same part of the network, moving capacity between the SW_NE4 and SW_NE7 sites does not have a significant impact on the rest of the network. However, increasing the total capacity of these sites (even if generation is removed elsewhere) would increase power flows across the network, leading to additional constraint costs or an increased requirement for boundary reinforcement.

Due to the above, and the fact that the published information related to SW_NE4's ScotWind option agreement does not currently reflect its full 2000 MW connection contract capacity, we have therefore only been able to include 1500 MW of SW_NE4's capacity within the HND. We expect to include the remaining 500 MW within the HND follow up process, although this may be subject to staging.

The follow up process to the HND will include the remaining capacities for SW_NE4 and SW_NE7.

Stakeholders have provided feedback to share concerns that designated sites, including MPAs, have not been able to be avoided by the proposed HND design and concerns have been raised about the impact that additional cable routes could have on sediment processes on the East Coast of England, particularly in relation to the Creyke Beck and Lincolnshire Connection Node sites. Concerns have also been raised regarding the increased cable routing in the Dogger Bank SAC in

[28] https://www.crownestatescotland.com/news/scotwind-offshore-wind-leasing-delivers-major-boost-to-scotlands-net-zero-aspirations

the recommended design. We have reviewed these concerns and considered whether there are alternative cable routing options. While it may be possible to reduce the length of cable in some protected areas, the location of the windfarms and the designated areas mean it is not possible to completely avoid them. Further consideration will need to be given in the DND stage to minimise environmental impact and follow the mitigation hierarchy.

Feedback from the R4_3 developer raised concerns about the dependency of their proposed connection to Lincolnshire Connection Node on the construction of the new circuit between south Humber and south Lincolnshire (GWNC). Economic analysis has identified a potential overall benefit to the consumer if a connection date can be sufficiently brought forward. This option is still being considered and further analysis is being undertaken.

5.3.13 Conclusions and next steps

The East Coast Region is complex and connects nine offshore wind farms to the onshore network as well as providing valuable connections offshore between England and Scotland.

Our assessment indicates there is clear value in transferring power through the offshore network from the eastern ScotWind zone to the south via the developments off the East Coast of England.

We envisage that a modular approach to offshore platforms in the coordinated East Coast design will aid deliverability and make the design more expandable for future requirements. Our assessment tells us that the need for a HVDC link from R4_2 to the Lincolnshire Connection Node, along with the AC connection from PA_1 itself, is triggered by the PA_1 connection. As there are likely to be different deliverability issues and time constraints for the different projects to work through, we recommend that the design for this grouping is taken forward in discrete packages with provision for offshore linkages at the appropriate point. A similar principle could be adopted for the SW_E1a and SW_E1b grouping, and it may be possible to complete a similar assessment in the follow up process to the HND. As envisaged by Ofgem, further analysis on the primary function of each asset will be needed to confirm who is responsible for each part of the coordinated design.

The recommended design is **economic and efficient**, offering savings of £5780 million compared with the alternative coordinated design. This is due to savings in converter station costs (offshore converter stations are significantly more expensive), and lower constraint costs in the recommended design due to a larger capacity to transfer power from Scotland to England. The recommended design is also more economic and efficient than the optimised radial design.

The design is **deliverable and operable** and provides the opportunity for in scope wind farms to be able to connect by 2030 under the current regulatory and planning frameworks. The longer, and more complex, HVDC links in the design are unlikely to be complete by 2030 in the absence of major acceleration in the supply chain. However, the design offers the potential to get generation connected by 2030, and increase capacity progressively, given timely allocation of responsibilities, delivery of the commitments in the *BESS* and a coordinated and concerted effort from all parties.

The design seeks to **minimise the impact on the environment** by avoiding areas of significant constraint where possible, although not all environmentally sensitive areas can be avoided. The north to south links in the design provide additional power flow capabilities without increasing the number of onshore connection points, and offset future requirements for reinforcement.

The design seeks to **minimise local community impact** where possible, by avoiding further connections into East Anglia at this time beyond those already planned. Careful planning at the DND stage should enable community impacts elsewhere to be minimised.

5.4 North Scotland Region

For the North Scotland Region, the recommended design uses radial connections only, with no coordination between wind farms. The design connects two wind farms, SW_N1 and SW_N4. Although a coordinated design was considered which linked these two wind farms, this did not perform well against the network design objectives due to the distance between the two projects.

It was not possible to identify an economically justifiable option to link to the west coast. For the generation considered within this phase of the HND we could not identify a technically viable option to link to the east coast via an offshore route.

It was concluded that coordination within this region does not perform well against the network design objectives.

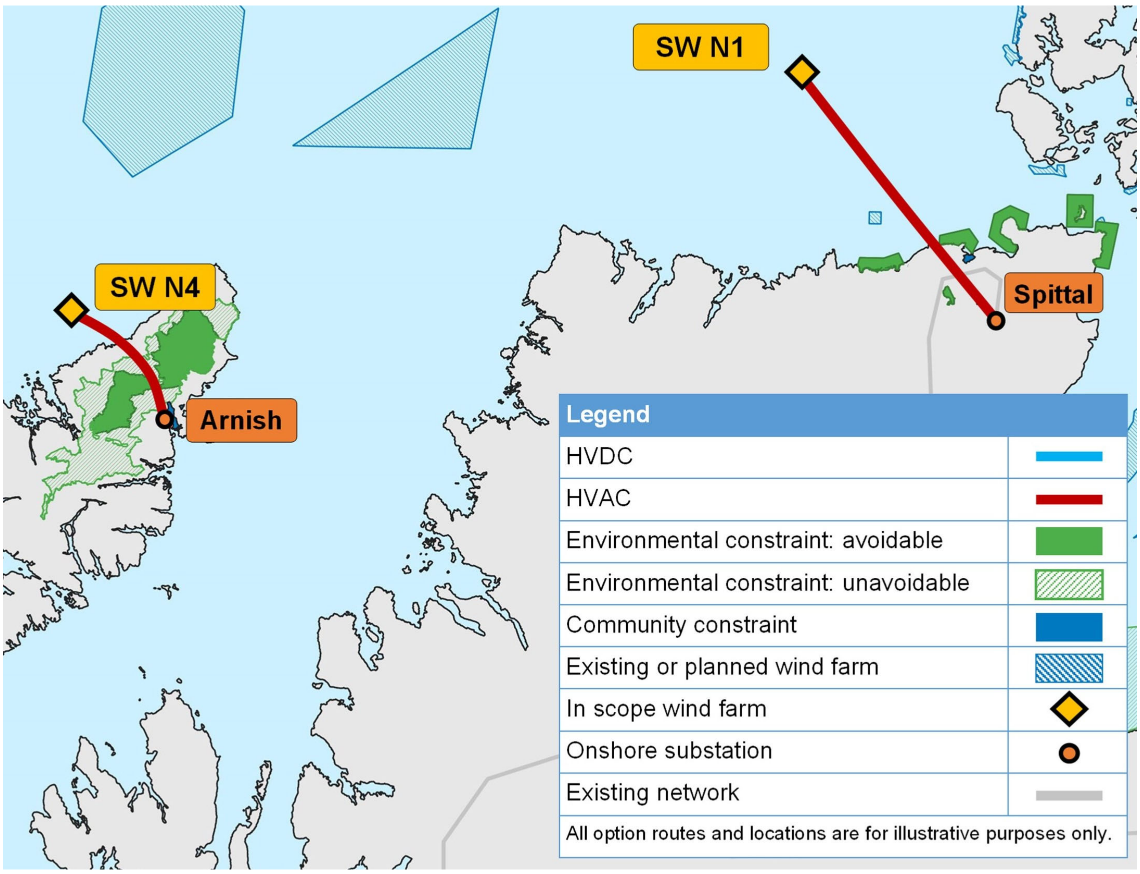
5.4.1 Projects in scope

The North Scotland Region design connects the following two projects in *Table 27*:

Project name	Capacity (MW)
SW_N1	2250
SW_N4	740

5.4.2 Offshore Design

Based on the known locations for these wind farms, the recommended design provides radial connections for both sites, connecting SW_N1 to Spittal substation and SW_N4 to Arnish (Lewis), shown in *Figure 22*:



This is our recommended design for the region.

The design consists of AC connections from SW_N1 to Spittal, and from SW_N4 to Arnish (Lewis).

Because SW_N4 is connecting to Arnish on the Western Isles, an HVDC link will need to be established from the Western Isles to the Great Britain mainland (forming part of SSEN's transmission network).

The nature of this link depends on whether SSEN's proposed 600 MW link from Arnish to Beauly (planned to be completed in 2027) goes ahead; this is dependent on regulatory approval and a sufficient volume of onshore generation on the Western Isles.

- If the 600 MW link does not go ahead, an 1800 MW HVDC link from Arnish to Beauly could be constructed.
- If the 600 MW link goes ahead, SSEN would construct a separate 1800 MW link from the Western Isles to the mainland (which would connect to a different mainland substation as it is not feasible to construct two separate links from Arnish to Beauly).

Our analysis within the HND assumes that connecting SW_N4 to Arnish would require a new 1800 MW link from Arnish to Beauly. This link would provide some headroom for additional generation to connect in the future.

Our choice of cable technology (HVDC or High Voltage Alternating Current (HVAC)) in this document has been made in the first instance on the optimal economic design solution based on our assumptions as set out in the Network design guidelines and network overview section. The choice between AC and DC cabling becomes less clear cut in the upper length range for AC cables (150-200 km) and will depend on other project specific factors, including environmental, technical and community constraints. The final choice of technology will be made as part of the DND phase.

The connections used in the design are described in *table 28*. While these connections represent our current proposal for the design, they may change in further stages of the design process.

Node 1	Node 2	Circuit capacity (MW)	Technology[29]		Distance (km)[30]
SW_N1	Spittal	2250	AC	4-6 cables	66
SW_N4	Arnish	740	AC	2-3 cables	40

5.4.3 Onshore works

The design requires onshore works at the interface sites (Arnish and Spittal) as well as wider sites *Table 29*.

Substation	Work required
Arnish	Establish a 1.8 GW monopole HVDC link from a new 275 kV substation site on the Western Isles, including bays for connection to the offshore network, to a site on the Great Britain mainland. The location of the new site on the Western Isles and the site on the Great Britain mainland is still to be confirmed.
Spittal	Establish a new 400 kV substation site in the vicinity of the existing Spittal 275 kV substation including bays for connection to the offshore network and works to connect the new site to

[29] AC cable numbers assume 500 MW is possible at 275 kV. Longer distances may require an additional parallel cable to account for reactive power losses.
[30] The distances shown relate to an indicative route. Route corridors will be determined as part of the Detailed Network Design process.

	the existing substation. The location of the new site is still to be confirmed.

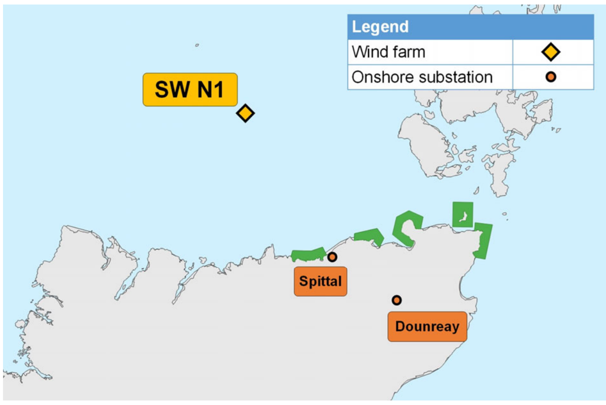
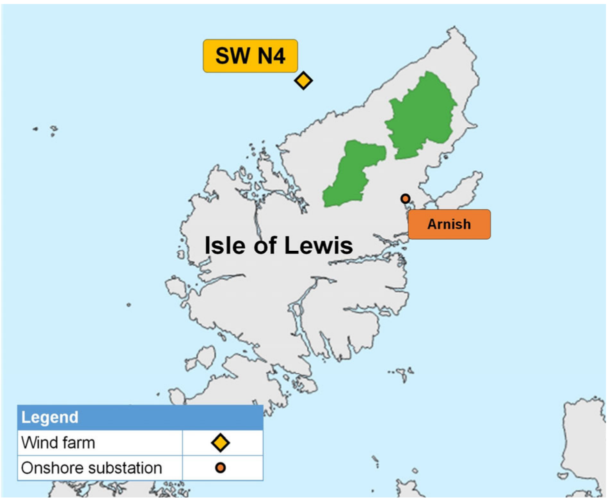
The design requires works at other sites including uprating, reconductoring and reinforcement. Wider onshore works are described in section the system-wide view section 5.5

5.4.4 Environment and Community considerations

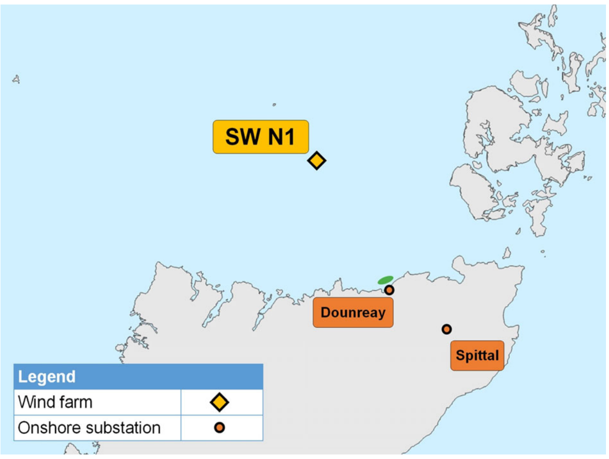
Although route corridors are not defined at this stage of the process, the HND has been developed with a view to avoiding the most significant environmental and community constraints. These include constraints with features expected to be sensitive to impacts from cabling or infrastructure where the risks of cabling would be significant.

Table 30 lists the significant constraints which it has been possible to avoid in the HND within the region. As in the regional overview, avoidable constraints are shown in solid fill whereas unavoidable constraints are cross hatched.

5.1.8 Environment and community constraints

Constraint	Map	Description
Constraint 1		**North Caithness Cliffs SPA and MPA** This site is designated for its very large populations of breeding seabirds such as peregrine kittiwake and guillemot. The site covers a number of sections of the north coast. Although it has been avoided by the HND, landfall opportunities are limited along this coastline and other options might need to be included in the future which might affect the SPA.
Constraint 2		**Lewis Peatlands (SAC)** The Lewis Peatlands SAC is designated for the presence of Blanket bog, depressions on peat substrates, acid peat-stained lakes and ponds, wet heathland with cross-leaved heath, clear-water lakes or lochs with aquatic vegetation and poor to moderate nutrient levels and otter species.

Constraint 3

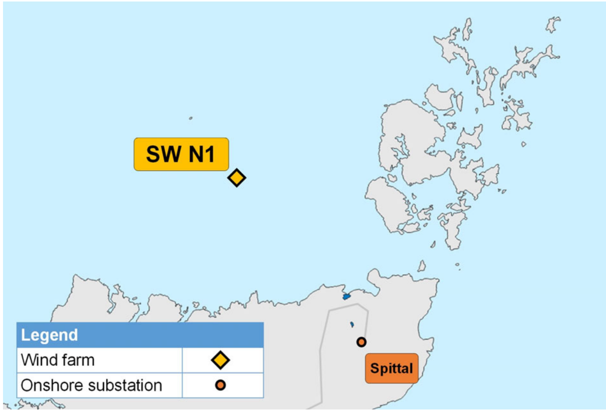


Dounreay Radioactive Particles

Radioactive particles are known to be present in the marine environment around the Dounreay nuclear site.

Approximate location shown in figure.

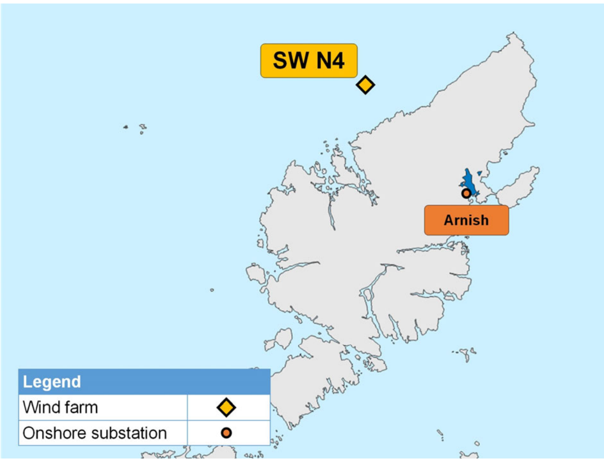
Constraint 4



Built-up areas

The urban area of Halkirk is within the potential cable approach, but there is potential to avoid it.

Constraint 4



Built-up areas

The urban area of Stornoway is located approximately 4 km from the Arnish (Lewis) substation.

