Beyond 2030: Celtic Sea Technical Annex

August 2024

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1 Introduction

This document is an annex to the *Beyond 2030: Celtic Sea* publication. It aims to expand upon the design recommendations presented in the main publication document, providing additional insights and detailed analysis.

As the Electricity System Operator (ESO), we are responsible for moving electricity around Great Britain to keep homes and businesses supplied with the energy they need.

One of our key responsibilities is to assess Great Britain's future energy supply and demand needs and then recommend an electricity network design that can meet those needs in a safe, efficient, and affordable way.

1.1 Government offshore wind target

In April 2022 the UK Government published the *British Energy Security Strategy*[1], aiming to deploy up to 50 GW of offshore wind capacity in the UK by 2030, with up to 5 GW coming from floating wind. To achieve this goal, a more coordinated approach to electricity transmission network planning is essential.

In 2020, we developed the *Offshore Coordination Phase 1 Final Report*[2],which assessed the costs and benefits of a coordinated offshore transmission network.

In July 2022, we published our Holistic Network Design (HND) recommendation[3] for connecting 23 GW of offshore wind to the onshore transmission network.

Following the HND recommendation, a follow up exercise was carried out to consider how to connect additional offshore wind farms in Scotland and the Celtic Sea[4].

The first element of the *HND Follow Up Exercise (HNDFUE)* was published in March 2024[5]. This exercise facilitated the connection of an additional 21 GW of offshore wind as a result of the ScotWind leasing round.

This report covers the Final Recommended Design to connect an additional 4.5 GW of offshore wind as part of The Crown Estate's (TCE's) Offshore Wind Leasing Round 5, which seeks to establish a new floating wind sector in the Celtic Sea off the coasts of South Wales and South West England[6]. Leasing Round 5 aims to deliver up to 4.5 GW across three Project Development Areas (PDAs), each with a capacity of up to 1.5 GW, with the potential to unlock further capacity in the region in the future.

1.2 Identifying and assessing future needs

As the ESO, we establish possible Future Energy Scenarios *(FES)*[7] to assess a current versus future projected network capability. Each scenario considers the sources and amount of energy needed for Great Britain to reach net zero by 2050.

Network capability is assessed based on the power flow across the network, defined by electrical boundaries across Great Britain and outlined annually in the *Electricity Ten Year Statement (ETYS*)[8]. ETYS provides our view of future transmission requirements and the capability of Great

[1] https://www.gov.uk/government/publications/british-energy-security-strategy/british-energy-security-strategy
[2] https://www.nationalgrideso.com/document/183031/download
[3] https://www.nationalgrideso.com/document/262676/download
[4] https://assets.publishing.service.gov.uk/media/64ef6dc513ae15000d6e30de/otnr-hnd-fue-tor.pdf
[5] https://www.nationalgrideso.com/document/304756/download
[6] https://www.thecrownestate.co.uk/our-business/marine/round-5
[7] https://www.nationalgrideso.com/document/322316/download
[8] https://www.nationalgrideso.com/document/286591/download

Britain's National Electricity Transmission System (NETS) over the next 10 years. Following the *FES,* network options to meet the required transfer capability are proposed by the Transmission Owners (TOs) and other interested persons, along with us as the ESO, through ESO-led alternative solutions.

The Network Options Assessment (NOA) identifies future network investment recommendations by considering the *FES* scenarios and the constraints identified in the *ETYS*. The NOA methodology is consulted annually and approved by the regulator, the Office of Gas and Electricity Markets (Ofgem), in accordance with our C27 condition in the Electricity Transmission License.

1.3 A holistic approach

A holistic network design takes a more integrated approach than the existing network planning process in assessing future network needs. It considers both the offshore and onshore network needs of the National Electricity Transmission System (NETS) to ensure a comprehensive and coordinated planning strategy.

Our analysis has recommended a network design for connecting the Celtic Sea Leasing Round 5 offshore wind farms, taking into account a representative set of onshore reinforcement and offshore infrastructure needs. The Transmission Owner (TO), National Grid Electricity Transmission (NGET), examined the onshore works required to facilitate the connection of Celtic Sea Leasing Round 5 wind farms, ensuring an understanding of the infrastructure required based on their assessment against the Construction Planning Assumption (CPA) we provided. A CPA is a planning assumption made around the volume of different technologies requesting connection to Great Britian's transmission system.

Onshore reinforcement needs outlined in this report focus on those essential for connecting the Celtic Sea wind farms. An initial assessment of wider system works has been conducted by NGET; however, further detailed analysis will be required in subsequent phases to develop a comprehensive recommendation of broader system needs to ensure compliance with the Security and Quality of Supply Standard (SQSS).

We have used four network design objectives to ensure we are considering a broad range of factors in planning our future networks responsibly. These network design objectives are described in detail in section 2.1 below. They are being economic and efficient; minimising environmental impact; minimising local community impact; and maximising deliverability and operability.

We developed this report in close collaboration with NGET and engaged with a range of stakeholders including:

- UK Government departments
- Devolved Governments
- Ofgem
- Offshore wind farm developers
- Environmental and community representatives.

Feedback from our stakeholders has been welcomed and appreciated. It has helped to shape our final recommendation provided in this report. More details on this stakeholder engagement can be found in the publication this annex supports, in *Part 1* of the *Beyond 2030: Celtic Sea Report*.

1.4 Purpose of this document

This annex provides further details on the Design Recommendation outlined in the *Beyond 2030: Celtic Sea* publication. It expands on this publication by explaining the offshore and onshore design options considered, the assessment process, and how the final recommendation was made.

This annex presents the Celtic Sea elements of the HNDFUE. Other elements of the HNDFUE includes the remainder of the ScotWind leasing round as found in our *Beyond 2030* publication[9] and the Innovation and Targeted Oil and Gas (INTOG) process. At the time of this report being published only the INTOG appraisal is pending, but it is not expected to impact the Final Design Recommendation in this annex.

1.5 Annex structure

This annex covers three main sections described below:

- **Overview of the design objectives and assessment approach**: an explanation of the key factors considered in assessing designs and the phased approach to determining the Final Recommendation (found in Section 2).
- **Identifying and assessing initial offshore network designs**: an explanation of the iterative process followed to identify and assess offshore designs while considering the high-level onshore network impact (found in Section 3).
- **Determining the Final Recommendation for connecting offshore wind farms**: an explanation of how we determined the recommended offshore network design and considered the impact of onshore network reinforcements (found in Section 4).

[9] https://www.nationalgrideso.com/document/304756/download

2 Overview of the design objectives and assessment approach

2.1 What design objectives did we consider?

To support the goal of a net-zero energy system, we as the Electricity System Operator (ESO), the UK Government and the Regulator have been evolving the way energy networks are designed. Following the UK Government's Offshore Transmission Network Review (OTNR) directive, we have adopted a more holistic approach to network design.

This Holistic Network Design Follow up Exercise (HNDFUE), as outlined in the *HNDFUE terms of reference (ToR)*[10], further supports the Government's previously stated targets for offshore wind and achieving net zero. This continued our use of a holistic approach to network design, considering the network needs both offshore and onshore, as well as a broad set of design objectives. The design objectives considered in this approach includes:

- **Economic and efficient**: delivered in an economic and efficient way, ensuring the best value for bill payers.
- **Deliverability and operability**: can be operated in a practical and economic way.
- **Environmental impact**: minimise the impact, where possible, on the natural environment
- **Local community impact**: minimise the impact, where possible, on the communities that host this infrastructure.

2.2 What was our approach to determining the network requirements?

Our approach to determine the Recommended Design considered each of the four design objectives on an equal footing for both the offshore and onshore networks. The design process involved evaluating various network designs before recommending a final, preferred design. The design process consists of five key steps, as shown in Figure 1. This process has been developed in collaboration with the Transmission Owner (TO), developers, environmental and community representatives, and considered feedback from stakeholders, particularly those involved in developing the earlier Holistic Network Design (HND) and the first element of the HNDFUE.

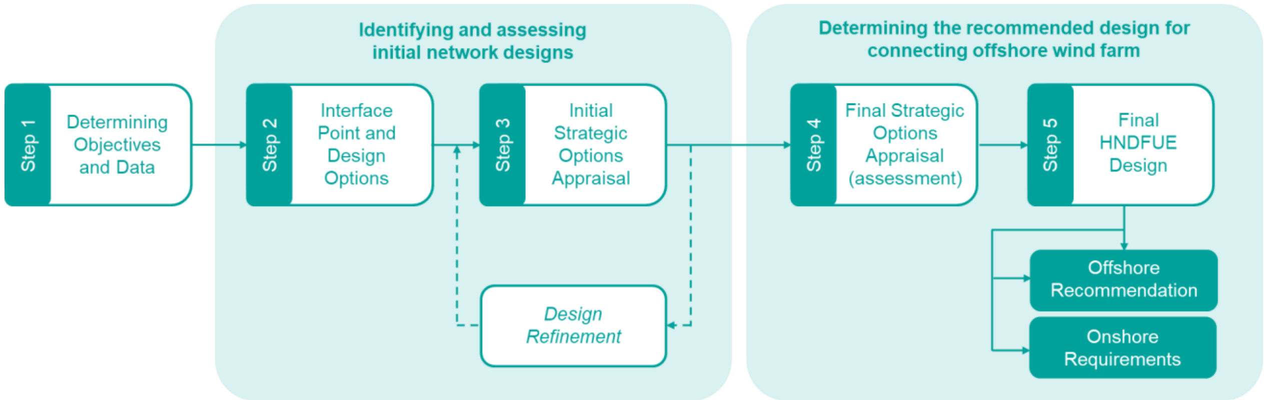


Figure 1: verview of the design process

[10] https://assets.publishing.service.gov.uk/media/64ef6dc513ae15000d6e30de/otnr-hnd-fue-tor.pdf

2.3 Determining objectives and data

The first step in developing the HNDFUE involves establishing the scope of the study, geographic area, and necessary background data. This includes setting design objectives and gathering relevant data. The design objectives as described in Section 2.1 above were set by the Offshore Transmission Network Review (OTNR) Project Board and documented in the *HNDFUE Terms of Reference (ToR)*[11].

Key input data for the HNDFUE development includes (this list is non-exhaustive):

- Identification of the HNDFUE background scenario
- Initial HND outcome
- Cost model for onshore and offshore assets
- Design rules and technology assumptions
- Environmental, community and technical constraint geographic information system (GIS) dataset.

2.3.1 How were designs assessed against the design objectives?

The assessment process considered the design objectives on equal footing across the onshore and offshore network. The approach to assessing objectives is based on expert judgement and feedback from stakeholder groups including environmental and community representatives. This expert judgement and stakeholder feedback assists in decision making and helps achieve an appropriate balance between the competing interests that must be considered when recommending a final design.

The community, environmental, deliverability and operability impacts were assessed using a BRAG (Black, Red, Amber, Green) assessment process. The economic assessment is not assigned a BRAG status as the costs are quantified with scenario-based forecasts. It uses a combination of financial information about the designs, such as capital infrastructure costs and operational costs to determine the value of each design in terms of Net Present Value (NPV). The NPV enabled us to compare the economic performance across each design.

Definitions of the BRAG ratings are provided below and remain consistent throughout each stage of the methodology.

- **Black** – The design is not viable in its current state.
- **Red** – The design has a high level of and is potentially viable, however will have to overcome many issues.
- **Amber** – The design has a medium level of constraints and is likely to be viable, however may have to overcome some issues.
- **Green** – The design has a low level of constraint and is likely to be viable without any major issues.

To provide more granularity and distinguish between designs that had the same BRAG ratings, we assigned a severity rating from one (best) to five (worst) to each BRAG rating and ranked the designs.

[11] https://assets.publishing.service.gov.uk/media/64ef6dc513ae15000d6e30de/otnr-hnd-fue-tor.pdf

2.3.2 Performance of design options

Designs with less offshore interconnection and infrastructure generally performed better in terms of deliverability and operability and were more economic. However, they often required more onshore boundary reinforcement, which could lead to the need for new infrastructure needs and associated onshore environmental and community issues.

2.3.3 Environment and community assessment

In considering environmental and local community impact, design options were assessed based on relevant features and constraints along the offshore, landfall and onshore cable route corridors. These corridors were appraised and given a BRAG rating, based on the interaction with environmental and community constraints, and the likely risk of these interactions to consenting. The designs were optimised at a high level to avoid the most sensitive constraints where possible. The appraisals focused on the location and construction of required infrastructure.

2.3.4 Deliverability and operability assessment

Several criteria were used to ascertain the overall BRAG status against the deliverability and operability objective, some of which includes:

- **Design complexity**: challenges in realising the design, including site interconnectivity and offshore substations.
- **Construction complexity**: risks associated with onshore and offshore construction activities.
- **Technology readiness**: comparing proven high voltage alternating current (HVAC) technology with the more complex HVDC connections.
- **Supply chain availability**: ensuring ambitious design goals while considering practical feasibility based on industry consultation.

2.3.5 Economic assessment

The economic assessment focused on evaluating the total costs associated with building and operating the infrastructure needed to connect the offshore wind farms to the selected interface points with the assumption that the wind farms in three Project Development Areas (PDA) will be built on broadly similar timelines. The evaluation includes the costs of reinforcing the onshore network, delivering power to where it is needed, and the costs of operating the market once the wind farms and associated infrastructure are in place.

2.4 Identifying and assessing initial offshore network designs

Once the wind farms' Project Development Areas (PDAs) and input data were finalised, potential onshore interface points and offshore designs were developed. A crucial aspect of the design process was determining the interface points (substations) where the wind farms would connect to the onshore network. These connections could be made to existing substations or new substations planned by the Transmission Owner (TO), either for existing customers or specifically triggered by this HNDFUE exercise.

Once feasible interface points are established by the TO, we then identify and assess various ways to connect the offshore generation to these points. The primary design options include:

- **Radial (point-to-point) connections:** Direct connections between wind farms and the interface point; and

- **Coordinated connections**: Interconnection between multiple wind farms with a shared connection to one or more interface points.

While the coordinated design configuration seeks to make the best use of landfall sites and minimizes environmental and community impact, it introduces increased complexity in terms of deliverability and operability, and potentially higher costs.

Following the environmental, community, deliverability, operability, and economic assessments by our subject matter experts, design options were refined to better align with the design objectives. This iterative process, conducted in collaboration with the TO, led to an improved set of high performing designs that were taken forward for detailed assessment in the final strategic options appraisal stage.

The objective of the initial network design appraisal was to determine the best performing design options using high-level assumptions. This approach was taken without waiting for all the required data concerning onshore reinforcement works, and detailed assessment of offshore works. Following the assessment of 21 options, seven high-performing designs were shortlisted for further development and assessment.

2.5 Determining the final recommended design for connecting offshore wind

The next phase built on the initial strategic options assessment phase by delving deeper into the shortlisted designs, with a particular focus on assessing their onshore requirements, while continuing more detailed evaluation of the offshore designs against the four design objectives.

The necessary onshore reinforcement requirements to facilitate the connections were considered for each shortlisted design to ensure a robust and reliable link to the onshore transmission network, and these reinforcements were factored into the overall performance evaluation.

An initial assessment of broader system needs was carried out by the TO. However, further detailed analysis is required to develop a comprehensive recommendation for wider system onshore works. This analysis will ensure compliance with Security and Quality of Supply Standard (SQSS).

Each design was compared and ranked on their overall performance, considering how well they met the design objectives for their offshore and onshore requirements.

Following a thorough comparison and ranking process, which incorporated feedback from various stakeholders, a final design was selected. This design represents the optimal balance across all four design objectives, for their offshore and onshore component.

3 Identifying and assessing initial offshore network designs

The purpose of this phase was to identify network designs that connect the offshore wind farms to the onshore transmission network and assess these against the design objectives. This phase aimed to shortlist a range of suitable designs that could be assessed in further detail in the next phase of the process.

3.1 Interface points and key constraints

To connect wind farms in the Celtic Sea to shore, suitable onshore interface points (substations) were identified. These interface points were provided by the Transmission Owner (TO) for our consideration and generally consisted of coastal locations where existing transmission infrastructure had the capacity to accommodate new connections. Proposed new substations, or those in early development stages were also considered as viable interface points. Each interface point was assessed based on its capacity for additional connection, relevant features and constraints along the offshore landfall site, and onshore cable route corridors to the interface point.

Figure 2 shows an overview of the Holistic Network Design Follow Up Exercise (HNDFUE) Celtic Sea interface points provided by National Grid Electricity Transmission (NGET).

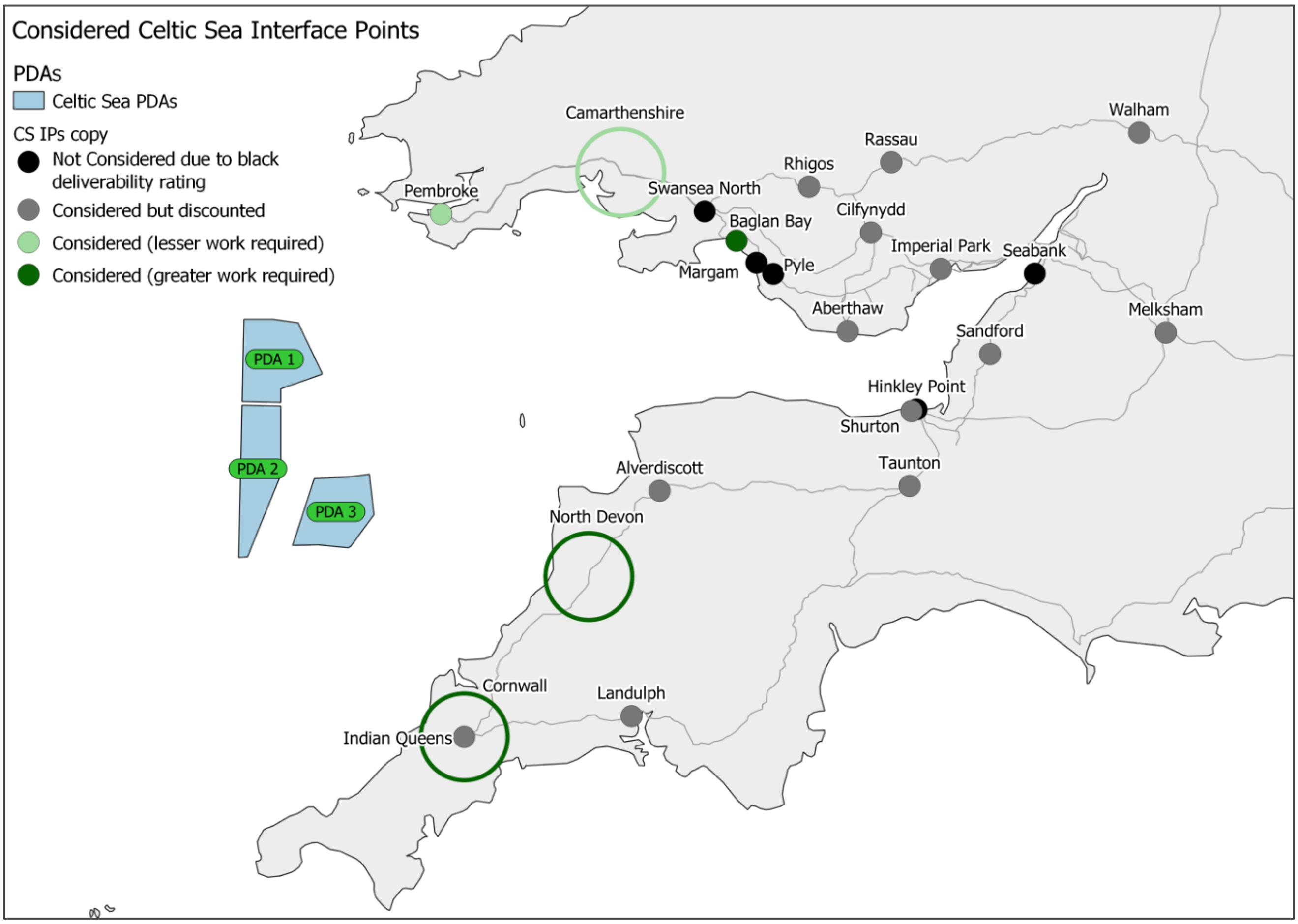


Figure 2: interface points considered for Celtic Sea Leasing Round 5

3.2 Selected interface points

Following a high-level appraisal of identified environmental and community constraints as well as substation capacity constraints, five interface points (shown in green in Figure 2) were selected for the offshore network design:

- **Pembroke 400 kV substation (South Wales)**: an existing substation requiring an extension to accommodate additional capacity from Celtic Sea PDAs.
- **Carmarthenshire 400 kV substation (South Wales**): a new proposed substation to be located east of the existing Pembroke substation.
- **Baglan Bay 275 kV substation (South Wales):** an existing 275 kV substation needing an extension and an upgrade to 400 kV. A high voltage direct current (HVDC) converter station might be necessary to facilitate connection due to its distance from the wind farms.
- **North Devon 400 kV substation (South West):** a proposed new substation located near the existing Alverdiscott substation. Alverdiscott substation has no available capacity due to the planned 3.6 GW Xlinks interconnector from Morocco. The new substation would likely be located between Alverdiscott and Indian Queens. Its specifics would depend on other network needs and the capacity connecting from the Celtic Sea.
- **Cornwall 400 kV substation (South West)**: a new proposed substation that could be triggered if the Celtic Sea capacity connects further south in the South West region. The existing Indian Queens substation is physically constrained and cannot be extended due to land limitations. The new substation would likely be located along the overhead line between Indian Queens and Landulph.