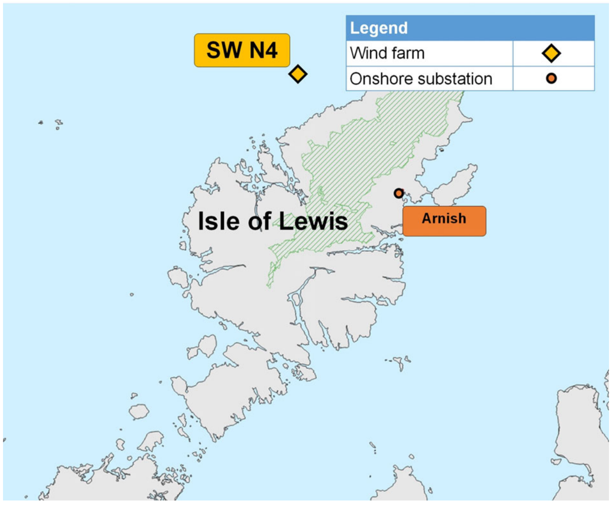
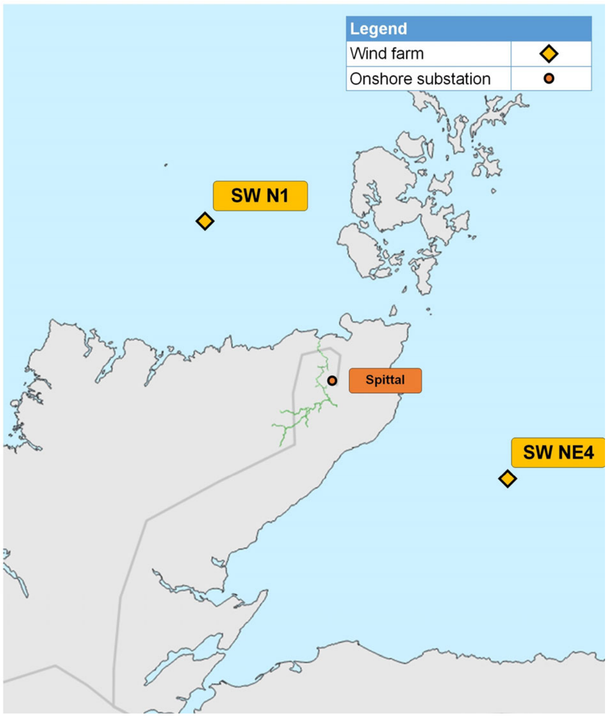
4.4.5 Unavoidable environmental constraints

There are some environmental constraints which cover extensive areas or are close to the point of the subsea cables making landfall that are unavoidable due to the locations of wind farms and onshore substations. *Table 31* lists the significant constraints that it is not possible to avoid in the region.

At this strategic route selection stage, the primary method of mitigation was to, as far as was possible, avoid features and/or environmental designations that were identified by the relevant statutory bodies as sensitive to cabling operations. In some instances, these environmental or physical features, or infrastructure, formed linear constraints to cable route corridors, that could not feasibly be circumvented. In these cases, consideration was given as to whether these features could be feasibly crossed over (e.g., infrastructure) with physical protection or under by directional drilling (environmental areas).

More detailed site surveys, routing and consideration of mitigation measures will be required at the DND stage to further avoid identified specific sensitivities or features within designated areas that have not been avoided, and to identify appropriate crossing locations and techniques. At the detailed design stage further mitigation such as limiting the seasonality of working may also be considered to minimise the potential impacts of cable laying operations in areas that are not practical to avoid. Beyond this, compensatory measures may be required at the DND stage to offset identified impacts.

Table 31 - Unavoidable environmental constraints

Constraint	Map	Description
Constraint 5		**Lewis Peatlands SPA** The Lewis Peatlands SPA is designated for the presence of breeding species of Black-throated diver, Dunlin, Golden eagle, Golden plover, Greenshank, Merlin and Red-throated diver. It is not feasible to design a route corridor which avoids the SPA.
Constraint 6		**River Thurso SAC** This site is designated for its importance to wintering Atlantic salmon and other fish species such as Grilse. The SAC cannot be avoided within the route corridor for SW_N1. It might be possible to drill beneath it.

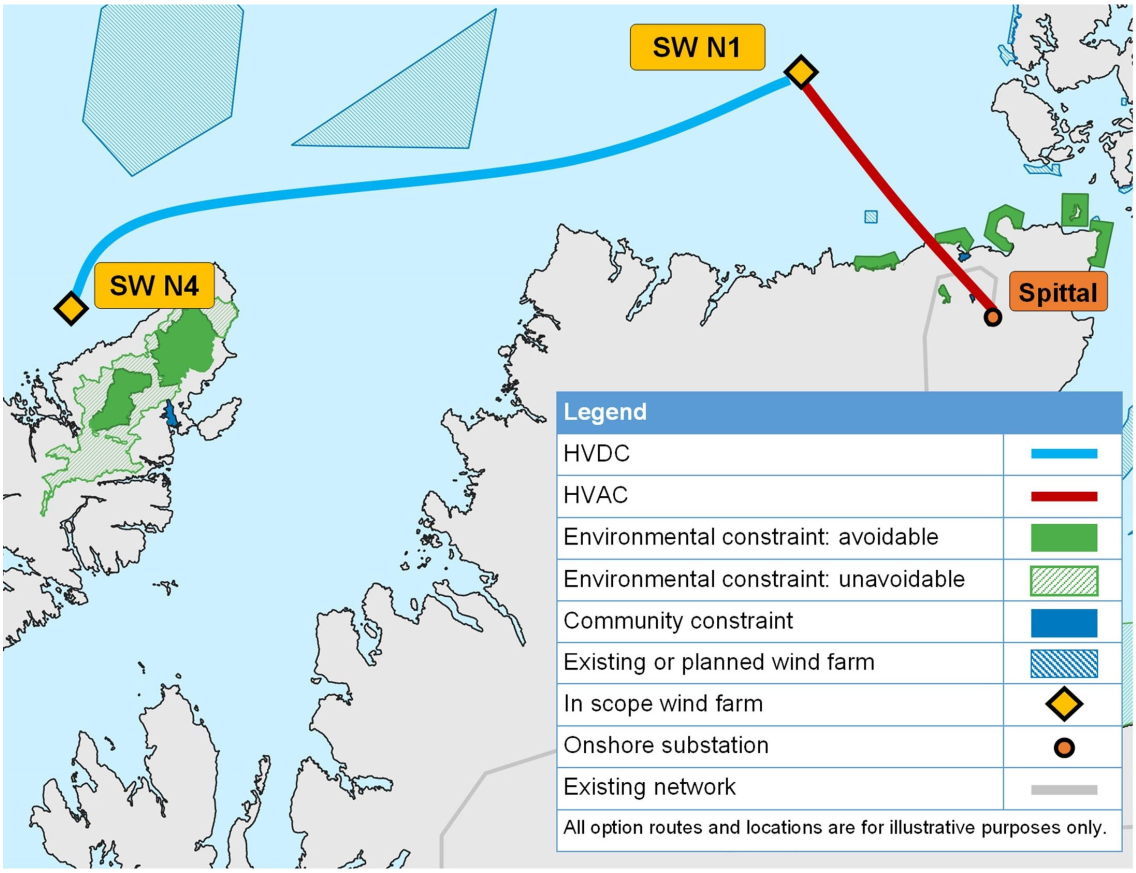
While these tables do not describe all the environmental and community constraints in the North Scotland Region, they provide an overview of the significant constraints that influenced the network design, including constraints that are very close to the interface points and those which have been identified by stakeholders as being particularly sensitive to cabling operations, and thus have significant potential to impact the viability of cable routes through the area. These constraints also highlight the sensitive areas that have been identified as difficult to avoid in designing cable route corridors.

5.4.6 Other offshore designs and variations we considered

As part of the HND process, several design options were considered. This section summarises alternative designs that were not selected for the HND. For the North of Scotland region, two alternative options were considered in detail, as well as further design options.

5.4.7 Alternative coordinated design

Figure 23 – Alternative design



This option connects SW_N4 to SW_N1 via a HVDC link. SW_N1 is connected to Spittal via an AC link.

This option would be £1059 million more expensive overall. This is due to the £879 million increase in capital costs, and £180 million increase in constraint costs. The costs and scope of onshore boundary reinforcements are broadly comparable between the two designs. These figures were calculated by changing the recommended design in North Scotland to the alternative coordinated design, but keeping the rest of the offshore design the same as the recommended design.[31]

The higher capital costs in the alternative design result from the HVDC link and associated offshore converter stations. The higher constraint costs would result from effectively connecting

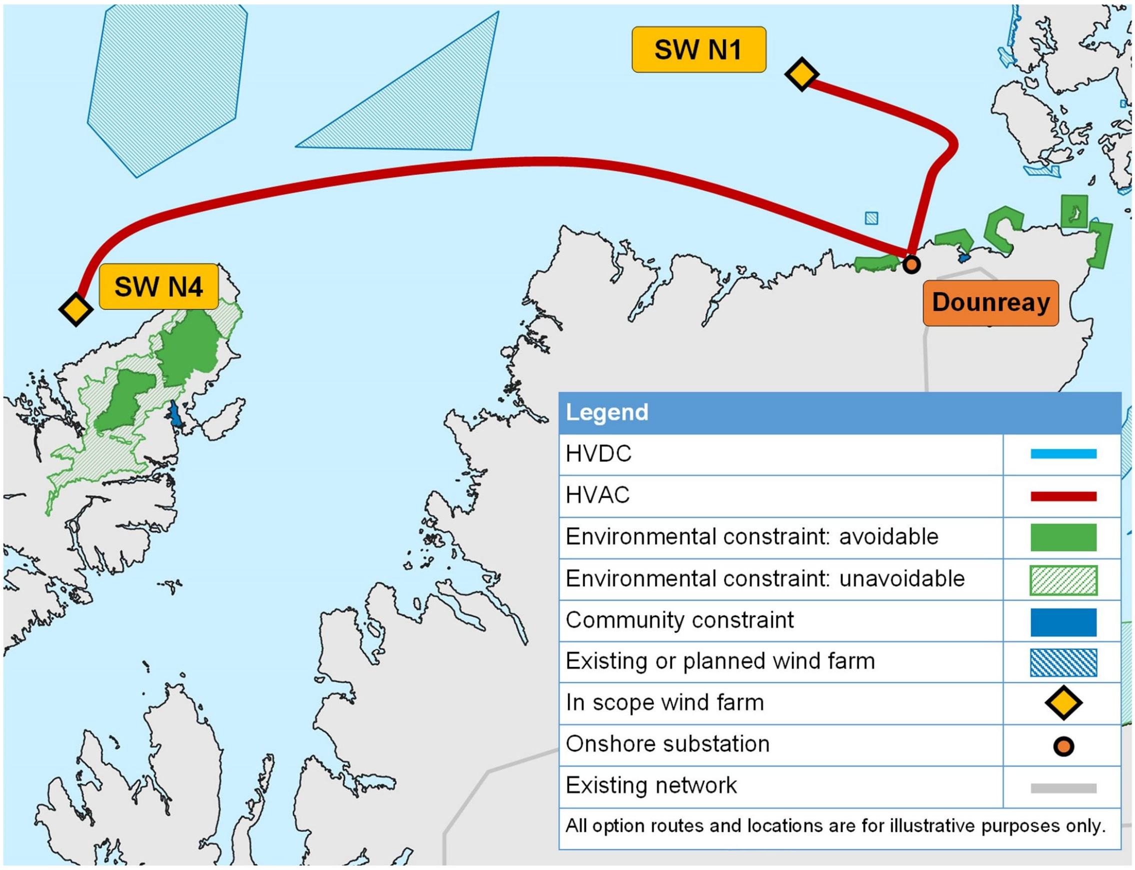
[31] Infrastructure cost differential corrected on (23.09.2022): this does not change the overall outcome.

the SW_N4 generation further north; this leads to higher constraint costs due to the distribution of generation and demand across Great Britain.

From a deliverability and operability perspective, this design may not be possible to deliver by 2030 due to the HVDC link and the requirement for multiple offshore converter station platforms.

5.4.8 Alternative radial design

The alternative radial design is shown in *Figure 24.* It connects both SW_N1 and SW_N4 to Dounreay substation.



Both connections are predominantly offshore with HVAC connections. This alternative was not chosen as it was deemed more challenging to deliver and not future proof to additional generation sited onshore and offshore on the Western Isles.

5.4.9 Other design options

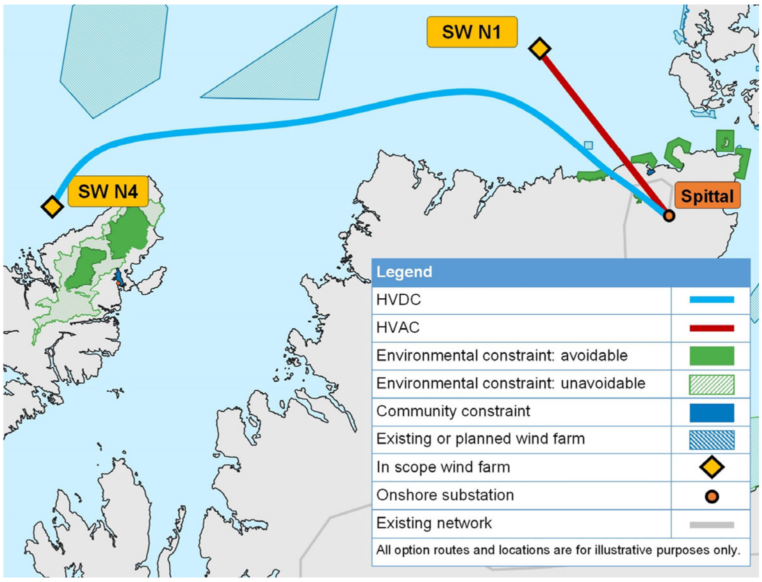
These options were considered as part of the design process but were not taken forward for detailed consideration. They are included here to demonstrate the range of designs that were assessed.

Figure 25 – Other designs

SW_N1 to Spittal and SW_N4 to Spittal

Variation

This design has radial connections for both wind farms, connecting to Spittal substation.

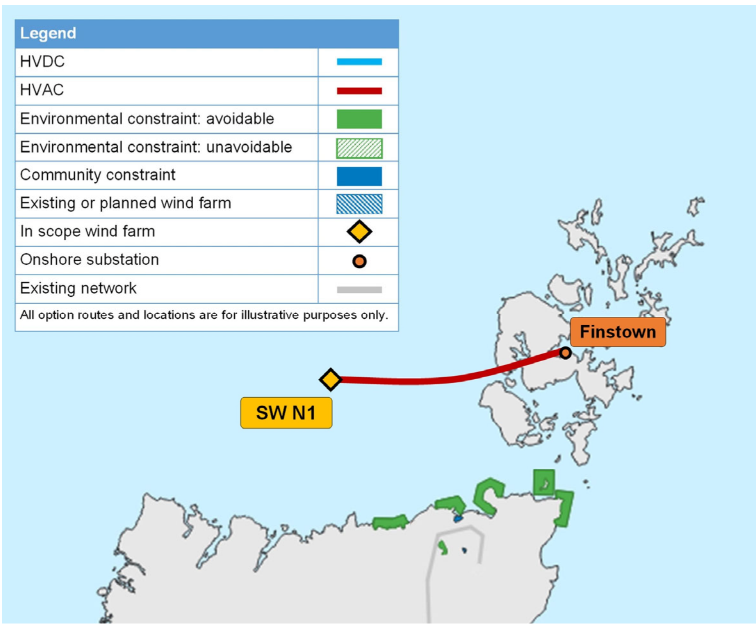


Comparison with chosen design	Both connections are radial but to the same substation, unlike the recommended design where SW_N4 is connected to Arnish
Reason for disregarding	Due to its longer onshore cable length, this design would have higher total costs and more environmental impact, in comparison to the recommended design.

SW_N1 to Finstown (Orkney)

Variation

SW_N1 runs to a different substation, Finstown on Orkney



Comparison with chosen design	There are technical constraints within the cable route corridor around Stromness Port and the rocky seabed to the south of Stromness with strong tidal streams. The alternative overland route from the west of Stromness to Finstown had multiple environmental constraints including the North-west Orkney and Hoy MPAs, the Hoy and Orkney Mainland Moors SPAs and a number of SSSIs. Further analysis would also be required to confirm the deliverability of the upgrade required to provide sufficient capacity on the planned Orkney connection to Dounreay.
Reason for disregarding	More environmental constraints and uncertainty around deliverability made this option less desirable.

5.4.10 Economic and Efficient considerations

From an economic perspective, the recommended design for this region (which is radial) performs better than the alternative (coordinated) design which was considered. The radial design offers savings in the costs of offshore infrastructure (approximately £879 million), and also in constraint costs (approximately £180 million), giving total savings of £1059 million. [32]

5.4.11 Deliverability and operability

The recommended design is relatively simple to deliver by 2030 given its radial nature.

It is expected that all radial AC offshore circuits are deliverable by 2030.

5.4.11.1 HVDC

The recommended design does not include HVDC connections to offshore wind farms, but it would require an HVDC connection between the Western Isles and the mainland (which would form part of SSEN's transmission network).

5.4.11.2 Overall complexity

This simple radial design does not introduce significant additional complexity beyond a required HVDC connection between the Western Isles and the mainland.

5.4.11.3 Technical and environmental

Technical issues with offshore cable routing for the region include the predominance of cliffs at the coastline for both potential cable routes, however, there are opportunities to avoid the highest cliffs within the route corridors.

5.4.11.4 Onshore works

All substation interface works are deliverable with an Earliest In Service Date (EISD) of 2030, although some NOA works associated with this option extend out to 2031.

We intend to work with the TOs to accelerate the essential options in order to enable the connections by 2030.

5.4.11.5 Operability

The radial nature of the design is not expected to provide any unusual operability issues.

[32] Infrastructure cost differential corrected on (23.09.2022): this does not change the overall outcome.

5.4.12 Stakeholder feedback

Stakeholders were generally supportive of the North Scotland design, and no changes were made in response to stakeholder feedback.

5.4.13 Conclusion and next steps

The recommended design for the North of Scotland connects two wind farms (SW_N4 and SW_N1) using radial connections.

The costs of coordination for the developments off the north coast of Scotland would be high due to the distance between the generation projects which are in scope. No economically justifiable options were identified to link to either the East Coast or the North West Regions.

The recommended design is **economic and efficient**, offering savings of £1059[33] million compared with the coordinated design considered for this region due to lower capital costs and lower constraint costs. The coordinated design would have higher costs, as it would include an HVDC link with associated offshore converter stations between SW_N4 and SW_N1.

The design is **deliverable and operable**, with minimal additional complexity due to the radial connections and no notable supply chain concerns. The HVAC offshore connections and works at the interface point substations are deliverable by 2030. We intend to work with the TOs to accelerate works which are required elsewhere on the network to enable the connections by 2030 in light of the commitments in the *BESS*. The timings and required works for each connection will be determined as part of the connection offer update process.