A summary of other interface points that were considered and the rationale for discounting them can be found in Appendix A – Discounted .

3.3 Offshore design option creation

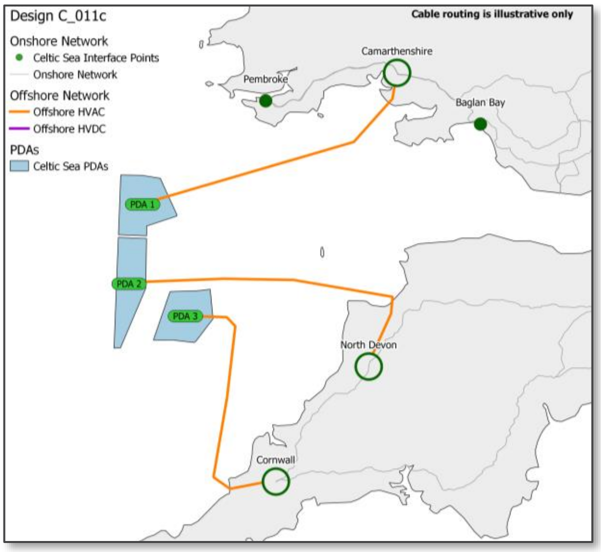
After identifying the best performing interface points, we explored different offshore designs to connect the offshore wind generation to the main transmission system optimally, considering the four design objectives.

Each offshore design was appraised individually against the community, environment, deliverability and operability, and economic design objectives. Design review workshops were held to review the designs collectively, ensuring all objectives were given equal consideration. Based on their performance, we decided whether to progress a design, iterate the design by changing certain features (e.g. change to interface point, or design configuration), or discount the design.

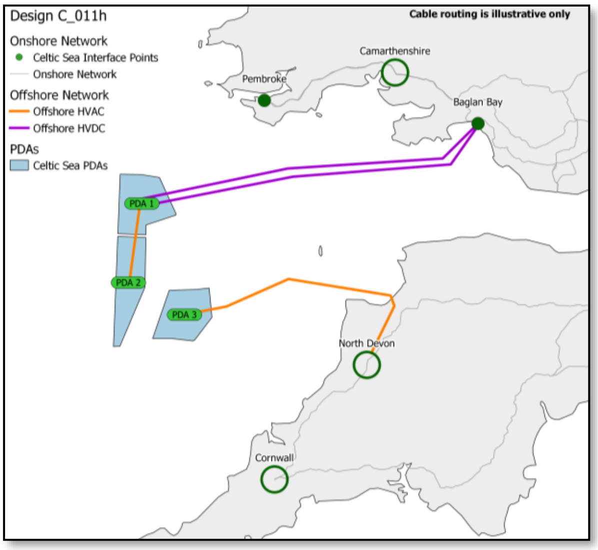
During the initial design development, we identified 21 possible network designs. The designs considered included a variety of options for connecting the Celtic Sea wind farms to shore, such as radial (point-to-point) designs, coordinated designs, and designs featuring interconnection between Project Development Areas (PDAs), that would enable power to flow between South Wales and the South West during low-wind conditions. Assessing a broad range of designs allowed us to determine how different features impacted performance.

To keep track of the variations, each design received a unique design reference. All designs considered for the Celtic Sea start with the letter C. This is followed by a number; design numbers 1-10 were created for the previous indicative PDA scenarios that covered different PDA locations and capacities. Design 11 covers designs for the three PDAs publicly announced by The Crown Estate (TCE) in October 2023, and the lower-case letter denotes the unique design within this scenario (e.g C_011a).

Radial design



Coordinated design



Interconnection between PDAs

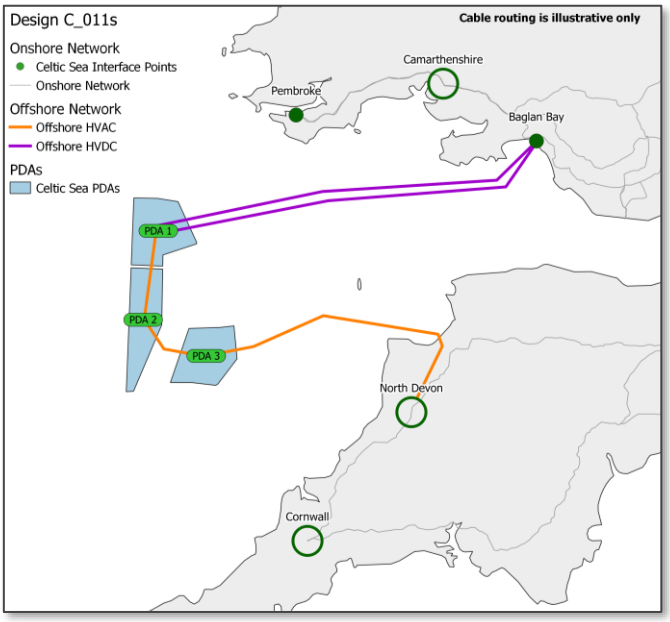


Figure 3: maps showing examples of varying level of design coordination

3.4 How did we determine the shortlisted designs?

Following the initial assessment, we shortlisted designs to assess and optimise in further detail before determining the recommended design. This selection was based on a comprehensive appraisal of environmental and community constraints, deliverability and operability performance and associated costs.

The performance of the designs was evaluated using a BRAG (Black, Red, Amber, Green) assessment. Internal design workshops were conducted to compare the performance of the design and to seek improvements. The purpose was to arrive at a shortlist that represented the variety of connection options available and the best performing design across the four objectives.

Out of the 21 designs, seven were shortlisted for further evaluation. The remaining designs were discounted for the following reasons:

- **Superseded designs**: designs similar to the shortlisted ones but performing worse against the four design objectives.
- **Regional connection focus**: designs connecting all capacity into one region: splitting the offshore wind capacity across both regions (the South West and South Wales) performed best across the four design objectives.
- **HVDC subsea reinforcement**: reinforcement to the onshore transmission system using offshore subsea cable route was considered but deferred to a later stage of the appraisal process as the TO may provide these types of works.
- **Three-PDA mesh coordination**: coordinating all PDAs into one interface point through a three-PDA mesh was impractical due to technology limitations regarding capacity accommodation by shared platform and HVDC cables.

Table 1 provides an overview and comparison of the shortlisted appraised designs. The table includes:

- BRAG Assessment: for community, environment, deliverability and operability objectives
- Economic assessment: initial cost assessment broken down into key cost categories.

3.4.1 Definition of cost categories:

- **Net Present Value (NPV):** the differential in cost between the design in question, and the most economic shortlisted design (which in this case is C_011u). The Net Present Value is a combination of the following three cost components:
- **Offshore infrastructure costs**: estimated cost of building, operating, and maintaining the offshore network (including infrastructure between the interface point and offshore wind farms, in addition to costs associated with each interface point).
- **Onshore infrastructure costs**: estimated cost of reinforcing the onshore transmission network to facilitate connection of the wind farm.
- **Market costs:** includes the approximate dispatch costs (approximate running costs) of thermal generation that is in merit, and the redispatch of the entire of Great Britain's system (cost of bids and offers due to thermal constraints, and cost of taking actions on interconnectors), over a 40-year period. These costs are based on a single snapshot year as modelled in the optimiser. The input costs that the optimiser uses to calculate this are consistent with those used in some of our other economic modelling, for example, Network Options Assessment (NOA).

3.5 Final options shortlisting

Following the assessment of all designs and considering the network design objectives on equal footing, we shortlisted seven designs that were considered for further evaluation.

Table 1: network design assessment overview – shortlisted designs

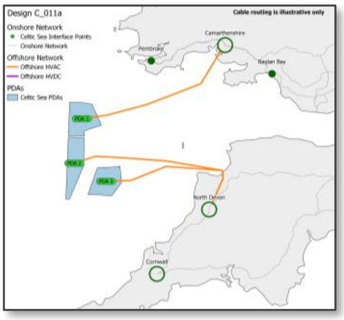
Design	Description	BRAG assessment			Economic costs (£ million)
		Environment	Community	Deliverability & Operability	**NPV** (cost difference to most economic shortlisted design)
C_011a	AC radial connections, 1.5 GW to Carmarthenshire, 3 GW to North Devon	A	G	G	+424
C_011c	AC radial connections, 1.5 GW to Carmarthenshire, 1.5 GW to North Devon and 1.5 GW to Cornwall	A	A	G	+458
C_011h	Coordinated 3 GW to Baglan Bay via HVDCs, 1.5 GW radial to North Devon	A	G	G	+3,421
C_011q	AC Radial connection, 1.5 GW to Pembroke and 1.5 GW to North Devon. DC radial connection – 1.5 GW to Baglan Bay	A	A	G	+390
C_011r	AC Radial connection, 1.5 GW to Carmarthenshire and 1.5 GW to Cornwall. DC radial connection – 1.5 GW to Baglan Bay	A	G	G	+831
C_011s	All PDAs linked, coordinated 3 GW into Baglan Bay via HVDCs, 1.5 GW to North Devon by AC cables	A	G	A	+2,732
C_011u	AC radial connections, 1.5 GW to Pembroke, 3 GW to North Devon	A	A	G	0

The assessment at this stage considered the economic, environmental, deliverability and operability, and community constraints between the offshore wind farms and onshore substations. It did not account for the impacts of any further onshore works other than with high level notional reinforcement.

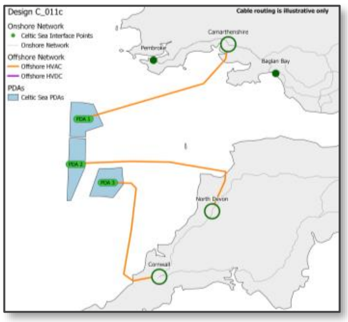
The seven designs selected provided a range from fully radial to significantly coordinated offshore connections, ensuring a comprehensive assessment of various network configurations and their performance across different criteria.

A summary of the discounted designs and the rationale for discounting them can be found in Appendix B - Designs discounted at the initial strategic options assessment.

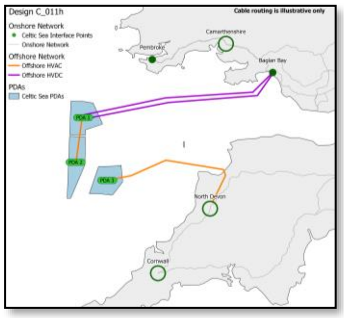
C_011a



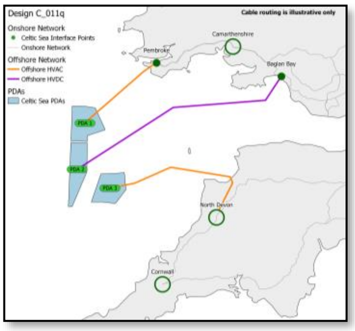
C_011c



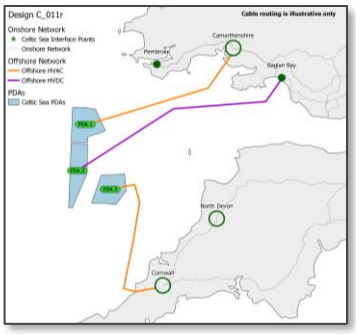
C_011h



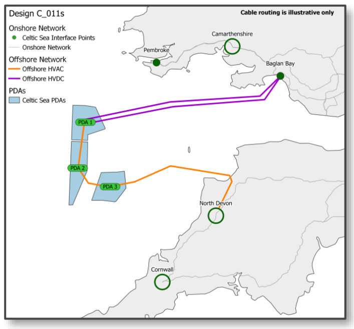
C_011q



C_011r



C_011s



C_011u

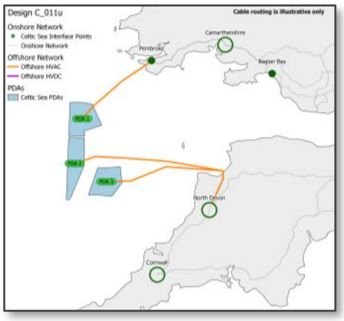


Figure 4: an overview of shortlisted network design

4 Determining the final recommended design

The purpose of this phase was to recommend a network design by thoroughly evaluating the shortlisted designs in terms of offshore and onshore works. This stage included:

- Power flow studies carried out by the Transmission Owner (TO), National Grid Electricity Transmission (NGET) to determine required onshore reinforcements for each of the shortlisted options.
- Assessing the technical deliverability and operability of each option including updated cable routes and onshore reinforcement needs provided by NGET.
- More detailed assessments of environmental and community impact using BRAG (Black, Red, Amber, Green) assessments considering both offshore and onshore impact of each option.
- More detailed cost assessments associated with building and operating each design option, considering the offshore and onshore component of each option.

The additional detailed assessment allowed for a re-evaluation of the shortlisted design against the four design objectives. This refined evaluation produced the final recommended combined offshore and onshore design.

4.1 How did we determine the final recommended offshore network design?

To assess the impact of each shortlisted designs, we worked closely with the TO to understand the necessary onshore reinforcement for each design to facilitate connection to the transmission grid. The process involved identifying the optimal combination of onshore reinforcement for each design, considering the four network objectives. We then evaluated the offshore requirements in greater detail to provide an overall appraisal for each design.

4.2 Onshore requirements

NGET provided a number of reinforcement paths for each shortlisted design. These reinforcement paths include enabling and wider onshore works required to facilitate connection of the Holistic Network Design Follow Up Exercise (HNDFUE) Celtic Sea Leasing Round 5 Floating Offshore Wind project. After thorough analysis we then selected the optimal reinforcement path for each design.

Enabling works are works that are needed to meet the Security and Quality of Supply Standard (SQSS) for a specific generator to connect to the transmission grid. These works include substation expansion and transmission upgrades to facilitate connection as well as measures to avoid unacceptable network overloads following a fault. Wider works aim to reinforce the broader network capability.

A number of the onshore reinforcement schemes included have already been triggered as necessary enabling work either for other generating customers or from drivers from the distribution network and so are not attributable to the Celtic Sea alone.

Onshore reinforcements are categorized into four main types:

- Hotwiring
- Reconductoring
- New circuit
- Cable upgrade.

Hotwiring and reconductoring are less costly per kilometre and have a lower environmental and community impact, while a new circuit and cable upgrade are more expensive and have a greater impact on the environment and community design objectives. Additionally, the prospective earliest in service date (EISD) for the TO works were also considered in the overall deliverability to ensure the reinforcement path aligns with the target date of 2035 as set by The Crown Estate (TCE). We have assessed dates for our recommendation based on information available at the time of analysis. These dates could change as designs are developed or national policies evolve.

While different combinations of these onshore works were required for each of the shortlisted designs, it was identified that designs connecting 3 GW into the South West will require a new onshore 400 kV overhead double circuit in the region to facilitate a firm connection. In contrast, the designs connecting 3 GW into South Wales does not trigger this new 400 kV overhead circuit, making designs with 3 GW into the South West more costly and impactful in terms of onshore reinforcements. It is likely that a new circuit would be required in South West England at some point to connect future generation, but designs that connect 3 GW to South Wales do not require a new circuit to facilitate the firm connection of all Project Development Areas (PDAs).

Further detailed design work, including connection studies for each individual generator within HNDFUE Celtic Sea, is needed following our recommendation. Further analysis is necessary to complete a full compliance assessment against the SQSS, either for the Construction Planning Assumption (CPA) provided to assess the Celtic Sea, or to meet the wider works that could be required to achieve network boundary flows. Once these studies are completed, the relevant onshore works will be determined and included in each generator’s connection agreement.

The timelines for onshore reinforcements and construction of new interface points are the main driver of the indicative EISDs for each design. The locations we have used and the EISDs for new interface points are indicative; before a location for a new substation is chosen, the TO will need to carry out a site selection study.

4.3 Final options appraisal

Each shortlisted design was individually assessed to determine the necessary onshore works required to facilitate connection. Once the combination of onshore works required for each design were identified, these were evaluated against the design objectives on equal footing along with their offshore component. A BRAG rating was assigned to each design and a severity rating was added to help further distinguish between the designs.

To determine the Recommended Design, we explored opportunities to iterate and refine designs by merging elements from various designs. This approach allowed us to create a hybrid design that incorporates the best features of each option.

4.3.1 Changes to interface point (Baglan Bay 275 kV to South Wales Connection Node)

Following the completion of the TO’s onshore studies for the shortlisted designs, the TO advised that connecting to the interface point at Baglan Bay 275 kV substation would require reinforcement of the whole 275 kV network in South Wales. This extensive upgrade would involve significant onshore works and pose a risk to the delivery date.

To avoid this, the TO proposed the establishment of a new 400 kV substation near Baglan Bay. This new substation has been designated as the South Wales Connection Node (SWCN). It is anticipated to be situated between Swansea North and Cilfynydd substations, although exact location is yet to be finalised by the TO.

For the purpose of assessing designs incorporating this new interface point, an indicative location for the substation was assumed along the existing 400 kV circuit. This location was selected based on fewer environmental and community constraints.

As a result of the proposed new substation, all designs initially connecting into Baglan Bay were updated. The following design names were changed:

- C_011h to C_011v
- C_011r to C_011y
- C_011s to C_011w
- C_011q to C_011x.

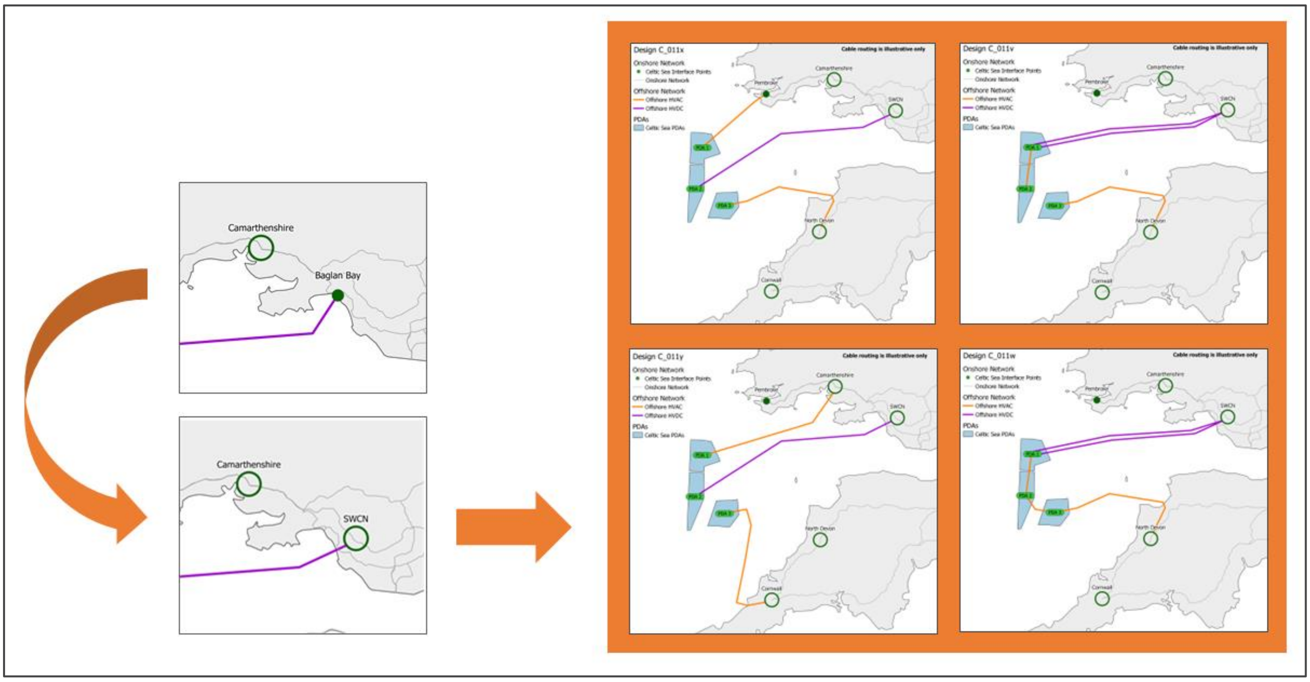


Figure 5: design name changes due to change of connection point

4.4 What is the recommended offshore network design?

After assessing the shortlisted designs, we identified a modified design (C_011z) by altering design C_011x (previously C_011r). The modification involved changing the interface point for PDA 1 from Pembroke (which has several environmental and community constraints), to Carmarthenshire, which is less restricted. This was included in the shortlisted designs, bringing the number of shortlisted designs up to eight.