The design seeks to **minimise the impact on the environment**, as it is expected to be possible to define a route corridor that avoids several onshore and offshore areas of environmental significance on the Isle of Lewis and the Great Britain mainland, such as the North Caithness Cliffs SPA and MPA, the Caithness Lochs SPA, and the Lewis Peatlands SAC.

The design seeks to **minimise local community impact**, as it is expected to be possible to define route corridors that avoid heritage assets and urban areas.

33 Infrastructure cost differential corrected on (23.09.2022): this does not change the overall outcome.

5.5 System-wide view

The current onshore transmission system has around 25,000 km of high voltage circuits to transmit power from generators to our towns and cities. While this network successfully meets our needs for today, the future requirements for the network, and the ambitious targets set by the Government, necessitate expanding the transmission network to ensure we have a power system capable of delivering on our 2030 offshore wind ambition and the UK's broader net zero target.

This section builds on the regional summaries of onshore works, which look to address specific regional connection drivers, and instead focuses on enabling bulk power flow requirements across the network in the most economic and efficient way while considering environmental and community impacts. This in-depth view articulates the upgrades required on the wider transmission network to not only meet these requirements but also maintain network compliance and ensure we have a transmission system capable of facilitating the connection of 50 GW of offshore wind by 2030.

The 2030 onshore transmission network will look very different to the one we see today. To meet the 2030 ambitions and facilitate the delivery of the offshore wind in scope of the Holistic Network Design (HND), 94 reinforcement projects, totalling £21.7 billion, are required to be delivered by the end of the decade. These range from very small upgrades to large new transmission infrastructure such as new circuits or subsea cables, with the sole purpose of transporting electricity from where it is produced to where there is demand for it.

Of the 94 reinforcements required by 2030, many should be delivered earlier to maximise consumer benefit. *The NOA 2021/22 Refresh* provides this additional insight via an optimal date; ensuring that reinforcements are delivered when they are needed, and that the costs of building them outweigh the costs of managing power flows around the network without them in place.

The NOA Refresh builds on the *NOA 2021/22* published in January 2022, assessing the impact of the HND's recommended offshore network on the power flows on the system. *The NOA 2021/22 Refresh* looks at 2030 and beyond to provide the optimal delivery dates for projects that it recommends and has been used to inform the HND of the necessary network upgrades required for 2030.

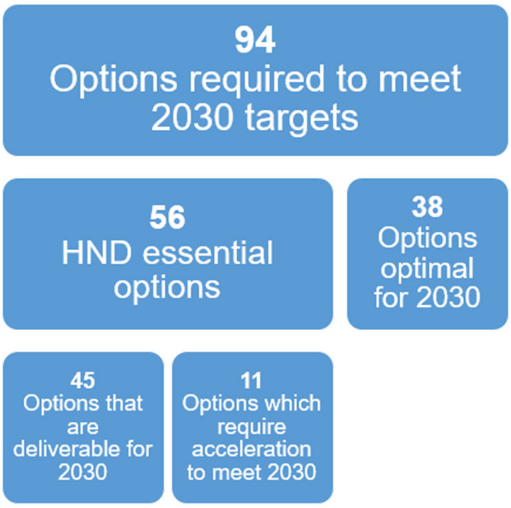
The full set of recommendations, which includes additional reinforcements to the 94 outlined in this HND report, can be found in the *NOA 2021/22 Refresh publication.*

Through the connection assessment process of the HND, a sub-set of these 94 reinforcements were determined to be essential for 2030 to provide a network compliant with the rules we must follow when designing the transmission system. These reinforcement options are often called enabling works, and offer our current, best view, of connection compliance in the context of HND and need to be delivered by 2030 to ensure this. As these reinforcements have been identified as essential for connections, they have not been reassessed through the *NOA 2021/22 Refresh* Cost Benefit Analysis (CBA) as they are all fundamental to delivering a network capable of connecting 50 GW by 2030.

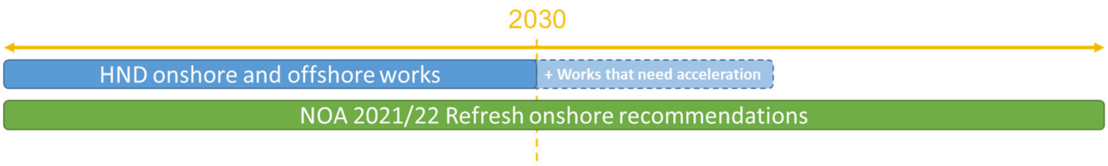
56 options were highlighted as essential for 2030 in the interface point identification stage; however, the NOA has indicated that more than half of these would be optimal, providing significant consumer benefit, if delivered earlier than 2030. In addition to these essential works, the NOA has identified a further 38 reinforcements that are optimal to be delivered on or before 2030, which work together to significantly reduce constraint costs.

Since the HND is effective from 2030, there's minimal change to the *NOA 2021/22* results prior to 2030. Options which fall into this category have been individually assessed ahead of the *NOA 2021/22 Refresh* analysis, and it was concluded they all justify maintaining their NOA recommendation based on no change to their original driver, and hence inherit their *NOA 2021/22* recommendation.

Almost 90 per cent of the required reinforcements are expected to be delivered and in place by 2030 based on EISDs provided by TOs. However, we have identified 11 that are essential for 2030 but will not be delivered in time under the current regulatory and consenting processes. Accelerating these projects would require the Government intervention as suggested in the April 2022 *BESS* and equivalent activities in Scotland. For both the onshore and offshore transmission network, the supply chain will also need to be in place to enable delivery in the required timescales. To emphasise our ambition to accelerate the delivery of onshore works, we have introduced a new term for the *NOA 2021/22 Refresh*: Required in Service Dates (RISDs). The inclusion of RISDs serves to differentiate what is currently achievable from what could be achieved with greater change and intervention. Delivering the onshore reinforcement recommendations in the *NOA 2021/22 Refresh* by 2030 will be challenging but will allow for earlier network reinforcement and drive greater consumer benefit whilst delivering a major milestone in our net zero journey. An illustrative breakdown of the results is shown in *Figure 26* below.



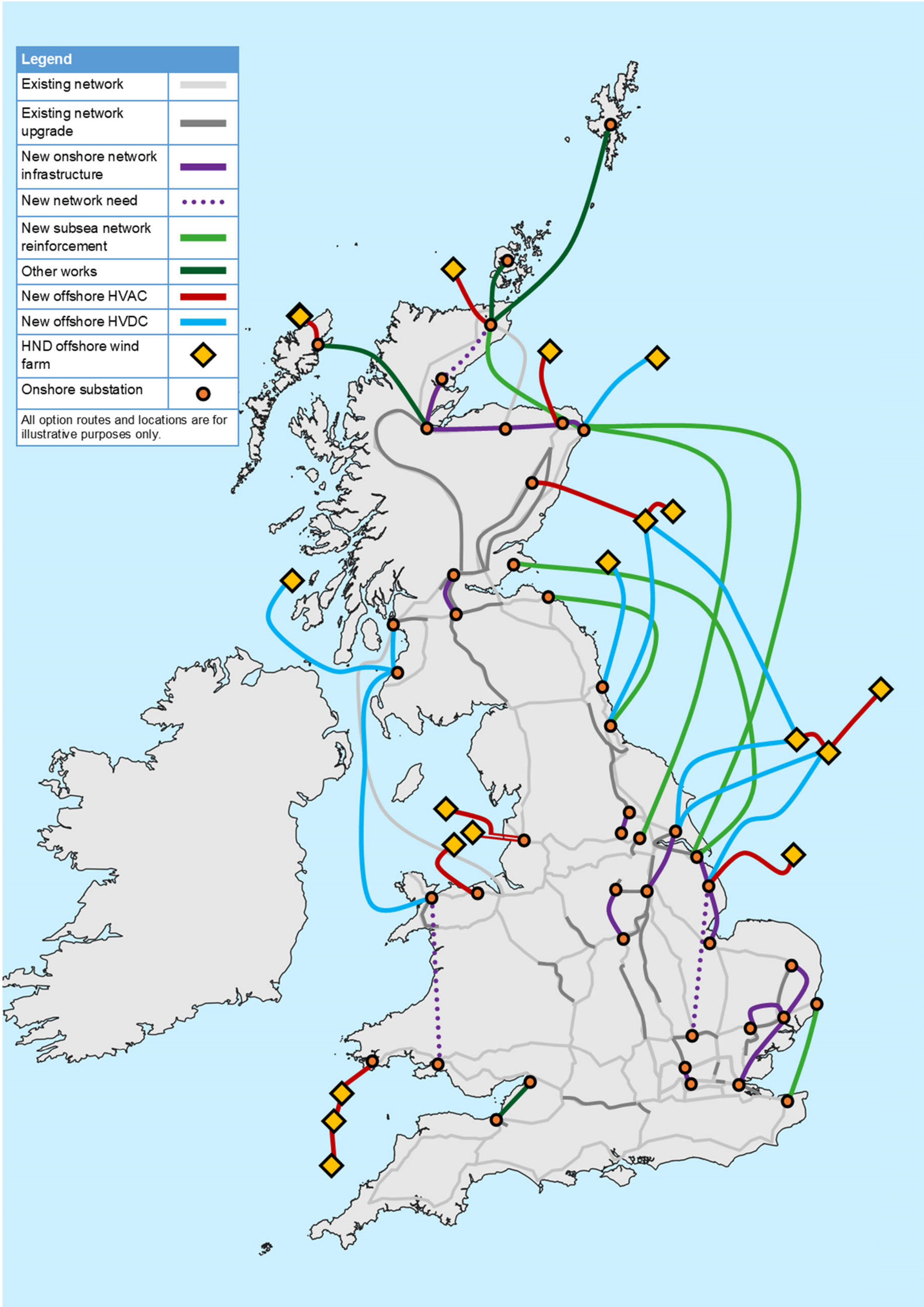
Planning the network and our transition to a zero carbon energy system does not end in 2030. Further to the 94 options required to deliver on 2030 targets, the *NOA 2021/22 Refresh* has provided recommendations for 26 reinforcements beyond 2030. The *NOA 2021/22 Refresh* has found 17 to be economically optimal to deliver and 9 non-optimal at this time. For more detail about network requirements beyond 2030 please refer to the *NOA 2021/22 Refresh* publication. The graphic below illustrates how the wider network reinforcements are considered across the HND and the *NOA 2021/22 Refresh* compare on a timeline *Figure 27*.



The map below shows the final HND and highlights the key wider transmission system upgrades, alongside the recommended offshore design, required to facilitate the connection of 50 GW of offshore wind by 2030. When considering the development of the transmission system, smaller, incremental reinforcements utilising existing assets are considered first. This begins with reduced and no build options, followed by increasing the capability of existing assets. Once these options are exhausted, larger reinforcement options must be considered. These include the construction of new transmission assets, or longer subsea cables to provide power transfer capability over greater distances. *Figure 28* illustrates this development journey highlighting upgrades to existing assets in pink with new onshore transmission assets in purple and new subsea network reinforcements in green.

Some reinforcement options of significance include the four eastern subsea HVDC links from Scotland to England, which are needed on top of the proposed coordinated offshore network to meet increasing bulk power flow requirements brought on by such vast volumes of low carbon generation. In addition, reinforcement options such as Peterhead to Spittal are proposed to bolster more remote, radial parts of the network in northern Scotland that see high volumes of power export. Travelling further down the network, England requires several new transmission circuits to facilitate power flow towards high demand centres in the south. This includes a route from North Lincolnshire to South Lincolnshire to enable the connection of more offshore wind, and a new network need between North Lincolnshire and Hertfordshire, further reinforcing the network and offering a new north to south path for power to flow. These are a snapshot of some of the works required to meet our 2030 targets. For the complete list, please refer to Appendix 1.

Figure 28 Final HND GB Map



5.5.1 Economic and efficient

The CBA is carried out using the same basis as the analysis of the offshore network, by comparing the capital expenditure (capex) of reinforcements against the reduction in constraints costs modelled for future years. Through the CBA we determine the optimal set of onshore reinforcements that complements the offshore network and provides the most value to consumers. The onshore reinforcement options used for *NOA 2021/22* were used as the basis for optimising the onshore network to find the optimal offshore network design. This was based on the best information available at the time and following the conclusion of the recommended offshore network design the onshore reinforcements were reassessed through the *NOA 2021/22 Refresh*. The HND's offshore network was fixed in the background for the final stage of onshore reinforcement analysis.

The NOA process provides our recommendations for which reinforcement projects should receive investment during the coming year to facilitate the development of an efficient, coordinated, and economical system of electricity transmission.

The NOA recommends where, when, and whether to invest in network upgrades across the Great Britain transmission system. It weighs up the benefit of investing in upgrading or building new transmission infrastructure against the costs of curtailing generation that would otherwise be incurred due to power transfer capability limitations in the existing network.

The modified Leading the Way scenario from the *2021 Future Energy Scenarios* that was developed for the HND analysis has been used in the *NOA 2021/22 Refresh* analysis. This modified scenario captures the changes in connection location of in scope offshore generators as a result of the recommended offshore network design. This ensures the onshore recommendations made through the *NOA 2021/22 Refresh* align with the HND's offshore network.

To determine the optimal onshore reinforcements for the HND, the *NOA 2021/22 Refresh* subsequently undertook the following analysis:

- We use boundaries to study the power flows on the electricity transmission network. A boundary splits the system into two parts, crossing critical circuit paths that carry power between areas where power flow limitations may be encountered. A boundary becomes constrained if more electricity is planned to cross the boundary than its capacity can handle. How constrained boundaries are varies from hour to hour, throughout the year. Power flow across the system is significantly impacted by changing demand and generation. For more information, visit our Electricity Ten Year Statement (ETYS) webpage.
- For every boundary, the future capability required was calculated by the application of the National Electricity Transmission System (NETS) Security and Quality of Supply Standard (SQSS) Chapter 4 - Economy and Security planning methodologies. We used the criteria stated in the NETS SQSS to produce the future transmission boundary requirements. We then shared these capability requirements and estimates with the TOs so they could identify future transmission options.
- The ESO and TOs completed boundary capability assessments via power system studies and submitted the results of their own boundary studies to us so that we could perform the CBA. We also performed boundary studies in parallel to the TOs for the purpose of verification.
- The CBA compared forecast capital costs and monetised transmission benefits over the project's lifespan, in order to provide an investment recommendation. Our CBA investigated the economic benefits of different combinations of reinforcement options to identify the single combination that provided the most value for the consumer. The CBA also determined the optimal year for delivery for each reinforcement.

5.5.2 Deliverable and Operable

Deliverability and operability of designs were considered for the regions as a whole, including offshore and onshore works together.

In response to the data on boundary capabilities and requirements, the TOs identified and developed multiple credible options that deliver boundary capability increases. The TOs' option submission included details of not only the uplift in capability for the boundaries it was designed for, but also information on the capital costs, delivery schedule, outage assessment and the development stage. Using the development stage and previous experience in delivering capital projects under the current consenting regime, the TOs submitted EISDs.

The following *Table 32* is used to describe project maturity:

Pre-Construction	*Scoping*	Identification of broad Needs Case and consideration of number of design and reinforcement options to solve boundary constraint issues.
	Optioneering	*The Needs Case is firm; a number of design options are being developed so that a preferred design solution can be identified.*
	Design/Development and consenting	Designing the preferred solution into greater levels of detail and preparing for the planning process including public consultation and stakeholder engagement.
	Planning/Consenting	Continuing with public consultation and adjusting the design as required all the way through the planning application process.
	Consents Approved	Consents obtained but construction has not started
Construction		Planning consent has been granted and the solution is under construction.

The HND recommendations outlined in Appendix 1 reflect our current and best view, based on information available today, of a capital delivery programme that maximises the consumer benefit of the projects assessed. As the development of these projects progresses towards delivery, more details will emerge and variations to the designs or delivery considerations may occur due to supply chain, network access or other constraints. Furthermore, combining multiple projects into a single optimised delivery programme could result in currently unforeseen challenges. Therefore, these recommended delivery dates may be subject to change in future.

There is an overarching risk that a large number of onshore projects are required to meet the 2030 targets and that these projects will need careful consideration and optimisation of their delivery programmes. However, the main deliverability risk from an onshore network perspective is the 11 essential works identified whose current delivery estimations exceed the required 2030 date under current regulations. Accelerating these projects will be challenging and will require the UK Government's intervention suggested in the April 2022 *BESS* and equivalent activities in Scotland. Accelerating these projects as required may also have a knock-on effect on other earlier planned work. This is because the earlier planned work may have to be advanced to create the capacity required to complete the accelerated projects. The options that need acceleration to a 2030 delivery date and their current estimated EISDs are listed below.

Table 33 The 11 NOA Options classified as HND Essential requiring acceleration to 2030

	NOA Code	Description	EISD
1	BLN4	Beauly to Loch Buidhe 400 kV reinforcement	2031
2	BPNC	A new 400 kV double circuit between Blackhillock and Peterhead	2031
3	CGNC	A new 400 kV double circuit between Creyke Beck and the south Humber	2031
4	E4L5	Eastern Scotland to England 3rd link: Peterhead to the south Humber offshore HVDC	2031

5	EDN2	A new Chesterfield to Ratcliffe-on-Soar 400 kV double circuit	2032
6	GWNC	A new 400 kV double circuit between south Humber and south Lincolnshire	2031
7	LRN4	A new network need between Lincolnshire and Hertfordshire	2033
8	PSNC	A new network need between North Wales and South Wales	2037
9	SHNS	Upgrade substation in the south Humber area	2031
10	TGDC	Eastern subsea HVDC Link from east Scotland to the south Humber area	2031
11	TKUP	East coast onshore 400 kV Phase 2 reinforcement (Scotland)	2032

5.5.3 Environmental and community considerations

The environmental and community impacts of the onshore works beyond the interface point have been assessed to different levels depending on where the works are within the TOs' development process. Further detail on the approach to onshore environmental and community assessment can be found in the methodology section.

The table below sets out, at a high level, the process that TOs follow when developing a project. The HND has a mix of reinforcement projects at different stages in the TO development process. Some projects have been through strategic options appraisals and had a strategic option selected; these projects are now progressing design and development and obtaining consent.

The HND also includes some projects which have recently received a "proceed" recommendation in NOA, or where the requirement has only first been identified within the HND process. These projects are therefore only in the scoping stage or recently passed through the "network need agreed" milestone *Table 34*.

Project Phase	Description of Environmental and Community Assessment
Scoping	Environmental constraints mapping and risk identification
Strategic Optioneering	Environmental constraints mapping, and environmental and community options assessment.
Design, Development and Consenting	Undertake environmental surveys, screening, scoping and prepare environmental impact assessments. Key stakeholder and community pre-application engagement
Planning/Consenting	Submit consent applications, formal consultation, advertising and determination
Construction	Discharge consent conditions (e.g. Construction Environmental Management Plan), undertake pre-construction surveys, establish auditing regime.

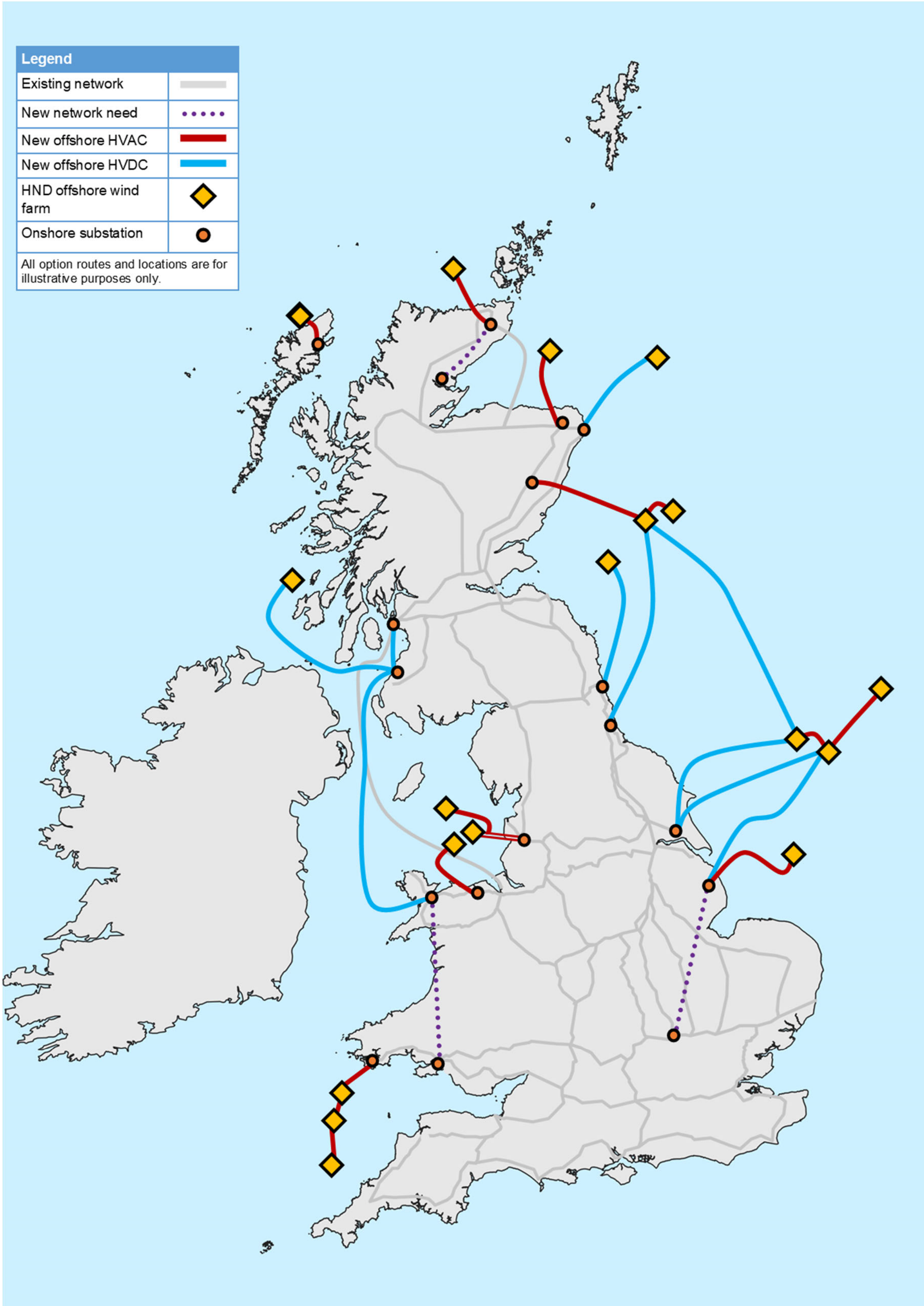
Overall, the HND has identified the need for 22 new transmission circuits. Six of these are new subsea HVDC network reinforcements, whose sole purpose is to enable greater power transfer from north to south. The remaining 16 are split into 13 onshore routes and three new network needs, which are in the early stage of development, having never been previously submitted into the NOA and may materialise as routes onshore, offshore or a mix of both.

The three new network needs, which have been identified as essential options for the HND, are:

1. SLU4 – A new network need in Scotland between Loch Buidhe and Spittal
2. PSNC – A new network need in Wales between North Wales and South Wales
3. LRN4 – A new network need in England between North Lincolnshire and Hertfordshire

These options are still in the early stages of development and were submitted into the NOA 2021/22 Refresh, which has recommended the continued development of options with similar capabilities. As these options have been shown to provide significant benefit, further detailed design assessments will need to be undertaken to ensure a solution which balances the needs of the electricity system, environment and cost to energy consumers is taken forward. These new network needs are highlighted on the map below in *Figure 29*.

Figure 29 GB Map showing new Network needs



To provide further details on the level of environmental and community assessment that has been completed on all the onshore reinforcement works within the HND, the works have been classified depending on their stage of development in *Appendix 1.* below shows the level of assessment undertaken at each stage within the development process.

It is worth noting that the mapping of milestones and development stages may not be precise. Depending on the particular project, the TOs might need to develop and undertake activities which fall into the design and development phase before a strategic solution can be selected. In most cases however, it is expected that a strategic solution will have been selected after completing strategic optioneering.

6. Overall conclusions and next steps

The UK Government's target for offshore wind means more network infrastructure is needed to connect the generation capacity to shore. The Holistic Network Design (HND) uses a coordinated approach to connection to balance the needs of consumers, developers, communities and the environment.

6.1 Design process

We have developed an HND which supports the Government's offshore wind targets of 50 GW by 2030 for Great Britain, including 11 GW in Scotland. Our proposed HND is economic and efficient, deliverable and operable, minimises the impact on the environment, and minimises the impact on local communities.

We have studied different options for offshore infrastructure including high voltage alternating current (HVAC) and high voltage direct current (HVDC) equipment as well as electrical connections between wind farms and onshore landing points. Our recommendations include potential locations of infrastructure and onshore landing points.

We determined an appropriate methodology for the HND, which was agreed with the Central Design Group (CDG) and published in February 2022.

We developed a counterfactual design which uses individual radial connections for each project. We compared the recommended design with the radial counterfactual in order to validate the value of a coordinated approach.

6.2 Recommended design

Offshore wind requires network infrastructure to transport its output to consumers. The HND balances the four network design objectives of being economic and efficient, deliverable and operable and considering environmental and community impacts on an equal footing in setting out a recommended design to do this.

The HND recommends an onshore and offshore transmission system design which is more economic and efficient than a radial design and ensures that required carbon emission reductions can be delivered. The recommended design includes additional offshore cable routes to deliver these emission reductions.

We have recommended a design which connects the 18 in scope wind farms to the National Electricity Transmission System (NETS), using 15 landing points to shore (including the T-point as an onshore landing point).

Our recommendations come in the form of a network topology which sets out a requirement for points of interconnection and the capability we assumed in arriving at our optimal suite of options. The design will need to be optimised appropriately at each stage and the final implementation will be shaped by the detailed decisions made by the parties responsible for construction.

The recommended design considers the four network design objectives:

Economic and Efficient

Our recommended design is economic and efficient. The total costs of our recommended design are estimated to be £5.5 billion lower than the costs of an optimised radial design. Although the recommended design has capital costs which are estimated to be £7.6 billion higher than the optimised radial design, constraint costs are estimated to be £13.1 billion lower in the recommended design.

Deliverable and Operable

The design is deliverable, operable, and provides the opportunity for wind farms to be able to connect by 2030. The longer, and more complex HVDC links in the design are unlikely to be complete by 2030 in the absence of major acceleration in the supply chain. However, the design offers the potential to get generation connected by 2030, and increase capacity progressively, given timely allocation of responsibilities, delivery of the commitments in the British Energy Security Strategy *(BESS)* and a coordinated and concerted effort from all parties. Our analysis has not identified any significant new operability challenges, although the detailed network design (DND) will explore this further. The timings and essential works for each connection will be determined as part of the connection contract update programme.

The HND has aimed to balance the complexity of the design against technology readiness and supply chain availability. It is recognised that the recommended design is more complex than a radial solution both due to the additional HVDC technology and also due to the commercial and technical complexity introduced through coordination.

To facilitate the delivery of the HND and enable government wind generation targets in consideration of community or environmental impacts, the following steps are required:

- A step change in supply chain capacity and rapid development of technology to support larger offshore connections.
- Acceleration and a more holistic approach to project development and consenting timelines.
- Better coordination and collaboration between project promotors.

Environmental impact

The design takes account of environmental constraints and seeks to minimise the impact on sensitive habitats through the coordination of wind farm connections to shore. Cable route corridors can avoid many of the identified environmentally sensitive features, however this is not possible in all cases. Further consideration will need to be given to cable routing in the DND stage to minimise environmental and consenting risks. While the environmental mitigation hierarchy should be followed, it is likely that environmental compensation measures will be required, assuming no viable alternatives are identified in the DND stage. This might include measures at a regional or national level. However, in the first instance measures to alleviate pressures on and protect sensitive habitats both within and outside MPAs should be considered, and compensation seen as a last resort.

The recommended design uses more cable (4%) than the optimised radial design, largely due to the long-distance cables used between wind farms offshore, although the designs cannot be compared on equal terms. The long HVDC links are needed because they minimise network constraints, enabling more zero carbon wind energy to be utilised, and offset the need for less environmentally friendly energy generation. Compared to the optimised radial design, the recommended design would reduce cumulative CO_2 emissions from gas powered generation between 2030 and 2032 by 2 million tonnes of CO_2. The long HVDC links also reduce the need for future infrastructure which would be needed to achieve the same emission reductions and does this while minimising environmental impact though designing the offshore network in a coordinated way.

The recommended design would lead to a reduced impact on the environment and communities, with up to a third fewer cables laid in each cable corridor to shore as a result of the increased use of HVDC technology, reducing the impact on the seabed.

The recommended design provides the following environmental benefits:

- Avoiding Morecambe Bay Special Area of Conservation (SAC) by recommending a shared cable corridor to Penwortham.
- Not recommending further connections at this time into East Anglia beyond those already planned. This avoids impacts on the Haisborough, Hammond and Winterton Special Area of Conservation (SAC), and Cromer Shoal Chalk Beds Marine Conservation Zone (MCZ).
- Minimising environmental impacts by coordinating landfall for the ScotWind East Zone wind farms at Fetteresso.
- Providing additional North to South power flow capability on the East and West coasts. These links minimise network constraints, enabling more zero carbon wind energy to be utilised. They also reduce the need for future infrastructure.

Community impact

The rapid development of offshore wind is already having an impact on coastal communities. The HND has sought to minimise the impact on communities in balance with the other three design objectives.

The recommended design reduces the impact on local communities, for example, relating to the volume of transmission network infrastructure in some areas, the cumulative impact associated with multiple connections, and onshore transmission reinforcements that are driven by the offshore network. There is also the potential for the route corridors to avoid many of the identified community constraints; specific route corridors will be defined as part of the DND.

While the HND has tried to reduce community impacts and reduce the number of cable routes to shore, it is not possible to fully eliminate community impacts. At Peterhead and Creyke Beck there is a significant amount of new infrastructure being proposed in addition to the HND, which will have a cumulative impact on communities in these regions. There are also new coastal sites being proposed on the west coast of Scotland and in Lincolnshire which will impact on coastal communities.

The recommended design provides the following community benefits:

- A reduced number of connection locations in the North West England Region by avoiding Middleton and instead proposing a shared cable corridor to Penwortham.
- Reducing the number of connection locations for ScotWind East Zone projects by recommending a coordinated connection to Fetteresso.
- Not recommending further connections at this time into East Anglia beyond those already planned, as there is already significant planned and existing offshore transmission network infrastructure in this region.

6.3. Next steps

6.3.1 Asset categorisation

Ahead of the start of the detailed network design (DND) and consenting process, an exercise will need to be undertaken by Ofgem to determine which of the transmission assets in the HND will be regulated and developed as 'onshore transmission' and which will be 'offshore transmission'. This will be determined from both a legal and a technical perspective based on their function within the transmission network, rather than where those assets are spatially. For example, there can be 'onshore transmission' in the sea and 'offshore transmission' on land. This exercise will help identify who will be responsible for the DND and consenting process for each of the recommended transmission assets within the HND.

For any 'offshore transmission', it will then be necessary to establish which of those assets are radial and which of those assets are non-radial in line with Ofgem's May 2022 Minded-to Decision on offshore delivery models[34]. This is because there are expected to be different arrangements for the delivery of radial offshore transmission assets within the HND than there are for non-radial offshore transmission assets within the HND.

Ofgem's publication states that where the HND recommends a radial solution, either the generator build model or the OFTO build model is available (as per the existing OFTO regime). For situations where the HND recommends a coordinated (non-radial) solution, Ofgem's minded to decision is for developers to design and build the infrastructure. Ofgem has stated they will work with the ESO and developers to agree how any non-radial offshore transmission system will be delivered once the HND is finalised.

Onshore transmission will be delivered via the usual onshore arrangements (via the incumbent TO under their price control arrangements, or subject to onshore competition).

6.3.2 Detailed Network Design (DND) and consenting process

The information provided in the HND will inform the DND, which will set out the next level of detail for the required network assets. The DND and consenting process will be progressed by the party responsible for delivering each asset.

The HND includes high-level indications of the potential location of infrastructure and technology choice, but it does not limit the ability of the parties undertaking the DND to exercise their engineering judgement or limit their ability to discharge their detailed planning and consenting obligations.

The DND and consenting process will develop the HND recommendations further to determine technology choices, route corridors, and the locations of cable landfalls, substations, offshore platforms and converter stations. Important assumptions and parameters from the HND will be confirmed in the DND phase. The DND will be informed by the feedback received to date, and there will be an opportunity for further stakeholder input as part of the consenting process.

The parties responsible for the DND will undertake the necessary environmental assessment and consenting processes including Habitats Regulations Assessments (HRA) and, depending on the outcome of the current Department for Environment, Food & Rural Affairs (Defra) consultation, providing Biodiversity Net Gain where appropriate. Biodiversity Net Gain is an approach to development which means that habitats for wildlife must be left in a measurably better state than they were in before the development.

It is worth noting that the capital cost differentials quoted are based on high-level cost assumptions. The costs of each of each part of the design are expected to change as the design is developed in more detail during the DND stage.

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[34] https://www.ofgem.gov.uk/sites/default/files/2022-05/Minded-to%20Decision%20and%20further%20consultation%20on%20Pathway%20to%202030_Final1652962587083.pdf

6.3.3 Connection contract updates

In parallel to the DND, the HND recommendations and the Ofgem Minded-to Decision on offshore delivery models for the HND need to be brought together and translated into connection contract updates for in scope developers. This is to identify the works to be delivered by each party, the works each party is dependent upon prior to their connection, the delivery date of those works and other required information. In addition, there are risks and uncertainties that need to be managed via the connection contracts. We will work with Ofgem and developers to agree how coordinated elements of the HND will be delivered so that connection contracts can be updated as soon as practicable.

6.3.4 HND follow up

We are also currently developing the HND follow up process, which aims to provide in scope developers with recommendations in Q1 2023. We will start this process following this publication in July 2022. This will include the remaining ScotWind leaseholders and any capacity made available through the ScotWind clearing process. It is also expected to include approximately 4 GW of Celtic Sea capacity.

The details of the follow up process, including confirmation of scope, a more detailed timeline and other key aspects, such as the methodology to be used for the process, will be communicated in the summer.

6.4 How we met the Terms of Reference (ToR)

The *table 35* below lays out the key requirements from the terms of reference for the HND and how these have been met as well as which section of the report provides the relevant detail on each of the key ToR requirements.