4.4.1 Recommended design: C_011z

Design C_011z, illustrated in Figure 6 has been identified as the best performing design, considering all objectives on an equal footing. It connects 3 GW into South Wales (Carmarthenshire and SWCN) and 1.5 GW into the South West (North Devon). The connection into SWCN is via high voltage direct current (HVDC) technology, while the connection to the remaining interface points is via high voltage alternating current (HVAC) technology.

Although it is more expensive than C_011a (the second-best performing design), C_011z offers a better balance across the environmental, community, deliverability, and operability objectives and has the lowest level of known risk to its timely development and delivery among all the designs considered. With a design configuration of 3 GW into South Wales, it avoids the immediate requirement for a new onshore 400 kV overhead double circuit and the associated delivery risk, significantly reducing its environmental and community impact and potentially delays to connection dates.

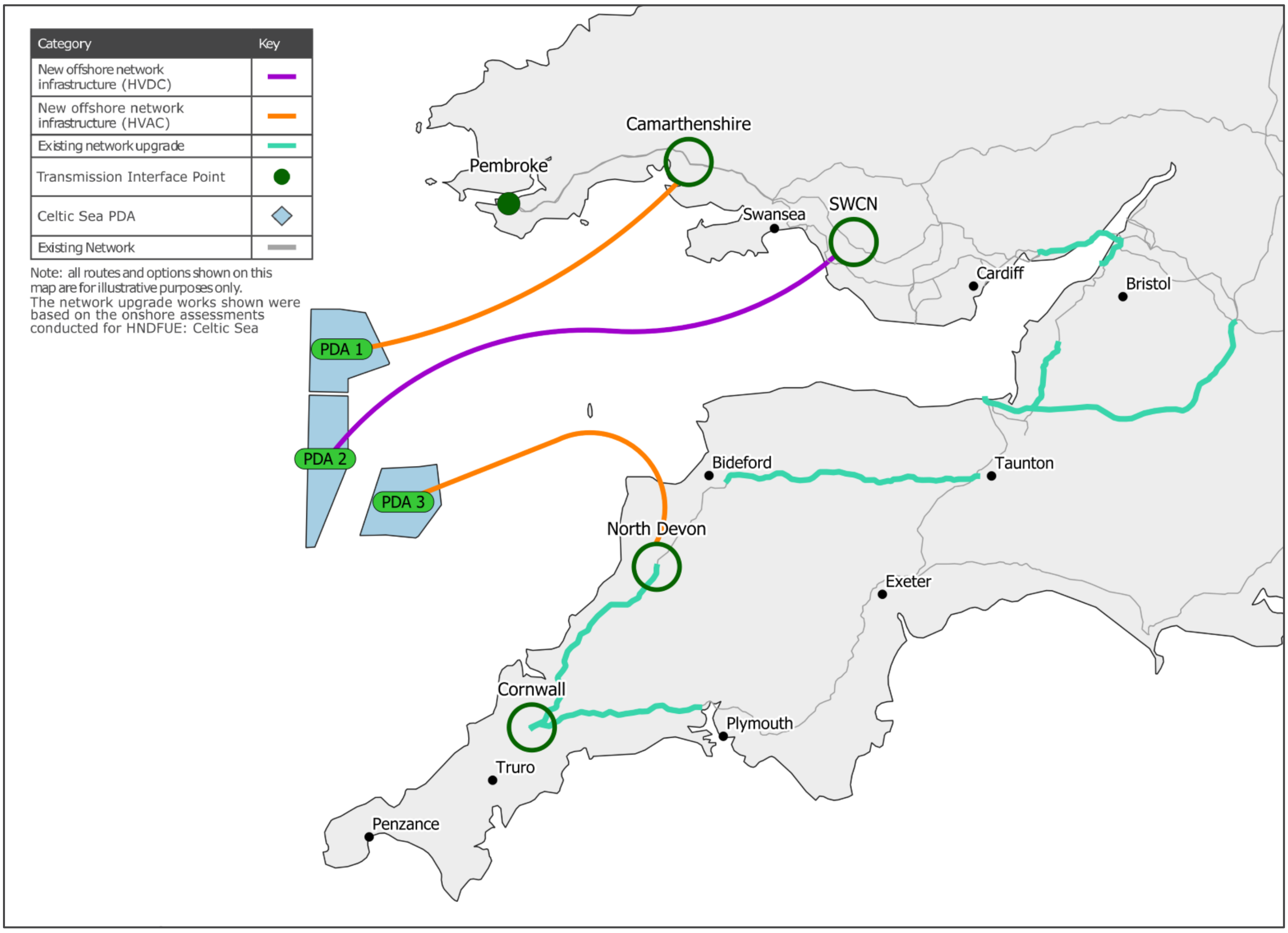


Figure 6: Recommended offshore design

Table 2 below shows representative connection works considered in arriving at the final recommendation.

Table 2: initial assessment of onshore works for the HNDFUE Celtic Sea design

Description	Category
Hinkley Point to Sandford circuit reconductoring	Reconductoring
Seabank to Whitson cable replacement	Cable upgrade
Alverdiscott to Taunton circuits reconductoring	Reconductoring
Reconductor Shurton – Bridgewater – Melksham double circuits	Reconductoring
Hinkley Point to Seabank circuit reconductoring	Reconductoring
Indian Queens and Landulph circuit reconductoring	Reconductoring
Reconductor Indian Queens to Alverdiscott 400 kV double circuits	Reconductoring

Economic ranking

Design C_011z is ranked 5th against the economic objective. The lower economic ranking is mainly due to the high offshore cost associated with HVDC export technology for the connection from PDA 2 to SWCN. Despite its efficient long-distance power transmission capabilities, HVDC technology involves substantial initial capital investment and maintenance costs.

Conversely, the onshore reinforcement cost for this option is relatively lower than other shortlisted designs, as it avoids the immediate need for a new onshore circuit for a firm connection, reducing the financial burden typically associated with constructing a new circuit. However, the high offshore costs have a more significant impact on its overall economic performance.

Deliverability and operability performance

Against the deliverability and operability objective, design C_011z is ranked the 4th best option. Offshore, there are deliverability and operability challenges due to the use of HVDC technology for connecting PDA 2 into SWCN (route length exceeds the limits for use of HVAC transmission cables without mid-point compensation). HVDC technology is less mature, with more limited supply and longer installation and commissioning times compared to HVAC.

Onshore, there are fewer reinforcements needed to facilitate firm connections for all PDAs compared to designs connecting 3 GW into the South West. Onshore works include reconductoring, and a cable upgrade (which is common among all options), with no new overhead lines required. This leads to a better onshore deliverability and operability performance. The design has an indicative earliest in service date (EISD) of 2035 or earlier for all PDAs.

Design C_011z offers an average performance overall against the deliverability and operability objection, benefitting from lesser onshore work requirements, but faces offshore challenges with the HVDC link.

Environmental performance

Design C_011z is the third best performing design against the environmental objective.

Offshore, design C_011z utilises three interface points: SWCN, North Devon substation and Carmarthenshire substation. Key offshore environmental constraint includes:

- Large stretches of the Bristol Channel Approaches Special areas of Conservation (SAC), which cannot be avoided by the routes into South Wales Connection Node, Carmarthenshire substation or North Devon substation.
- NRW Key Sensitive Habitats, located within Carmarthen Bay and Estuaries SAC enroute into Carmarthenshire substation.
- The route corridor to North Devon substation intersects the Mermaid's Pool to Rowden Gut site of special scientific interest (SSSI).
- Other significant unavoidable constraints across all three routes include the wider Carmarthen Bay and Estuaries SAC, the Carmarthen Bay Special Protection Area (SPA), Pembrey SSSI, areas of Annex I Reef, areas of Annex I Sandbank and areas of ancient woodland.

Onshore, C_011z, avoids the immediate need for a new overhead line, requiring less onerous works such as reconductoring that have a lower environmental impact. It also requires a more impactful cable upgrade reinforcement, but this is common across all the shortlisted design option and has an adverse impact on the overall onshore ratings. The new South Wales Connection Node (SWCN) interface point also requires an HVDC converter station to be built, which means the connection of PDA 2 to SWCN impacts two locations – the new substation site and the new converter station site. However, these potential sites are considered to be moderately constrained by avoidable environmental factors such as ancient woodland.

Overall, there are some environmental constraints associated with both the offshore and onshore elements of C_011z, but many of the constraints are common across the other designs and the design configuration with 3 GW into South Wales and the chosen interface points means that C_011z performs well overall comparatively.

Community Impact

C_011z is ranked third overall against the community design objective. It features three interface points, two in South Wales (the proposed Carmarthenshire substation and SWCN) and one in the South West (North Devon substation). Key community constraints include:

- North Devon area of outstanding natural beauty (AONB), Hartland Heritage Coast and the South West Coast Path, all of which stretch the length of the coastline at the landfall for North Devon substation and cannot be avoided.
- Potential cumulative impact with Xlinks project: There is potential for in-combination effects with Xlinks project at the North Devon substation landfall, which could impact local communities. There is also a potential opportunity for coordination, though this cannot be guaranteed at this stage. This design carries less risk of cumulative impact than designs that connect two PDAs to North Devon.

C_011z is a radial design that connects 3 GW into South Wales avoiding a new overhead line but including the common cable upgrade works. Onshore community constraints include five scheduled monuments, four registered parks and gardens and multiple listed buildings located within the study area for the cable upgrade, although these could potentially be avoided through careful routing.