Table 35 - How we met the Terms of Reference

HND Terms of Reference Requirement	How this has been met
Purpose: To support Government offshore wind targets of 40 GW by 2030 for Great Britain, including 11 GW by 2030 for Scotland, as well as net zero by 2050 for Great Britain and by 2045 for Scotland.	The HND balances the four network design objectives to provide a design which facilitates the connection of 23 GW of offshore wind (including 11 GW of ScotWind generation) to enable 50 GW of offshore wind to be connected by 2030. The HND sets out the onshore and offshore network required to achieve this, and we note that changes will be required to existing transmission planning and consenting processes.
The HND must identify the requirements for network capacity on the NETS across Great Britain and in offshore waters.	The HND identifies requirements for capacity across the NETS. Section 4.4 of this report sets out the requirements for the offshore network and section 4.5 sets out the requirements for the onshore network.
The HND should as far as reasonably possible include indications on the potential location of infrastructure such as onshore landing points and locations of new substations, as well as technology type (e.g. AC vs. DC) and other key parts of the specification. It should provide developers with potential connection points and connection dates.	The HND recommends interface points, substations where the offshore network is proposed to connect to the onshore network, giving a high-level indication of onshore landing points. It provides a topology for the offshore network (as shown in *Figure 7*), showing where each wind farm will connect. It also identifies preferred technology types for the offshore network. The HND identifies the works essential to enable generation in each region to connect, and connection dates for each developer will be confirmed as part of the connection offer update process.
The HND needs to consider the Network Design Objectives cost, deliverability and operability, environmental impacts, and community impacts on an equal footing.	The four design objectives in the HND have been considered on equal footing in the strategic options appraisal process. The *HND methodology* document and section 3 provide more detail on our approach to this assessment.
The HND should provide a sufficient level of detail to allow the parties undertaking the DND to make decisions about the specific Network Assets that would fulfil the requirements of the HND. The HND should include a number of “fixed” design components, but it should not limit the ability of the parties undertaking the DND to exercise their engineering judgement or limit their ability to discharge their detailed planning and consenting obligations.	The HND sets out a high-level network design for each region, identifying network requirements and potential route corridors. While indicative route corridors have been identified to determine feasibility, the design does not define cable routes, onshore substation or offshore platform design. The HND does not limit the ability of the parties undertaking the DND to exercise their engineering judgement or limit their ability to discharge their detailed planning and consenting obligations. Aspects such as technology choice, detailed cable route corridors, landfalls and locations of new substations will be considered further in the DND stage, which will be informed by the feedback received to date.
How the third output of the terms of reference will be met (recommend changes to industry technical and commercial codes required in respect to the HND).	Alongside this document, we have published an *Industry Code, Standard and Licence Recommendation Report* as part of the HND publication package. This will include our initial views and planned next steps in relation to where changes to industry codes, standard or licences may be required to facilitate the HND recommendations.
The HND should take account of the views of developers and as already stipulated by individual licences, environmental and community stakeholders, as far as is appropriate and reasonably practicable.	Alongside this document, we have published the *Stakeholder Approach, Engagement and Feedback Report* as part of the HND publication package. This report provides an overview of how we have engaged, who with, and what we have done with feedback provided during the development of the HND.

7. Optimised radial design

This section sets out the optimised radial design, which was developed to enable the evaluation of the benefits of a coordinated design relative to an optimised radial design.

7.1 North West Region

The wind farms within the scope of the Holistic Network Design (HND) for this region are within the Irish Sea (R4_4, R4_5 and R4_6) and off the West Coast of Scotland (SW_W1).

The connections used in the North West radial design are as follows *Table 36*:

Generation	Interface site	Circuit capacity (MW)	Technology[35]		Distance (km)[36]
R4_4	Bodelwyddan	1500	AC	3-4 cables	75
R4_5	Middleton	480	AC	1-2 cables	60
R4_6	Penwortham	1500	AC	3-4 cables	95
SW_W1	Pentir	2000	DC	525 kV XLPE pair with co-axial metallic return	410

The significant environmental constraints in this region include the Morecambe Bay SAC, Ribble and Alt Estuaries SPA and the Liverpool Bay SPA, which cannot be completely avoided. These have been identified by Natural England (NE) and the Joint Nature Conservation Committee (JNCC) as being sensitive to cabling and therefore present significant consenting risks that cannot be resolved at the strategic level.

The significant community constraints in the region include the major settlements of Blackpool, Lytham St Annes, Warton and Abergele, Towyn, Bodelwyddan and St Asaph.

There are several constraints around the Penwortham area which make it difficult to find a cable corridor that avoids all constraints. The constraints are both environmental and community, and may present technical constraints on cable-laying operations.

7.2 South West Region

For the South West region, it would be premature to propose a finalised design before more certainty on the Celtic Sea leasing round is known. For the purposes of this iteration of the HND, 1 GW of Celtic Sea floating wind has been assumed, split into 2 x 300 MW wind farms and 1 x 400 MW wind farm. This assumption was based on the ambitions for the region at the time that the scope for the HND was defined, as well as the size of projects that were being developed. The design will be updated once more detail is known about the capacity and location of seabed leases in the Celtic Sea.

[35] AC cable numbers assume 500 MW is possible at 275 kV. Longer distances may require an additional parallel cable to account for reactive power losses.

[36] The distances shown relate to an indicative route. For the recommended design, route corridors will be determined as part of the Detailed Network Design process

The connections used in the South West radial design are as follows *Table 37*:

Generation	Interface site	Circuit capacity (MW)	Technology[37]		Distance (km)[38]
CS_FW_1	Pembroke	300	AC	1-2 cables	45
CS_FW_2a	Baglan Bay	300	AC	1-2 cables	130
CS_FW_2b	Baglan Bay	400	AC	1-2 cables	160

Our analysis shows that Pembroke is the best radial connection site for CS_FW_1. However, our economic analysis shows that for the other notional wind farms considered, the overall costs associated with connecting to the South West Peninsula (e.g. Alverdiscott) and South Wales are very similar.

The radial design in this region has significant environmental constraints. These include Natural Resources Wales (NRW) key sensitive habitats, such as mudflats and sandflats not covered by seawater, reefs and sandbanks, as well as the Limestone Coast of South West Wales/Arfordir Calchfaen de Orllewin Cymru SAC.

There is limited scope to avoid the NRW identified areas of mudflats and sandflats not covered by seawater, and reefs. The Bristol Channel Approaches SAC and the Northwest of Lundy MCZ also cannot be avoided.

For this region most community constraints can be avoided. The significant community constraints include scheduled monuments and the urban regions of Sandfields, Rhoscrowther, Port Talbot and Baglan Energy Park. Most of these constraints can be avoided within a cable route corridor, with the exception of the Baglan Energy Park in the routes to Baglan Bay substation, which may be considered part of the substation.

[37] AC cable numbers assume 500 MW is possible at 275 kV. Longer distances may require an additional parallel cable to account for reactive power losses.
[38] The distances shown relate to an indicative route. For the recommended design, route corridors will be determined as part of the Detailed Network Design process

7.3 East Coast Region

The wind farms within the scope of the *HND* for this region include wind farms off the east coast of Scotland (PA_2, SW_E1a, SW_E1b, SW_NE4 and SW_NE7) as well as off the east coast of England (PA_1, R4_1, R4_2 and R4_3).

Table 38 - The connections used in the East Coast radial design are as follows:

Generation	Interface site	Circuit capacity (MW)	Technology[39]		Distance (km)[40]
PA_2	Branxton	1800	AC	4-5 Cables	60
SW_E1b	Peterhead	1200	AC	3 cables	135
SW_NE7	Peterhead	1500	DC	525 kV XLPE bundled pair	135
SW_NE4	New Deer	1500	AC	3-4 cables	90
SW_E1a	Blyth	1500	DC	525 kV XLPE bundled pair	180
R4_1	Creyke Beck	1500	AC	3-4 cables	160
R4_2	Creyke Beck	1500	AC	3-4 cables	180
R4_3	Lincolnshire connection node	1500	AC	3-4 cables	105
PA_1	Hawthorn Pit	1320	DC	525 kV XLPE bundled pair	280

The significant environmental constraints in Scotland include the Outer Firth of Forth and St Andrews Bay Complex SPA, Firth of Forth Complex MPA, Annex I Reefs, Berwick to St Mary's MCZ, Coquet to St Mary's MCZ, Northumberland Marine SPA, Northumberland Coast SSSI, Buchan Ness to Collieston Coast SPA and MPA, Rosehearty to Fraserburgh Coast SSSI, and the Southern Trench MPA. It is not expected to be possible to define a set of radial route corridors which avoid all of these constraints.

The east coast of England has many environmental sensitivities and designations that are constraints to offshore cabling, with no route options on the east coast managing to avoid all designated sites. The significant environmental constraints include Dogger Bank SAC, Berwickshire and North Northumberland coast SAC, Berwick to St Marys MCZ and the Coquet to St Marys MCZ, all of which have been identified as being sensitive to cabling by JNCC/NE. It is not expected to be possible to define a set of radial route corridors which avoids all of these SACs and MCZs.

The significant community constraints in Scotland include urban areas and scheduled monuments, however there is the potential to avoid these constraints in potential cable corridors.

[39] AC cable numbers assume 500 MW is possible at 275 kV. Longer distances may require an additional parallel cable to account for reactive power losses.
[40] The distances shown relate to an indicative route. For the recommended design, route corridors will be determined as part of the Detailed Network Design process

The significant community constraints in England include the major settlements/urban areas of Seaham, Dawdon, Murton, South Hetton, Easington Lane, Blyth, Bedlington, Sutton on Sea, Sandilands, Long Riston, Skirlaugh, Woodmansey and Kingswood and Hornsea. However, there is the potential to define route corridors which avoid these constraints.

7.4 North Scotland Region

The radial design for the North Scotland Region is the recommended design. This design is described in the main body of this report.

A1 - Appendix 1 Onshore and Offshore List of Works

This link provides a comprehensive list of onshore and offshore network recommendations, including offshore works and onshore connections and wider (NOA) works

A2 Appendix 2 Community and Environmental Assessment Approach

A2.1 Introduction

A2.1.1 Purpose

The purpose of this appendix is to provide an overview of the how the Environment and Community network design objectives have been appraised in arriving at the recommended HND. This appendix also provides a summary of how the cable routing assessments were undertaken. These assessments were used to inform the selection of grid connection locations (also referred to as interface point sites) within the HND.

The purpose of the Holistic Network Design (HND) is to provide a coordinated onshore and offshore design for a 2030 network to meet government objectives of connecting 40 GW of offshore wind in Great Britain by 2030, including 11 GW in Scotland.

The HND has been developed in accordance with the OTNR[41] HND terms of reference[42] (ToR) that have been agreed with the OTNR partners. The ToR set out that the HND should provide the following:

The HND should ensure an economic, efficient, operable, sustainable and coordinated National Electricity Transmission System (NETS) (including onshore and offshore assets required to connect offshore wind) to present options, and a recommended HND for offshore connections works. This includes connections and associated strategic onshore infrastructure necessary to connect offshore generation in order to facilitate the pace and certainty required to deliver the 2030 offshore wind targets and the 2045 and 2050 net zero targets.

The HND ToR set out four network design objectives, which are to be considered on an equal footing:

- **Economic and efficient costs** – the network design should be economic and efficient.
- **Deliverability and operability** – the network design should be deliverable by 2030 and the resulting system should be safe, reliable and operable.
- **Environmental impact** – environmental impacts should be avoided, minimised or mitigated by the network design, and best practice in environmental management incorporated in the network design.
- **Local communities impact** – impacts on local communities should be avoided, minimised or mitigated by the network design.

The methodology used to develop the HND incorporating all of the design objectives has been set out in the HND Methodology (February 2022)[43].

A2.1.2 Background

Offshore wind has been identified as a critical technology in achieving net zero greenhouse gas emissions by 2050. In order to realise this target, a step-change in both the speed and scale of deployment of offshore wind is required. Delivering the ambition for offshore wind deployment in the timescales required will be a challenge and will rely on an offshore and onshore transmission network that enables this growth. The transmission network needs to be expanded in a way that is efficient for consumers, and considers the impacts on communities and the environment.

The potential effects of the cables, substations, and other electrical transmission infrastructure to on the marine and terrestrial environment and on coastal communities is recognised. A number of statutory and non-statutory environmental bodies have published advice seeking to avoid or reduce

[41] https://www.gov.uk/government/groups/offshore-transmission-network-review
[42] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1059676/otnr-central-design-group-network-design-tor.pdf
43 https://www.nationalgrideso.com/document/239466/download

environmental effects from cabling operations[44,45,46] . The ESO Phase 1 Offshore Coordination report reported the concerns of local councils over the local community impacts particularly in respect of disruption during construction, long term impacts from some of the large structures required, lack of coordination and inadequate mitigation and compensation[47]. The potential to reduce disruption, cumulative environmental impacts and impacts on coastal communities through greater coordination has been recognised in emerging national policy[48].

It has also been recognised that some areas of the GB coastline may be subject to particular pressure. This may arise from any one or a combination of: the physical or man-made features of the coastline (e.g., cliffs or urban development); environmentally sensitive habitats and/or designations; the pattern of previous coastal developments including existing and planned offshore wind transmission systems, interconnectors, sub-sea pipelines and telecommunication cables; and the location of the offshore wind development proposed to meet current targets.

The HND recommends the optimal transmission network based on the four network design objectives to both connect the offshore wind farms to the transmission network and transport their power to where it is needed, but route corridors and siting are not defined at this stage. It has been developed to provide a sufficient level of detail to enable a Detailed Network Design (DND), which will make decisions about specific network assets. The HND contains recommendations on the potential location of infrastructure, including cable route corridors and the locations of new substations, as well as technology choices for the offshore network. At the same time, the HND does not limit the ability of parties undertaking the DND to exercise their engineering judgement or discharge their detailed planning obligations.

We have sought to achieve the environment and community objectives of the ToR by applying the mitigation hierarchy of avoid, reduce, mitigate to the environmental and community designations, constraints and features identified to inform the HND. This includes, as far as possible, avoiding constraints with features expected to be sensitive to impacts from cabling or infrastructure, where the risks of cabling or siting would be significant.

In some cases, economically better design solutions have not been included on environmental and community grounds, but it has not been possible to avoid all designated sites or other features of importance. The route corridors that have been identified will be confirmed in the next stage of detailed network design. At this stage, construction methods, the assessment of effects and mitigation will also be examined. Where effects on designated sites cannot be avoided, reduced or adequately mitigated they may need to be compensated for. Although this is the last resort of the mitigation hierarchy, it is likely that environmental compensation measures will be required, which might include measures at a regional or national level. The need for further consideration of such measures to deliver the UK's ambitions for more power generation from wind is acknowledged in the British Energy Security Strategy (*BESS).*

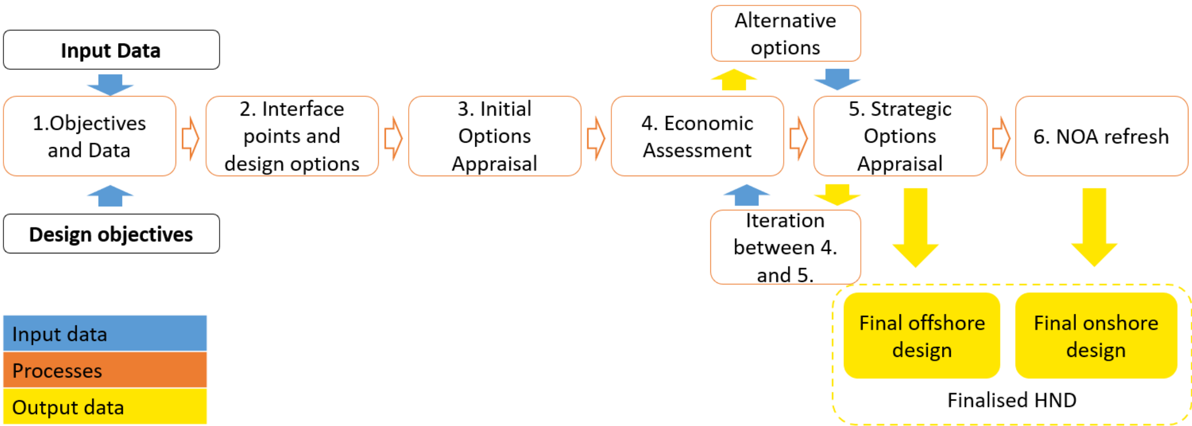
[44] Natural England and JNCC advice on key sensitivities of habitats and Marine Protected Areas in English Waters to offshore wind farm cabling within Proposed Round 4 leasing areas, September 2019.
[45] Sensitivity of marine ecology receptors to cabling activities in Wales, Natural Resources Wales, 2019.
[46] Sectoral Marine Plan for Offshore Wind Energy. Scottish Government October 2020
[47] Offshore Coordination Phase 1 Final Report, Summary of findings - Community and Social, National Grid ESO, December 2020.
[48] Draft Overarching National Policy Statement for Energy (EN-1), BEIS, September 2021.

A2.2 Holistic Network Design Appraisal Process

A2.2.1 Overview of process

A structured appraisal process was developed to consider the design objectives set out in the HND ToR which is detailed in the HND Methodology. This is summarised in *Figure 30* below.

Figure 30 - Overview of HND process



Each of these steps is described in more detail in the HND Methodology, and the outcomes including the recommended design are set out in our suite of HND publications (as published in July 2022). The design is described in detail in the *Holistic Network Design* report, and a high-level summary can be found in the *Pathway to 2030* document.

We appointed RPS as specialist cable routing consultants to assist us with identifying cable route corridors and infrastructure options that met the environment and community design objectives. The following sections set out how these objectives were taken into account at each stage of the process.

A2.2.2 Establishment of HND data set

The first step in developing the HND was to establish the scope of the study and the background data sets required. This included establishing the offshore generation in scope which would determine the spatial scope of the environmental and community data required to support the design. How the scope was defined is set out in the HND Methodology. The projects in-scope were primarily those that secured seabed leases in The Crown Estate Leasing Round 4[49] and those successful in the ScotWind[50] leasing round as well as other spatially relevant wind farm developments that fitted with the Pathway to 2030 criteria. 1 GW of offshore wind within the Celtic Sea[51] was also considered.

The data required to support the appraisal of the environment and community objectives therefore extended to almost all of GB waters within the jurisdiction of the Exclusive Economic Zone, and the land of GB onshore, but excluding Northern Ireland.

Environmental and community data sources were identified and evaluated that were relevant to meeting the design objectives and available at GB scale. In most cases these were created and made available by the relevant agencies of the administrations of England, Scotland or Wales. As far as possible these were organised to achieve consistency across the HND dataset, so the planning factors used in developing the HND were consistent across GB and its waters. Relevant technical data such as seabed depths, seabed types, vessel density and cliff heights, were acquired from national or commercial data sources depending on the best quality of data available.

[49] https://www.thecrownestate.co.uk/en-gb/what-we-do/on-the-seabed/offshore-wind-leasing-round-4/
[50] https://www.crownestatescotland.com/what-we-do/marine/asset/offshore-wind/section/scotwind-leasing
[51] https://www.thecrownestate.co.uk/en-gb/media-and-insights/news/the-crown-estate-to-create-new-floating-wind-leasing-opportunity-in-the-celtic-sea/

The data obtained is listed in Appendix A of this document. Each dataset was also classified according to the degree of constraint and/or risk it posed to cable routing or infrastructure siting. The classification was Black/Red/Amber/Green defined as set out in the table below. This became known as the BRAG Ranking.

Table 39 - BRAG Ranking Table

Rank	**Environment/Community**	**Technical**
Black	Features or designations which affect the likelihood of an option being achievable to such a degree that the option should not be considered as part of the HND.	Features or constraints that are likely to affect the feasibility of construction and/or buildability of the HND to such a degree that the option should not be considered as part of the design.
Red	Features or designations that are so significant or pose such a high degree of risk to the design that they should be avoided[52], except in exceptional cases which include where potential mitigation (or compensation) is known; where the potential benefits to the design would clearly outweigh the potential harm and/or impacts; or where there are no alternatives.	Features or constraints that are likely to affect the feasibility of construction and/or buildability of the design to such a degree that options affecting them should not be included in the HND without potential solutions to the issues raised.
Amber	The most protected features and/or areas that are likely to require detailed assessment and/or mitigation and should be avoided if possible.	Significant technical constraints that may cause cost increases and/or significant schedule delays; not ideal but likely to be achievable and/or capable of resolution.
Green	Features or designations to be taken into account in constraint assessment/study but which are likely to be capable of resolution.	Informative of approach but medium to low likely technical constraint causing significant cost increase and/or significant schedule delays.

The data in the BRAG ranking was collated in a Geographical Information System (GIS). The GIS dataset developed for the appraisal therefore consisted of a GB-wide environment and community dataset that included:

- GIS maps;
- Environmental constraint data;
- Community constraint data;
- Technical constraint data;
- BRAG rankings
- NETS substations/interface points.

In addition, data was also collated to inform the appraisal on:

- Other plans and projects that might affect HND options, including network reinforcements in our *Network Options Assessment* (*NOA*).
- Typical forms of development for the purposes of appraisal e.g. cable types and spacing required, and the size of substations and converter stations used in offshore transmission systems.

[52] To be avoided except for linear constraints - being point to point features, where it may not be possible to avoid crossing these constraints.

A.2.2.3 Identification of offshore design options and interface points

Once the study area and input data had been finalised, offshore designs and potential interface points for the connection of in-scope generators connecting to the NETS were developed. We worked with the Transmission Owners to identify potential interface points where in-scope offshore generators could connect to the onshore NETS.

The potential interface points with the NETS were initially identified by proximity to the coast and the location of the windfarms. Other relevant data, including planned network developments and known limitations of the network, were also considered. Appendix B of this section of the report provides a case study for North West England covering the identification of interface point sites.

This process identified a long list of options for interface points and offshore designs that were subject to a high-level appraisal process to refine them into a short list of options. Potential options included both existing onshore NETS substations and potential new locations.

A2.2.4 Initial options appraisal process

The high-level community and environmental constraint mapping then overlaid with the offshore generators and the potential interface points.

The high-level environmental and community constraints were considered alongside technical routing, onshore grid technical factors and deliverability considerations, to produce a long list of potential interface points for initial appraisal. Interface points likely to be subject to constraints were avoided where possible. However, if the design objectives could not be met without including them, some options with constraints were taken forward to be considered in more detail at the initial appraisal stage. Most of the sites where technical constraints indicated routes to access them were clearly not buildable or deliverable within the timeframes for the HND, were not taken forward. The options that were taken forward for appraisal were mainly those where there was good potential for a technically deliverable grid connection within reasonable proximity of the coast.

A2.2.5 Cable Routing and Siting Assessment

For infrastructure siting and cable routing, the objective of this stage of the appraisal was to identify feasible cable routes from the generators to the interface points and to provide an initial appraisal of the environmental and community effects, to enable each option to be assessed against all four network design objectives on an equal footing.

For each potential option, a cable route corridor was defined which avoided the principal constraints in the BRAG data set as far as possible. An initial appraisal was then completed for each cable route corridor. An example initial appraisal is given at Appendix C of this section of the report.

These initial appraisals were completed for each potential cable route corridors and were refined and amended to avoid or reduce potential impacts where possible. In total initial appraisals were completed for approximately 170 potential cable route corridors.

A2.2.6 Strategic options appraisal

The strategic options appraisal followed a similar process as the initial options appraisal process but incorporating a more detailed assessment using the cable routing and siting BRAG assessments and the results of the economic and deliverability assessments.

The appraisals of environmental and community effects of options for connecting the generators to the NETS were considered on an equal footing together with the other design objectives.

The relevant factors against each objective were weighed up between multiple options in the strategic appraisal and each overall option given a BRAG status. Where options performed poorly against one objective such that the design objectives as a whole would not be met (black rating), they were removed. Where options performed comparatively well across objectives, additional analysis was carried out in order to differentiate between them and enable a recommendation to be made.

In balancing the four network design objectives, the relevant factors in each area were part of the decision-making process and considered equally alongside other factors based on expert judgement.

The weighting attached to any of the factors depended on the magnitude of the issue in the context of all factors affecting the decision being made at the time.

This process was carried out for the radial and coordinated designs, although where a route corridor or initial option combination used in the coordinated design was very similar to one that had already been appraised for the radial design, the radial design appraisal was also used in the appraisal of the coordinated design rather than being repeated.

Option Appraisal Summary Tables (OASTs) were completed for the short-listed radial and coordinated design options in each region. From the comparison of radial design options, a preferred radial design was selected. The short-listed coordinated designs and the preferred radial designs were then compared in the coordinated OASTs to select the recommended option for each region.

A2.3 Conclusions

The conclusions of the appraisals and the recommended HND are set out in our July 2022 suite of HND publications.

A summary of the environmental and community appraisal for each element in the recommended design is given in the tables below.

Table 39 - Offshore Transmission Summary Appraisal of Recommended Option By Wind Farm Location

Offshore Wind Farm	Recommended Interface Point (or end point)	Technology [2]	Capacity (GW)	No. of Cables [2]	Route Corridor Length (km) [1]	BRAG Rating			
						Technical Offshore Cabling	Offshore Environmental	Onshore to Substation Environmental	Onshore to Substation Community
R4_4	Bodelwyddan	HVAC	1.5	3-4	75	Amber	Amber	Green	Green
R4_5	Penwortham	HVAC	0.48	1	60	Amber	Amber	Amber	Amber
R4_6	Penwortham	HVAC	1.5	3	96	Amber	Amber	Amber	Amber
SW_W1	T-Point	HVDC	2	2	180	Amber	Amber	Green	Amber
T-Point	Pentir	HVDC	2	2	315	Amber	Amber	Amber	Amber
T-Point	Hunterston	HVDC	2	2	55	Amber	Amber	Green	Amber
SW_N4	Arnish (Lewis)	HVAC	0.74	2-3	40	Amber	Amber	Amber	Green
SW_N1	Spittal	HVAC	2.25	4-6	65	Amber	Amber	Amber	Green
SW_NE4	New Deer	HVAC	1.5	3-4	90	Amber	Amber	Amber	Green
SW_NE7	Peterhead	HVDC	1.5	2	135	Amber	Amber	Amber	Amber
SW_E1a	Hawthorn Pit	HVDC	1.8	2	225	Amber	Amber	Green	Green
SW_E1a	Fetteresso	HVAC	2	4-5	115	Amber	Amber	Green	Green
SW_E1a	SW_E1b	HVAC	1.2	3-4	80	Green	Green	N/A	N/A
PA_2	Blyth	HVDC	1.8	2	145	Amber	Red	Amber	Green
R4_1	SW_E1a	HVDC	1.8	2	285	Amber	Red	N/A	N/A
R4_1	R4_2	HVAC	1.5	3-4	30	Green	Red	N/A	N/A
R4_1	Creyke Beck	HVDC	1.8	2	160	Amber	Amber	Green	Green
R4_2	Creyke Beck	HVDC	1.8	2	180	Amber	Amber	Green	Green
R4_2	Lincolnshire Connection Node	HVDC	1.8	2	210	Amber	Red	Green	Green
R4_2	PA_1	HVAC	1.32	3-4	85	Amber	Red	N/A	N/A
R4_3	Lincolnshire Connection Node	HVAC	1.5	3-4	105	Amber	Amber	Green	Green

Offshore Wind Farm	Recommended Interface Point (or end point)	Technology [2]	Capacity (GW)	No. of Cables [2]	Route Corridor Length (km) [1]	BRAG Rating			
						Technical Offshore Cabling	Offshore Environmental	Onshore to Substation Environmental	Onshore to Substation Community
CS_FW1	Pembroke	HVAC	1	2-3	45				
CS_FW2a	CS_FW1	HVAC	0.7	2	35			N/A	N/A
CS_FW2b	CS_FW2a	HVAC	0.4	1-2	45			N/A	N/A

[1] The HND recommends the optimal transmission network based on the four network design objectives to both connect the offshore wind farms to the transmission network and transport their power to where it is needed, but route corridors and siting are not defined at this stage. Detailed Network Design (DND) will make decisions about specific network assets.
[2] The choice between AC and DC cabling becomes less clear cut in the upper length range for AC cables (150-200 km) and will depend on other project specific factors, including environmental, technical and community constraints. The final choice of technology will be made as part of the Detailed Network Design phase. AC cable numbers assume 500 MW is possible at 275 kV and AC marine cables have three phases together in one cable or bundle.
[3] Two alternative route corridors were considered for the approach to Pentir with an HVDC connection at the Strategic Options Appraisal stage. One route corridor (296km) approached from the north and west but its feasibility was uncertain because of potential effects on the Menai Strait and Conwy Bay SAC and habitats sensitive to cabling operations, or technical constraints of limited space and rocky terrain with an onshore route (or both). The approach from the South was ultimately included in the HND to avoid these constraints but is longer. We would expect the route to be reviewed again at the DND stage.
[4] The route corridor originally developed from SW_NE7 to Peterhead was an AC route corridor overland from the north because of limitations on the space available for cable laying directly into Peterhead from the sea. The final recommended design is for an HVDC connection from SW_NE7. This might allow an opportunity to access Peterhead from an alternative landfall reducing to the cable route to c.110km
[5] Two alternative route corridors were considered for the final design. One that runs to the north of Triton Knoll offshore wind farm and so avoids the Inner Dowsing, Race Bank and North Ridge SAC, and an area of steep seabed gradient known as the Silver Pit. The other route takes a route to the south of Triton Knoll but overlaps with part of the SAC; the impact of this route would need to be determined through a more detailed EIA (Environmental impact Assessment). The first route is 105km, the second is 95km and the first also requires more crossings of other pipeline and existing cable route infrastructure. It is recommended that the advantages and disadvantages of both alternatives are considered as part of the route selection for the Detailed Network Design, when further information on likely cable burial and protection measures will also be available.

Table 40

Theme	Data displaying	Offshore cables	Offshore platforms	Landfall	Onshore cables	Onshore stations
National Parks	UK National Parks	N/A	N/A	A	A	R
Areas of Outstanding Natural Beauty (AONBs)	England and Wales AONB and Scotland NSAs	N/A	N/A	A	A	R
Heritage Coasts	England and Wales Heritage Coasts	N/A	N/A	A	A	R
National trails	England and Wales National Trails, and Scotland's Great Trails	N/A	N/A	A	A	A
Special Areas of Conservation (SAC)	Onshore and offshore UK SACs - identified as having sensitive features	R	R	R	R	R
	Onshore and offshore UK SACs - not identified as having sensitive features	A	A	A	A	R
Special Protection Areas (SPA)	Onshore and offshore UK SPAs - identified as having sensitive features	R	R	R	R	R
	Onshore and offshore UK SPAs - not identified as having sensitive features	A	A	A	A	R
pSPAs	England and Scotland proposed SPAs	A	A	A	A	R
cSACs	UK candidate SACs	A	A	A	A	R
SCI	Sites of Community Importance	A	A	A	A	R
Ramsar sites	UK RAMSAR sites	A	A	A	A	R
Proposed Ramsar sites	UK Proposed Ramsar sites	A	A	A	A	R
SSSIs	UK SSSIs	A	A	A	A	A
National Nature Reserves (NNRs)	UK National Nature Reserves	A	A	A	A	A
Biosphere Reserves	UK Biosphere Reserves	G	G	G	G	G
Marine Protected Areas	UK Marine Protected Areas	A	A	A	N/A	N/A
Marine Conservation Zones	UK Marine Conservation Zones - identified as having sensitive features	R	R	R	N/A	N/A
	UK Marine Conservation Zones - not identified as having sensitive features	A	A	A	N/A	N/A
Ancient Woodlands	UK Ancient Woodlands	N/A	N/A	A	A	R
Important Bird Areas	UK Important Bird Areas	G	G	G	G	A
RSPB Reserves	UK RSPB Reserves	G	G	G	G	A
Seabird At Sea Density (Summer/Winter)	UK Seabirds at Sea Density	G	G	N/A	N/A	N/A

Theme	Data displaying	Offshore cables	Offshore platforms	Landfall	Onshore cables	Onshore stations
Annex 1 Sandbanks	UK Annex 1 Sandbanks	A	A	A	N/A	N/A
Annex 1 Submarine Structures	UK Annex 1 Submarine Structures	A	A	A	N/A	N/A
Annex 1 Saltmarsh	UK Annex 1 Saltmarsh	A	A	A	N/A	N/A
UK Grey Seals	UK Grey Seal - High density	G	G	A	N/A	N/A
UK Harbour Seals	UK Harbour Seal - High density	G	G	A	N/A	N/A
SCANS 3 (marine mammal densities)	UK Marine Mammal densities	G	G	G	N/A	N/A
Fish spawning grounds	UK Fish spawning grounds 2010	G	G	N/A	N/A	N/A
Fish nursery grounds	UK Fish Nursery grounds 2010	G	G	N/A	N/A	N/A
World Heritage Sites (WHS)	UK World Heritage Sites	R	R	R	R	B
Scheduled Monuments	UK Scheduled Monuments	R	R	R	R	R
Listed Buildings	UK listed buildings (Grade I, II* and II listed buildings)	N/A	N/A	A	A	R
Registered Parks and Gardens & Gardens and Designed Landscape	Registered Parks and Gardens & Gardens and Designed Landscape	N/A	N/A	A	A	R
Wreck locations	UK wreck locations	R	R	R	N/A	N/A
Protected wrecks	England and Wales protected wrecks	R	R	R	N/A	NA
Ship Hulk	Ship Hulk	R	R	R	N/A	NA
Registered Battlefields	England and Scotland Registered Battlefields	N/A	N/A	A	A	B
Historic marine protected areas	Scotland Historic Marine Protected areas	R	B	R	N/A	NA
Air Quality Management Areas (AQMAs)	UK Air Quality Management Areas	NA	NA	NA	G	G
Major Settlements	UK Major Urban Settlements (for noise, see also Socio-Economics)	N/A	N/A	G	G	A

Theme	Data displaying	Offshore cables	Offshore platforms	Landfall	Onshore cables	Onshore stations
Geoparks	UK Geoparks	N/A	N/A	G	G	G
Water- lakes	Lakes and large water bodies for GB	N/A	N/A	N/A	A	B
Water- rivers	Rivers for GB	N/A	N/A	G	G	R
National Flood Zones/Areas Benefiting from Defences	3 National Flood Zones & 3 Areas benefiting from defences	N/A	N/A	G	G	A
Former landfill sites	England and Wales former landfill sites	N/A	N/A	A	A	A
Major settlements/Urban Areas	UK Major Urban Settlements	N/A	N/A	R	R	R
National Trust Land	National Trust Open Land and Limited Access Land	N/A	N/A	A	A	R
Trans-European Networks (roads or national/European walking/cycling routes)	Roads and Railway	N/A	N/A	G	G	R
Military Airfields/ Sites/ Practice Areas	Military Areas - Onshore sites and Offshore live firing areas	A	R	A	G	R
Passenger Airports	Airports	N/A	N/A	A	A	R
Major onshore utilities and other installations	Includes electrical and gas but not telecoms	N/A	N/A	A	A	B
Port Lands		R	R	R	R	R
Harbour Areas		G	A	G	N/A	N/A
RYA marinas	RYA marinas - check buffer	R	R	R	N/A	N/A
RYA sailing and racing areas	RYA Boating Areas	G	A	G	N/A	N/A
Dredging	UK Dredging Navigation	A	R	A	N/A	N/A
	UK Aggregate Dredging Extraction	R	R	R	N/A	N/A
Dredge and Spoil Dumping Sites	UK Dredge Spoil Dumping Sites	R	A	N/A	N/A	N/A
Offshore energy generation and cable routes	UK Offshore Energy Generation Sites - Existing	R	R	N/A	N/A	N/A
	UK Offshore Energy Generation Sites - Proposed	G	A	N/A	N/A	N/A
	UK Offshore Energy Cable Routes - Existing	A	A	R	N/A	N/A
	UK Offshore Energy Cable Routes - Proposed	G	A	G	N/A	N/A

Theme	Data displaying	Offshore cables	Offshore platforms	Landfall	Onshore cables	Onshore stations
Offshore Infrastructure	Offshore Telecom Cables	A	A	A	N/A	N/A
	Offshore Power Cables	A	A	A	N/A	N/A
	Offshore Pipelines	A	A	A	N/A	N/A
	UK Oil and Gas Wells & Diffusers	R	R	N/A	N/A	N/A
	UK Offshore Oil and Gas Installations	R	R	R	N/A	N/A
	UK Offshore Carbon Capture and Storage Site Agreements	A	A	N/A	N/A	N/A
	UK Offshore Meteorological and Oceanographic Equipment Agreements	A	A	N/A	N/A	N/A
Other planned infrastructure (e.g. coastal development near potential landfall areas)	-	A	A	A	A	A
Traffic separation zone	Traffic Separation Zones	A	B	N/A	N/A	N/A
Shipping lanes	Shipping lanes	A	B	A	N/A	N/A
AIS Vessel Density Grid	UK AIS Vessel Density grid - High density shipping areas	A	A	A	N/A	N/A
Designated anchorage areas	Designated anchorage areas	R	R	R	N/A	N/A
Bathing waters	Bathing Water	G	R	G	N/A	N/A
Shellfish waters	Shellfish Waters	G	A	G	N/A	N/A
Fishing activity	UK Fishing Activity - Areas of high intensity fishing effort	G	G	G	N/A	N/A
Marine Fish Farms	UK Marine Finfish	A	R	A	N/A	N/A
Bathymetry	Slope 10 - 15%	G	G	G	N/A	N/A
Bathymetry	Slope >15%	R	B	R	N/A	N/A
Bathymetry	Depth <10m	G	N/A	N/A	N/A	N/A
Bathymetry	Depth <20m & Depth >50m	N/A	B	N/A	N/A	N/A
Cliff Shoreline	>15m	N/A	N/A	R	N/A	N/A
Average Wave Height (sig wave 50%tile)	>2.5m	N/A	R	N/A	N/A	N/A
Topography - Uplands	>200m	N/A	N/A	N/A	G	R
Topography - Slope	Slope >57% (30 degrees)	N/A	N/A	N/A	R	R

Theme	Data displaying	Offshore cables	Offshore platforms	Landfall	Onshore cables	Onshore stations
Areas of mobile sediment- from sand or Rock/ other substrata part of this data	Offshore Sand	G	G	G	N/A	N/A
Known geological constraints Offshore – e.g. boulder fields, exposed bedrock	Offshore Rock	A	A	A	N/A	N/A
Known geological constraints Onshore – e.g. Shallow soils, exposed rock	Shallow soils and exposed rock	N/A	N/A	A	A	G

Appendix B - Case Study North West England Interface Point Identification

The generation considered in the North West Region, included the generators in scope of the HND listed in *Table 40* and on *Figure 37* below. The principal environmental and community constraints in the region are shown in *Figure 38*.