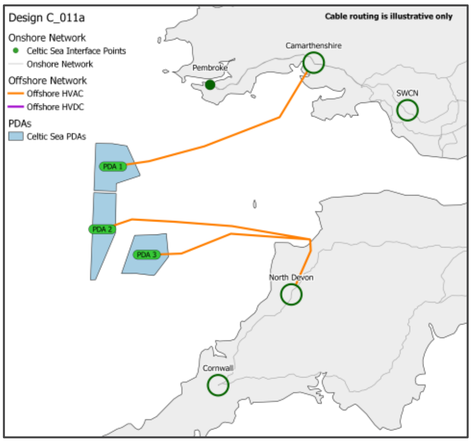
Overall, onshore community constraints are considered more impactful than offshore. However due to the less onerous onshore works, C_011z performs well against the community design objective.

4.4.2 How did the other shortlisted designs perform?

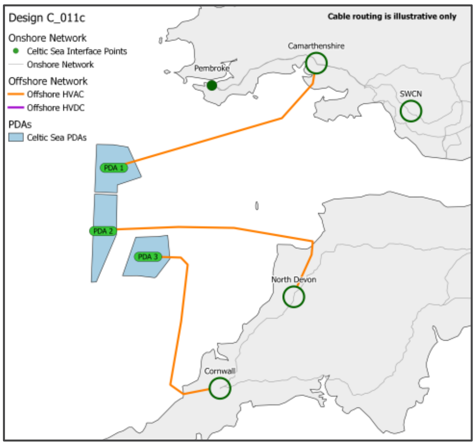
The final strategic options appraisal compared all the shortlisted options against each other considering the four network design objectives.

Figure 7 provides an overview of the eight shortlisted designs (including the Final Recommended Design which is a modification of design C_011x).

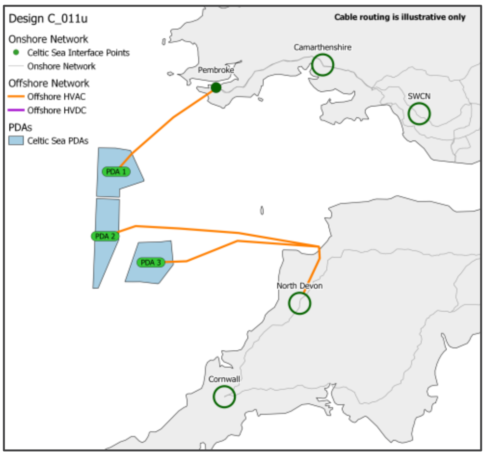
C_011a



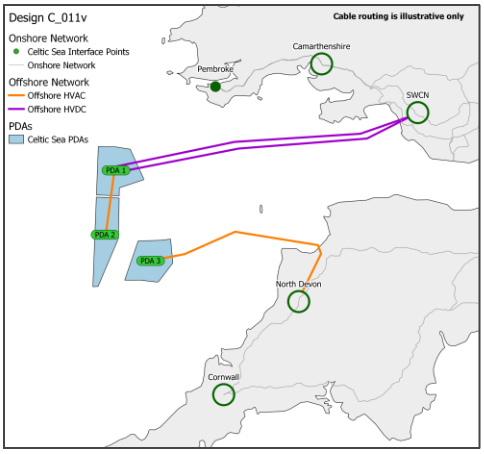
C_011c



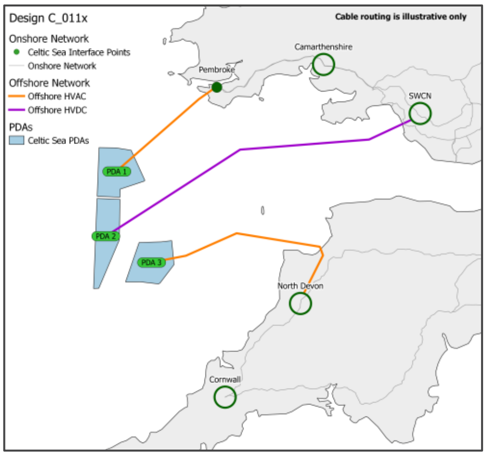
C_011u



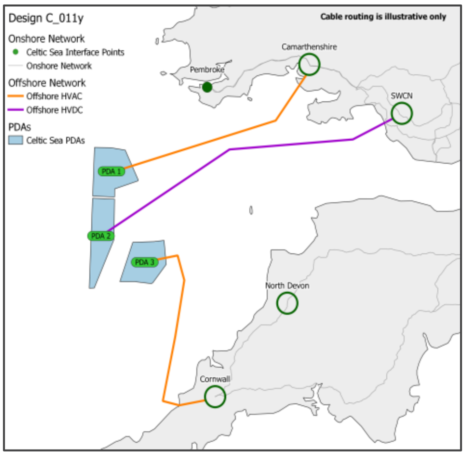
C_011v



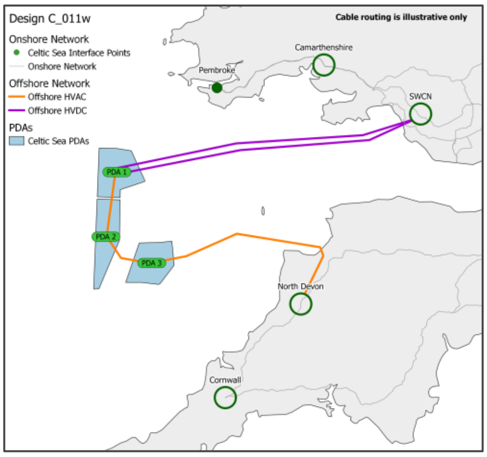
C_011x



C_011y



C_011w



C_011z

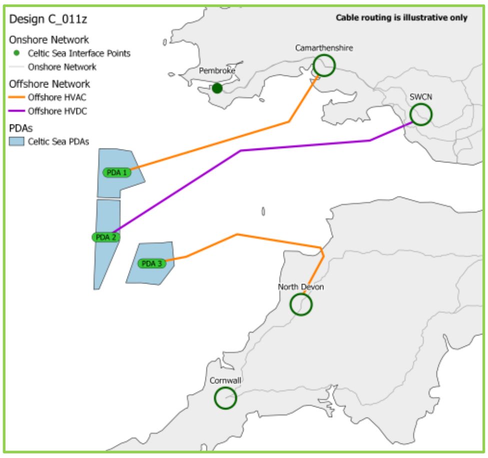
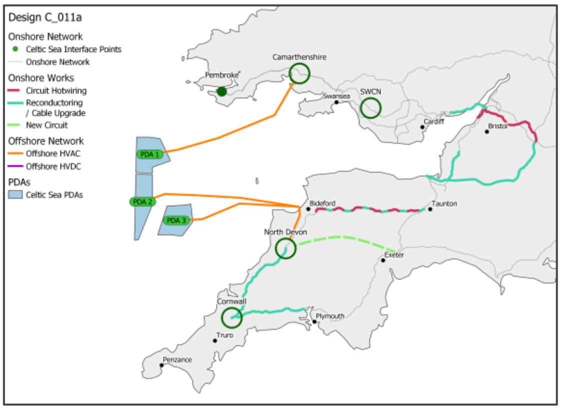
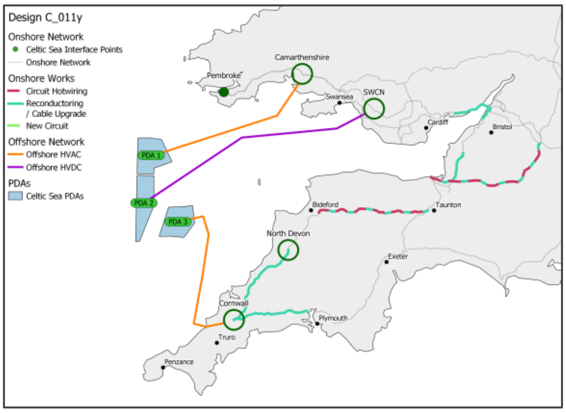


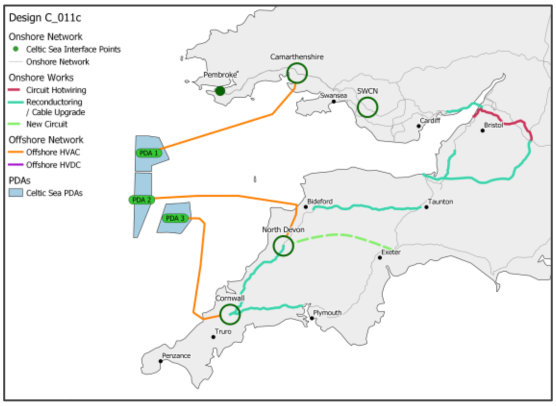
Figure 7: an overview of the shortlisted designs considered at the final strategic options appraisal stage

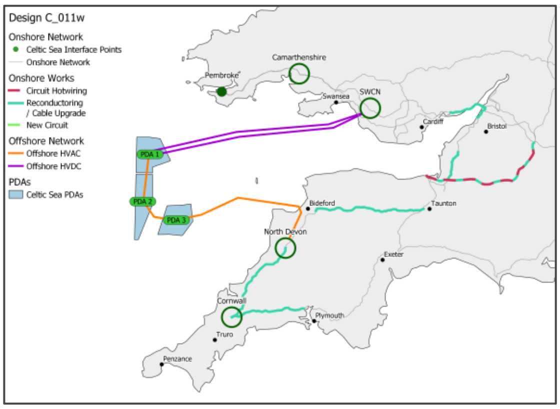
Table 3: design assessment overview comparison