Table 40 - Generation Scope considered for radial design for the North West Region

Generator Ref	Capacity (MW)	Number of Submarine cables assumed
R4_4	1500	3-4 HVAC Cables
R4_5	480	1-2 HVAC Cables
R4_6	1500	3-4 HVAC Cables

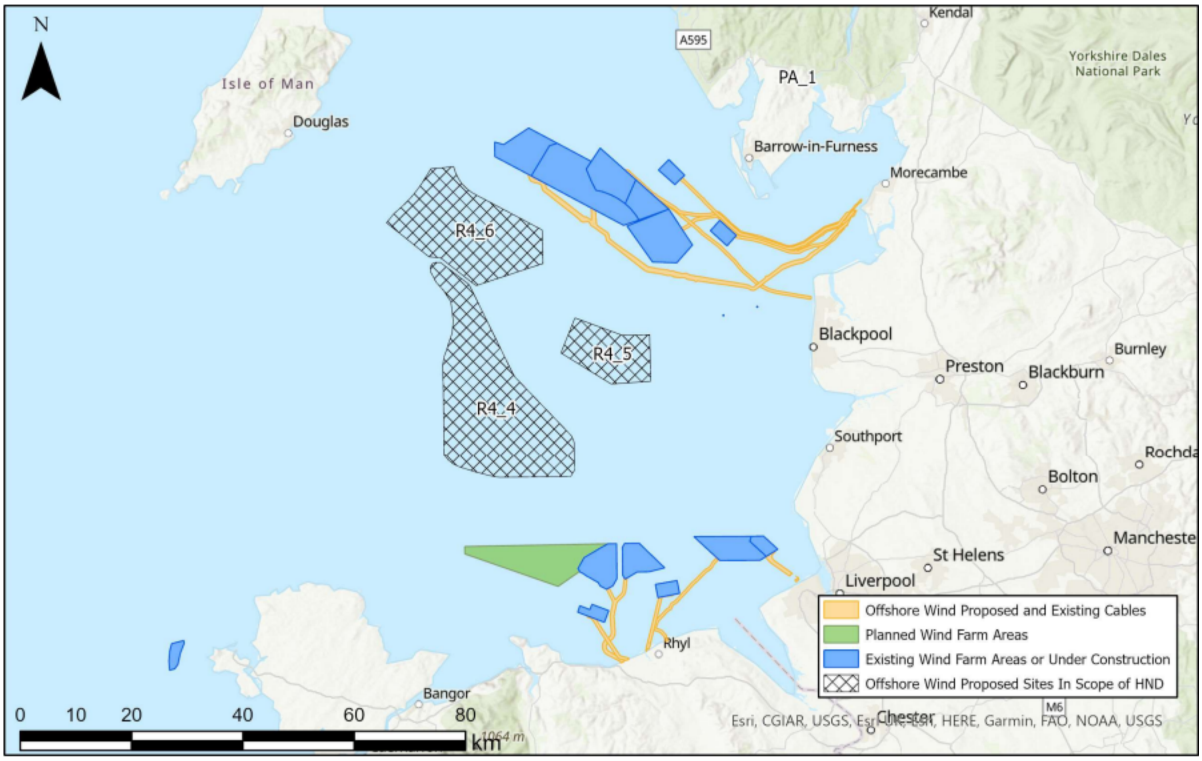


Figure 31 - Generation Scope Considered for North West Radial HND

The potential interface points with the NETS in the North West Region were identified by proximity to the coast between the northern extent of Morecambe Bay in the north, and Anglesey in the south and west. These limits were determined by the location of the generators in scope within the region and other relevant data in the HND dataset including forecast network demand, planned network improvements and other known limitations of the network. Energy demand was biased towards the south of England.

The network map of existing NETS substations and principal environmental constraints are shown on *Figure 32.*

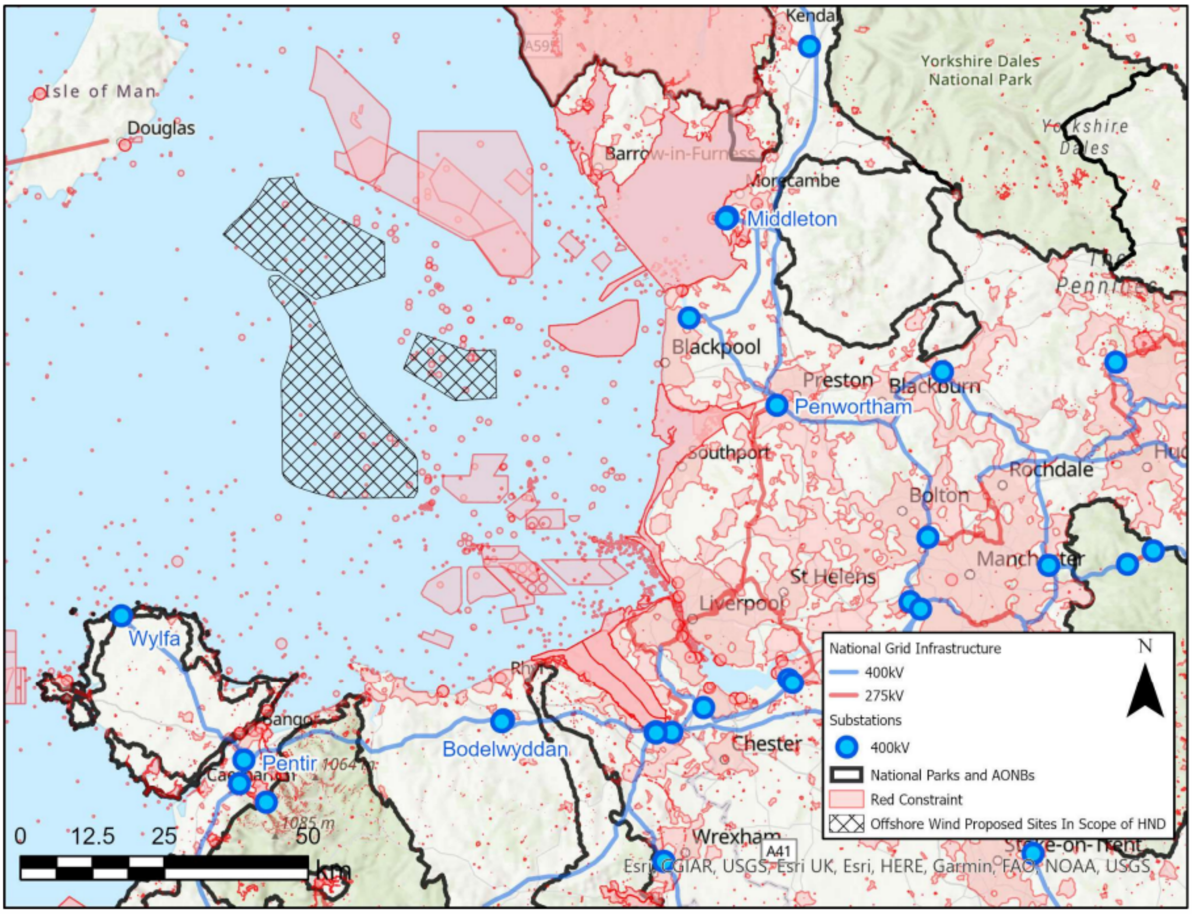


Figure 32 - High-Level Environmental and Community Constraints for North West

Potential interface point sites were initially ranked in terms of potential capacity (including planned capacity) to accept new generation inputs using information provided by the Transmission Owners (TOs).

This exercise included all existing and planned substations on the 400kV and 275kV network in the region and the study area was based on TO network information and the economic advantages of connecting close to the coast where possible. This did not preclude potential interfaces at new substation sites. It was noted at the outset that no new planned or potential substation locations were identified, and that these could be added if constraints to existing substations, or merits of potential new locations, warranted the consideration of new interface points.

The principal constraints in the North West Region were the environment constraints on the offshore transmission cable routes and landfalls, and no distinct advantages of new substation locations were identified. The interface points considered therefore remained focused only on existing substation sites in the region.

These locations, and all other potential interface points, were considered at a ‘high level’ (i.e. principal considerations) in a workshop in terms of deliverability (Objective 2) and environment and community constraints (Objectives 3 and 4). Environmental and community constraints were presented to focus on the highest level (Red in the BRAG dataset) at this stage, although information on characteristics behind these constraints, and other constraints, were also available.

The main environmental and community factors in the region are shown on *Figure 33*

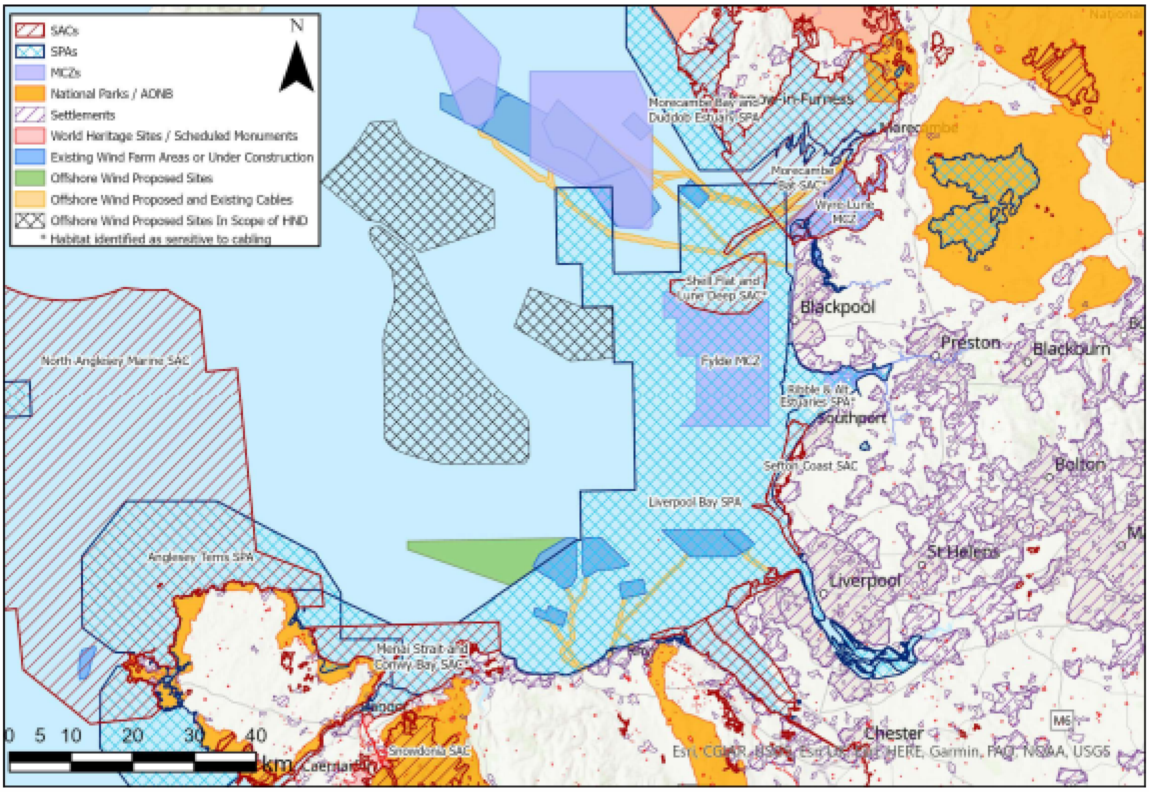


Figure 33 Principal High Level Environmental and Community Designations for North West

The interface sites selected for further consideration for both the radial and coordinated designs in the North West Region were Middleton, Penwortham, Bodelwyddan and Pentir.

North Scotland Region – NS2 - SW_N1 – Spittal				
Offshore Generation	**Onshore Station**	**Route No.**	**Option No.**	**Revision**
SW_N1	Spittal	NS2	2,3	F01
Author	**Reviewed**	**Approved**	**Date**	
BM	KC/MB/LMcA	DC	31/01/2022	

Route Description

The identified offshore route corridor from SW_N1 (West of Orkney) to Spittal substation extends SE for 46km avoiding the Highland Wind windfarm and nearby telecom cables before it makes landfall, at which point it continues for 22.5km SE before approaching the onshore substation from the NW.

Route Length - Total	Route Length - Offshore	Route Length - Onshore
66.4 km	45.7 km	20.7 km
SW_N1; 2,250 MW AC	4 to 6, 3 core submarine cables	4 to 6 underground cable circuit trenches

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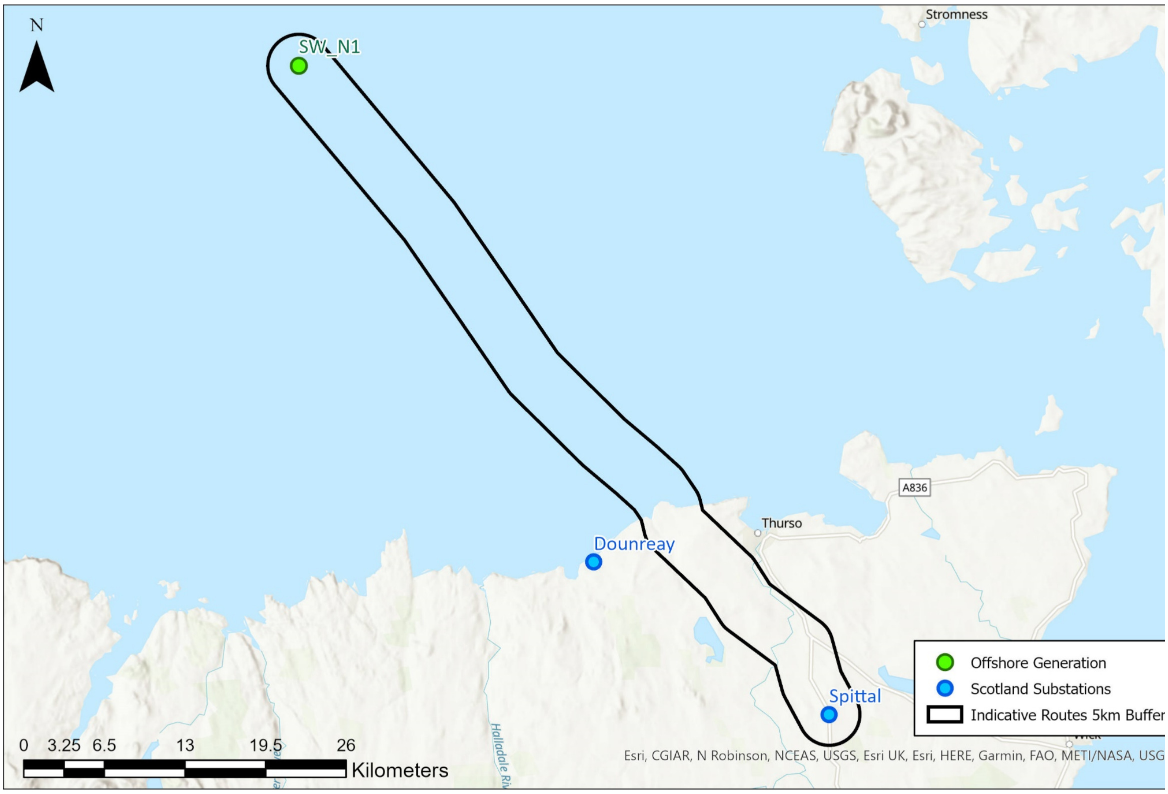
Route Overview Map – NS2 - SW_N1 – Spittal



Summary of Appraisal – NS2 - SW_N1 – Spittal

Technical

The technical constraint along the route corridor SW_N1 (West or Orkney) to Spittal is the predominance of cliffs at coastline many of which are > 15m in height. However, within the route corridor, there is some potential to avoid the highest cliffs to either side of Ushat Head at Crosskirk or Brims Ness.

Environmental

There are significant environmental constraints within the route corridor, but it should be possible to avoid these with cable routing. The corridor does clip the western edge of the North Caithness Cliffs SPA, cross the Thurso River SAC and include the Ushat Head, Loch Lieurary, Spittal Quarry, Achanarras Quarry, Banniskirk Quarry, Newlands of Geise Mire and River Thurso SSSIs, all of which can be avoided.

Community

The community constraints along the route corridor SW_N1 to Spittal include the urban area of Halkirk, which can be avoided.

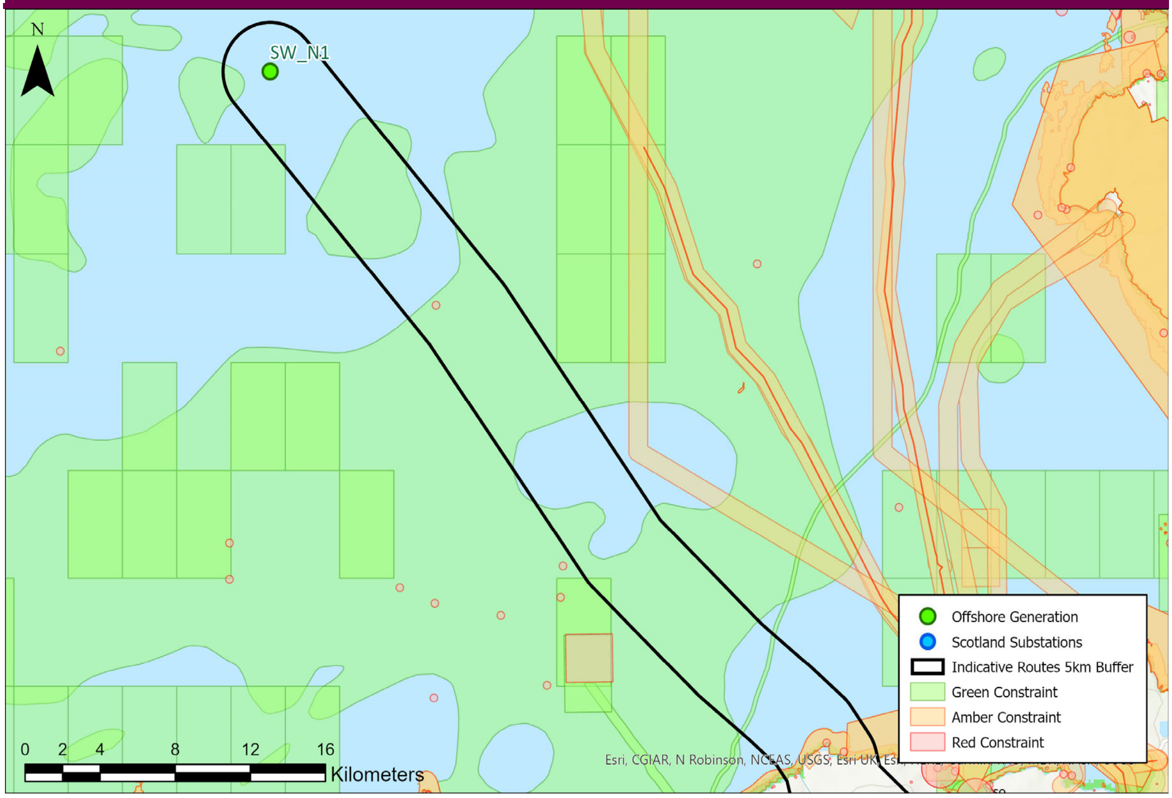
Conclusion

Overall, the NS2 route is lightly to moderately constraint as all significant constraints have the potential to be avoided both onshore and offshore.

Constraint Ranking	Technical	Environment / Community
Black	Features or constraints that are likely to affect the feasibility of construction and/or buildability of the HND to such a degree that the option should not be considered as part of the design.	Features or designations which affect the likelihood of an option being achievable to such a degree that the option should not be considered as part of the HND.
Red	Features or constraints that are likely to affect the feasibility of construction and/or buildability of the design to such a degree that the option affecting them should not be included in the HND without potential solutions to the issues raised.	Features or designations that are so significant or pose such a high degree of risk to the design that they should be avoided*, except in exceptional cases which include: where potential mitigation (or compensation) is known; where the potential benefits to the design would clearly outweigh the potential harm and/or impacts; or where there are no alternatives.
Amber	Significant technical constraints that may cause cost increases and/or significant schedule delays; not ideal but likely to be achievable and/or capable of resolution.	The most protected features and/or areas that are likely to require detailed assessment and/or mitigation and should be avoided* if possible.
Green	Informative of approach but medium to low likely technical constraint causing significant cost increase and/or significant schedule delays.	Features or designations to be taken into account in constraint assessment/study but which are likely to be capable of resolution.

*To be avoided except for linear constraints - being point to point features, where it may not be possible to avoid crossing these constraints.

Offshore Constraints Map – NS2 - SW_N1 – Spittal



Feature/Constraint	Name	Description/Features/ Potential Effects (adverse and beneficial)	Ranking	Mitigation Identified/Residual Effects	Ranking with Mitigation
Technical and Construction Constraints – Offshore					
Offshore rock	Offshore rock	There is an area of identified offshore rock at the coastline, north of Crosskirk, that spans the approximate width of the corridor.		Cannot avoid these areas of offshore rock within the route corridor.	
Offshore energy generation and cables	Proposed electric cable	There is a proposed electrical interconnector from SSEN Transmission (to Orkney) within the route corridor.		Cannot avoid crossing the proposed cable route.	
Bathymetry	Depth <10m	There is an area offshore with a depth of <10m.		Cannot avoid passing through an area of depth <10m.	
Offshore sand	Offshore sand	There are large areas of offshore sand all along the route corridor.		Cannot avoid offshore sand within the route corridor.	
Environmental Constraints – Offshore					
SPA	North Caithness Cliffs SPA	This site is designated for its very large populations of breeding seabirds such as the Peregrine and Guillemot. The site intersects with a 2.5km^2 area of the route corridor on the coastline.		There is a potential to avoid the SPA within the route corridor.	
Annex 1 Reefs	Annex 1 Reefs	There are scattered areas of reef that span the width of the route corridor at the coastline, just offshore of Crosskirk.		Cannot avoid the annex 1 reef within the route corridor.	
Community Constraints – Offshore					
Wreck locations	Wreck locations (2)	There are two wrecks within the route corridor.		There is the potential to avoid wreck locations within the route corridor.	
Fishing activity	Fishing intensity	There is an area of high fishing intensity within the route corridor.		Potential to avoid passing through areas of high intensity fishing activity.	

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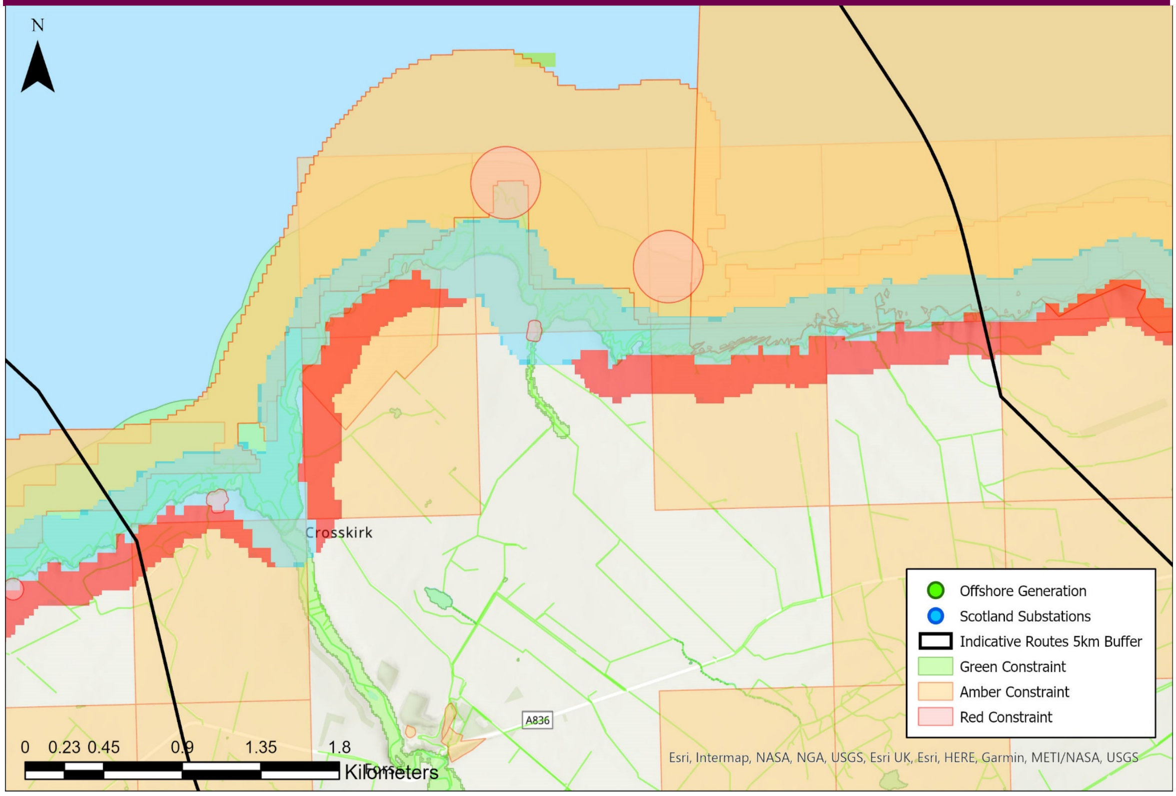
Landfall Constraints Map – NS2 - SW_N1 – Spittal



Feature/Constraint	Name	Description/Features/ Potential Effects (adverse and beneficial)	Ranking	Mitigation Identified/Residual Effects	Ranking with Mitigation
Technical and Construction Constraints – Landfall					
Cliff shoreline	Cliffs > 15m in height	Along the majority of the coastline the cliffs are > 15m in height. Two lower sections of cliff provide circa 1.3km of coastline for landfall.	Red	There is limited potential to avoid areas of the cliff within the route corridor.	Green
Offshore rock	Offshore rock	There is an area of identified offshore rock north of Crosskirk that spans the width of the corridor.	Amber	Cannot avoid these areas of offshore rock within the route corridor.	Amber
Shallow soils and exposed rock	Shallow soils and exposed rock	There are areas of identified clastic rocks with limestone, sandstone and mudstone located within the route corridor.	Amber	Cannot avoid these areas of shallow soils and exposed rock within the route corridor.	Amber
Rivers	Rivers	There are a number of rivers located within the route corridor.	Green	Rivers will need to be avoided or crossed within the route corridor.	Green

Roads	Roads	There are a number of roads located within the route corridor.		There is potential to avoid the roads within the corridor.	
National Flood Zones	National Flood Zones	Areas of National Flood Zones.		Areas of flood zones cannot be avoided within the cable route corridor.	
Environmental Constraints – Landfall					
SPA	North Caithness Cliffs SPA	This site is designated for its very large populations of breeding seabirds such as the peregrine and guillemot.		There is a potential to avoid the SPA within the route corridor.	
SSSI	Ushat Head SSSI	This site was designated for its impressive cliffs and geological features.		There is a potential to avoid the SSSI within the route corridor.	
Annex 1 Reefs	Annex 1 Reefs	There are scattered areas of reef that span the width of the route corridor just offshore of Crosskirk.		Cannot avoid the annex 1 reef within the route corridor.	
Community Constraints – Landfall					
Scheduled monuments	Scheduled monuments (2)	There are two scheduled monuments located within the route corridor.		There is potential to avoid the scheduled monuments within the route corridor.	
Wreck locations	Wreck locations (2)	There are two wrecks within the route corridor.		There is the potential to avoid wreck locations within the route corridor.	

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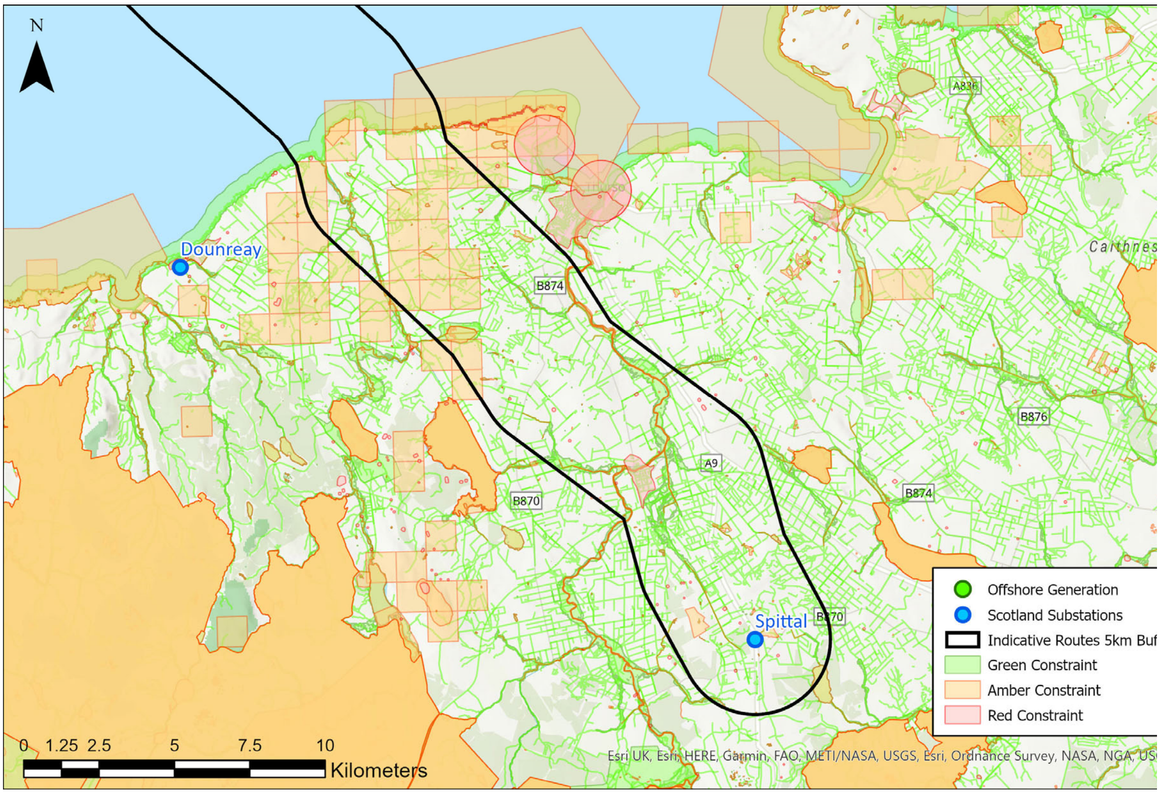
Onshore Constraints Map – NS2 - SW_N1 – Spittal



Feature/Constraint	Name	Description/Features/ Potential Effects (adverse and beneficial)	Ranking	Mitigation Identified/Residual Effects	Ranking with Mitigation
Technical and Construction Constraints – Onshore					
Lakes	Lakes	There are a number of lakes located within the route corridor.		There is the potential to avoid lakes within the route corridor.	
Shallow soils and exposed rock	Shallow soils and exposed rock	There are areas of identified clastic rocks with limestone, sandstone and mudstone located within the route corridor.		Cannot avoid all areas of shallow soils and exposed rock within the route corridor.	
Rivers	Rivers	There are a number of rivers located within the route corridor.		Rivers will need to be avoided or crossed within route corridor.	
Roads and railways	Roads and railways	There are a number of roads and one railway line within the route corridor.		Roads will need to be avoided or crossed. The railway line will need to be crossed.	

National Flood Zones	National Flood Zones	Areas of National Flood Zones.		Areas of flood zones cannot be avoided within the cable route corridor.	
Environmental Constraints – Onshore					
SAC	River Thurso SAC	This site is designated for its importance to wintering Atlantic Salmon and other fish species such as Grilse.		The SAC cannot be avoided within the route corridor. It might be possible to drill beneath it.	
SSSI	Achanarras Quarry SSSI	This site is designated for its impressive number of rare and good quality fossils.		There is a potential to avoid the SSSI within the route corridor.	
SSSI	Banniskirk Quarry SSSI	This site is designated for its scientific interest in quarry restoration.		There is a potential to avoid the SSSI within the route corridor.	
SSSI	Loch Lieurary SSSI	The site is designated for its importance to highland biodiversity.		There is a potential to avoid the SSSI within the route corridor.	
SSSI	Newlands of Geise Mire SSSI	This site is designated for its scientific importance.		There is a potential to avoid the SSSI within the route corridor.	
SSSI	River Thurso SSSI	The site is designated for its importance to wintering Atlantic salmon and other fish species such as grilse.		There is a potential to avoid the SSSI within the route corridor.	
SSSI	Spittal Quarry SSSI	This site is designated for its impressive number of rare and good quality fossils		There is a potential to avoid the SSSI within the route corridor.	
SSSI	Ushat Head SSSI	This site was designated for its impressive cliffs and geological features.		There is a potential to avoid the SSSI within	

				the route corridor.	
Ancient Woodland	Ancient woodland	There is an area of ancient within the route corridor.		There is potential to avoid areas of ancient woodland along the route corridor.	
Community Constraints – Onshore					
Scheduled monuments	Scheduled monuments (21)	There are 21 scheduled monuments within the route corridor.		There is potential to avoid all scheduled monuments within the route corridor.	
Major settlements / urban regions	Major settlements / urban regions	The urban area of Halkirk is within the route corridor.		There is potential to avoid this urban area within the route corridor.	