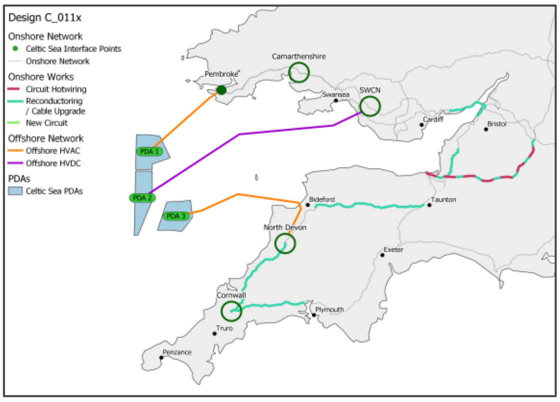
Rank	Design	Description	Environment			Community			Deliverability and Operability			Economic and Efficient	
			Rank	Offshore BRAG	Onshore BRAG	Rank	Offshore BRAG	Onshore BRAG	Rank	Offshore BRAG	Onshore BRAG	Rank	NPV Variance, £bn
1st	C_011z	HVAC Radial connection, 1.5 GW to Carmarthenshire and 1.5GW to North Devon. DC radial connection – 1.5 GW to SWCN	3rd	A5	A4	3rd	G4	A1	4th	G5	A3	5th	£1.85
2nd	C_011a	HVAC radial connections, 1.5GW to Carmarthenshire, 3 GW to North Devon	5th	A4	R1	6th	G5	A5	2nd	G2	R1	2nd	£0.68
3rd	C_011y	HVAC Radial connection, 1.5 GW to Carmarthenshire and 1.5 GW to Cornwall. DC radial connection – 1.5 GW to SWCN	4th	A5	A5	4th	G4	A2	6th	G5	A3	6th	£1.89
4th	C_011c	HVAC radial connections, 1.5 GW to Carmarthenshire, 1.5 GW to North Devon and 1.5 GW to Cornwall	6th	A5	R2	8th	A3	A5	5th	G3	R1	3rd	£0.88
5th	C_011w	All Project Development Areas (PDAs) linked, coordinated 3 GW into SWCN via HVDCs, 1.5 GW to North Devon by HVAC cables	1st	A3	A4	1st	A1	G3	8th	A3	A5	7th	£3.68
6th	C_011x	HVAC Radial connection, 1.5 GW to Pembroke and 1.5 GW to North Devon. DC radial connection – 1.5 GW to SWCN	7th	R3	A4	5th	A3	A1	3rd	G4	A3	4th	£1.14
7th	C_011u	HVAC radial connections, 1.5 GW to Pembroke, 3 GW to North Devon	8th	R3	R1	7th	A2	A5	1st	G2	R1	1st	-
8th	C_011v	Coordinated 3 GW to SWCN via HVDCs, 1.5 GW radial to North Devon by HVAC cables	2nd	A3	A4	2nd	A1	G3	7th	A5	A3	8th	£4.12

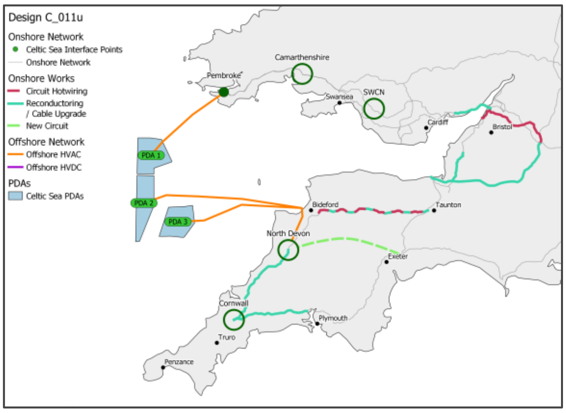
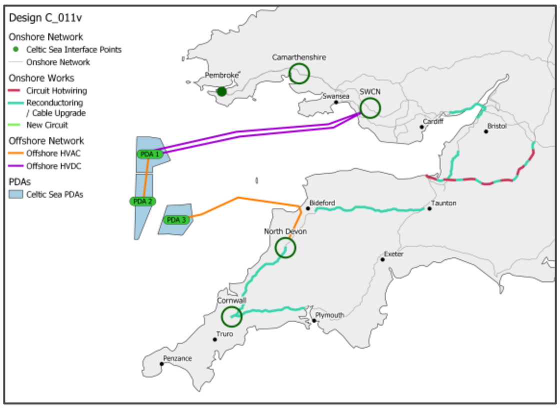
Design	Overview	Assessment commentary
C_011a		Design is ranked second overall. It aims to connect 3 GW into the South West (North Devon substation) and 1.5 GW into South Wales (Carmarthenshire) via HVAC cables. Onshore it requires a new 400 kV overhead circuit to facilitate firm connection, as it connects 3 GW into the South West; this has an adverse impact on its environmental and community performance. From a deliverability and operability perspective, the design performs better than the recommended design, as due to the shorter route length of each PDA to shore (less than 120km), the more mature and simpler HVAC technology can be used for all power exports, while the Recommended Design requires a more complex HVDC connection for one of its interface points. However, there is a risk of delay to connection date as the new onshore 400 kV circuit must be completed before the design can export its full capacity and this reinforcement has a potential earliest in service date (EISD) of 2037. Despite the high onshore cost due to the new 400 kV circuit, the design is economically better than the recommended design; this is down to the cheaper offshore cost of using HVAC technology to export all generation, making it more cost effective than the Recommended Design, which requires the use of HVDC technology for connection into SWCN. There is also a risk of cumulative impact at the landfall and onshore route to the interface point if civil works for PDA 2 and PDA 3 are not coordinated. Additionally, there is a risk of in combination effects from Xlinks interconnector, which uses the same landfall. We have assumed three HVAC cables per PDA will be sufficient to transport 1.5 GW, but if more than three HVAC cable per PDA is required, as has been suggested by some stakeholders, there will not be room to accommodate the connections of PDA 2 and

Design	Overview	Assessment commentary
		PDA 3 at the landfall for North Devon substation, due to space constraints and the Xlinks interconnector utilising the same landfall. Design C_011a was ranked below the Recommended Design C_011z due to its poor environmental and community performance and potential delays in connecting all PDAs by 2035, which is caused by the need for a new onshore 400 kV circuit.
C_011y		Design is ranked 3rd overall with an aim to connect 3 GW of power to South Wales (Carmarthenshire and SWCN) and 1.5 GW into the South West (Cornwall). Onshore works are less demanding. As it avoids the need for a new onshore circuit, the main onshore task involves reconductoring and cable upgrade. This positively impacts design's performance against the environment and local community objectives. However, design performs slightly worse than the Recommended Design against the environmental and community objective due to needing a new substation at Cornwall interface point which will be fully attributable to HNDFUE Celtic Sea. Against the deliverability and operability design objective, the design has a slightly worse performance than the Recommended Design, again because of the requirement for a brand new 400 kV substation at Cornwall. Also, against the economic objective, the main difference between this design and the Recommended Design is the cost of the new 400 kV substation at Cornwall. This makes the Recommended Design slightly more economic. This design is similar to the Recommended Design but requires additional investment for the new 400 kV substation at Cornwall, leading to its lower ranking.

<table>
<tr><th>Design</th><th>Overview</th><th>Assessment commentary</th></tr>
<tr><td>C_011c</td><td>
</td><td> Design is ranked 4th overall with an aim to connect 3 GW of power to the South West (North Devon and Cornwall) and 1.5 GW into South Wales (Carmarthenshire).
Similar to C_011a, this design requires a new 400 kV onshore circuit to facilitate connection. In addition to the new circuit, similar to C_011y this design will require a new 400 kV substation at Cornwall. These aspects of the design have an adverse impact on the environment and community, making it worse than the Recommended Design against these design objectives.
From a deliverability and operability perspective, similar to design C_011a, this design uses simpler HVAC technology for power exports, while the Recommended Design requires more complex HVDC technology for one of its interface points. However, there is a risk that this design will not meet the 2035 date for firm connection of all PDAs, due to the need for the new 400 kV circuit and substation, making it slightly less deliverable than the Recommended Design.
Against the economic objective, this design outperforms the recommended design, due to its use of cheaper HVAC technology to connects all PDAs to the grid, despite its higher onshore reinforcement cost.
Due to the risk in meeting the connection date of 2035 as a result of requiring a new 400 kV circuit for firm connection, and its poor community and environmental impact, the design ranked lower than the Recommended Design. </td></tr>
</table>

Design	Overview	Assessment commentary
C_011w		Design is ranked 5th overall with an aim to connect 3 GW of power to South Wales, linking into the proposed South Wales connection Node (SWCN) via two HVDC circuit and 1.5 GW into the South West (North Devon) with full coordination among the PDAs. Onshore works are less onerous as it avoids the need for a new 400 kV circuit. This is the best performing design against the environmental and community objective, due to fewer onshore works and landing points. This design also allows for power transfer between boundaries in South Wales and the South West during period of low winds, providing wider system benefits and further reducing the need for onshore reinforcement works. This is one of the most complex designs from a deliverability and operability perspective, this complexity is down to the requirement for staging and coordination between the PDAs as well as the use of two HVDC circuits for power export from PDA 2. This is the 2nd most expensive design as the high cost of the offshore HVDC circuits outweighs the savings realised from the cheaper onshore works. Despite performing well considering environment and community impact, the design is ranked lower than the recommended design. This is due to its complexity and high cost leading to poor performance against the deliverability and operability and economic objective. The Recommended Design is better balanced across all four design objectives.

<table>
<tr><th>Design</th><th>Overview</th><th>Assessment commentary</th></tr>
<tr><td>C_011x</td><td>
</td><td>
Design is ranked 6th overall, with an aim to connect 3 GW of power into South Wales (Pembroke and SWCN) and 1.5 GW into South West (North Devon).
This design avoids the need for a new 400 kV circuit, reducing the onshore works required. However, the landfall at Pembroke faces several environmental and community constraints, with the offshore route passing through areas that are sensitive to cabling, negatively impacting its environmental and community performance.
The design is slightly better than the Recommended Design C_011z against the deliverability and operability objective due to its overall shorter offshore route length and connecting to existing interface point, Pembroke, rather than proposed interface point Carmarthenshire substation.
Similar to deliverability and operability, this design is more economical than the Recommended Design, because of its overall shorter offshore route length.
This design is slightly better than the Recommended Design in terms of deliverability and operability, and it is more economical because of its shorter offshore routes. Despite these advantages, its poor environmental and community impact results in a lower overall ranking compared to the recommended design, which is better balanced across all four design objectives.
</td></tr>
</table>

Design	Overview	Assessment commentary
C_011u		Design is ranked 7th overall with an aim to connect 3 GW of power into the South West (North Devon substation) and 1.5 GW into South Wales (Pembroke). Similar to all designs connecting 3 GW into the South West, a new 400 kV onshore circuit will be required to facilitate connection. Also, the landfall at Pembroke has several environmental and community constraints sensitive to cabling. This makes it the worst design in terms of environmental and community impact as it performs poorly onshore and offshore. However, it is the best-performing design against the deliverability and operability objective, due to its shorter overall route length, simpler HVAC connection technology and only connecting to two interface points, one of which is existing. It is also the most economical design, with the lower offshore cost offsetting the increased onshore cost. Despite excelling in economic performance and deliverability and operability, its poor environmental and community impact makes the Recommended Design preferable to C_011u.
C_011v		Design is ranked last overall and aims to connect 3 GW into South Wales, via two HVDC circuits, linking into the proposed South Wales Connection Node (SWCN) and 1.5 GW into the South West North Devon, with partial coordination among the PDAs. Onshore, it avoids the need for a new 400 kV circuit, making onshore works less demanding, performing well in terms of environmental and community impact. However, this design faces challenges in deliverability and operability due to the complexity of coordinating two HVDC circuit. Additionally, it is the most expensive design, with the high offshore cost outweighing the

Design	Overview	Assessment commentary
		savings from less expensive onshore works. Despite its strong environmental and community performance, its issues with deliverability and operability and economic feasibility result in a lower ranking than the Recommended Design.

This stage of the process provided a recommended offshore network configuration, which connects offshore wind farms to interface points. The recommendation considered the onshore network needs; however, these studies do not reflect the works necessary to meet the full requirements of the SQSS and further onshore reinforcement analysis needs to be conducted, considering a range of future energy scenarios.

5 Conclusion and next steps

This *Technical Annex* supports the *Beyond 2030: Celtic Sea* publication and has:

- Outlined our overall design objectives and assessment approach.
- Explained how we have identified and assessed initial offshore network designs.
- Explained how we have appraised network designs to iteratively shortlist and compare designs.
- Described the recommended network design for connecting offshore wind farms in accordance with The Crown Estate’s (TCE) Floating Offshore Leasing Round 5.

Concurrent with the publication of this recommendation in August 2024, TCE will issue an Invitation to Tender, followed by an auction process that is expected to take place in Spring 2025. This will result in agreements for lease and the rights to develop areas of the seabed being awarded to successful developers to deliver the floating offshore wind projects for the Project Development Areas (PDAs) described in this document.

Once the successful developers are identified, we will work with each developer to produce connection contract offers allowing the projects to connect to the electricity network.

We will also work with the host Transmission Owner (TO), National Grid Electricity Transmission (NGET), to continue development on relevant works for this recommendation as it progresses into the detailed network design stage.

We also intend to continue to work closely with TCE for consideration of seabed leasing opportunities and the associated network designs to meet the future offshore wind generation ambitions.

Appendix A – Discounted interface points

Region	Discounted interface points	Rationale
South Wales	Swansea North 400 kV	Received a Black deliverability rating because there are no spare bays at this substation and no possibility of extending due to the lack of space within the site boundary. The substation is constrained by solar panel developments, woodlands, and existing transmission network infrastructure outside of the site boundary. Therefore, a new interface point would be required, and we are considering new substations, Carmarthenshire and Baglan Bay 275 kV in this area.
	Cilfynydd 400 kV	Received a poor deliverability rating as there is no capacity at the existing substation and so a new substation would be triggered. The onshore approach from landfall is constrained by urban areas and steep sloping land, which may be difficult to cable between, and by several areas of ancient woodland and sites of special scientific interest (SSSIs) that may be difficult to completely avoid, and so this location was deemed to be unfavourable for a new interface point.
	275 kV Network	Interface points on the 275 kV network in South Wales have been considered, including Baglan Bay, Margam, Pyle and Aberthaw. The voltage rating of these interface points places restrictions on how much capacity can be accommodated at the sites. Additionally, the sites would need to be rebuilt to facilitate any additional connections. Due to the location of Baglan Bay (closer to the Project Development Areas (PDAs) and closer to the 400 kV network), the nature of the site, the available space and potential for expansion, Baglan Bay was determined to be a preferable option to test the practicality of connecting 1.5 GW or more to the 275 kV network. Additionally, there are environmental benefits of connecting to Baglan Bay as the approach and surrounding areas are less sensitive. Other 275 kV interface points were assigned Black deliverability ratings due to a lack of space to rebuild or the area being constrained by the existing transmission network.
South West	Alverdiscott 400 kV	There is no available capacity to connect here with as the Xlinks interconnector is contracted to connect into this interface point. There is no room on site to extend or rebuild and so instead a new substation may be triggered in this region and has been considered in our designs as North Devon.
	Indian Queens 400 kV	There is no spare capacity at the existing substation and no room on site to extend or rebuild due to the surrounding Breney Common and Goss and Tregoss Moors Special Area of Conservation (SAC), upland areas, several SSSIs and the existing transmission network. A new interface point, Cornwall, is being considered in this region.

Region	Discounted interface points	Rationale
	Landulph 400 kV	Further from all PDAs under consideration and this greater distance would lead to higher costs and likely a higher environmental and community impact. Additionally, the site would require a rebuild to accommodate a Celtic Sea connection and as such, it performs poorly against the deliverability and operability design objective. For 1 GW of capacity or above, if this is built on a new site, it will require double turn in of the existing circuit, not just the substation. The Landulph substation area appears heavily constrained by the existing transmission network. There is heavy development along the shoreline that could constrain the cabling from landfall. A potential new interface point, Cornwall, is under consideration, which may be located between existing Indian Queens and Landulph sites.
	Taunton 400 kV	Further from all PDAs under consideration and this greater distance would lead to higher costs and likely a higher environmental and community impact. Additionally, the site would require a rebuild to accommodate a Celtic Sea connection and as such, it performs poorly against the deliverability and operability design objective. It is physically constrained on site; the area appears moderately constrained by the existing transmission network. There are areas within the vicinity that may be suitable for a substation location, but there is development along the shoreline that may leave limited approaches for offshore connections. Alternative site, North Devon, in the area has been considered for a new interface point.
	Seabank 400 kV	Received a Black deliverability rating as it is a small gas insulated substation (GIS) on the generator's site. Currently, two circuits are banked into one bay at Seabank, effectively creating a three-ended circuit. Therefore, it is not possible to connect additional bays or circuits at this site, especially as it is an indoor GIS surrounded by generator owned land. There are wider environmental impacts of working with SF6 in GISs and the industry is looking to use alternatives to SF6 going forward. A new interface point would be required, and this area was found to be an unfavourable location as it is further from the PDAs than other interface points. Also, the offshore approach is constrained by the Severn Estuary SPA/Ramsar and, within the Bristol Channel, dredging areas, large areas of offshore rock and existing cables. There are large areas Annex I Reef and Annex I Sandbanks which cannot be completely avoided.
	Sandford 400 kV	Discounted as a new substation would be required due to lack of space and set up of the existing mesh substation. A

Region	Discounted interface points	Rationale
		double turn-in into a new substation in this area of the network would be required to facilitate a connection. As with Seabank, this area was found to be an unfavourable location for a new interface point for Celtic Sea as it is further from the PDAs than other interface points and the offshore approach encounters the same constraints as Seabank. New interface points in the South West region are being considered in more favourable locations.
	Hinkley Point 400 kV/ Shurton 400 kV	Hinkley Point interface point was discounted due to receiving a Black deliverability rating. This interface point is close to the nuclear generation site, which could result in difficulty carrying out any work to connect in or extend the substation. It will be difficult to get consents and planning permission to carry out work in this location and this could extend timescales for connection. A new circuit would likely be required to allow Celtic Sea to connect here, due to Hinkley Point C connecting in the region, and a new circuit cannot be accommodated at this site. Shurton 400 kV was purpose built and is specifically used for the Hinkley Point C with 3340 MW without any other types of generators connected. As with Hinkley Point 400 kV, there are difficulties in carrying out work to connect in or extend the substation and so this interface point was also discounted.
Further inland interface points		Interface points such as Rhigos, Rassau, Imperial Park, Walham, Melksham that are located further inland and further from all PDAs were considered at a high level but discounted due to poor performance across the design objectives. These interface points have a poor performance against environmental and community as they interface with additional constraints onshore, are more expensive as they require more infrastructure and are more complex to connect to. As these interface points are also constrained and would require rebuilds/extensions to allow for a connection, we did not see a benefit to connecting further inland.

Appendix B - Designs discounted at the initial strategic options assessment.

Design and overall BRAG	Description	Rationale for discounting
C_011b	All radial connections, 3 GW to Carmarthenshire and 1.5 GW to North Devon.	Discounted due to very poor score for environment and bad score for community. Similar to other radial designs.
C_011d	All radial connections, 3 GW to Carmarthenshire and Baglan Bay and 1.5 GW to North Devon.	Superseded by C_011i, which is the same design but with a high voltage direct current (HVDC) link to Baglan Bay. Due to the length of this route, it is considered that HVDC is more practical and the more likely solution.
C_011e	HVDC coordinated with 3 GW to North Devon and 1.5 GW to Carmarthenshire.	Less preferable to have 3 GW into the South West, worst deliverability, worst economically and similar scenario to C_011h.
C_011f	HVDC shared platform with Project Development Area (PDA) 1 split, connections to Pembroke and North Devon.	This option has been discounted as it is aimed at allowing a connection to Pembroke in a scenario where 1.5 GW cannot be connected. This option does not perform well, and we have instead ensured a design option that connects 1.5 GW to Pembroke is included in the shortlist. Splitting PDAs is not preferable and does not perform well.
C_011g	3 GW to Carmarthenshire via HVDC and HVAC connection to North Devon.	Discounted due to poor economics and deliverability and similarity to C_011h, which performs better and has been shortlisted.
C_011i	All radial connections, 3 GW to South Wales with HVDC to Baglan Bay, high voltage alternating current (HVAC) connections to Carmarthenshire and North Devon.	Superseded by C_011q, which performs better on environment and gives a connection to Pembroke.
C_011j	All PDAs coordinated with 3 GW into North Devon via HVDC and HVAC connection to Carmarthenshire.	Very expensive option, discounted in favour of better performing designs with the same benefits. C_011s best design with all PDAs coordinated and has been shortlisted.
C_011k	All PDAs coordinated with 3.6 GW into North Devon and HVDC into Carmarthenshire.	Very expensive option, discounted in favour of better performing designs with the same benefits. C_011s best design with all PDAs coordinated and has been shortlisted.
C_011l	All PDAs linked and PDA 1 split, HVAC connections to Pembroke and North Devon and HVDC to Carmarthenshire.	There are other, better design options that include Pembroke without splitting capacity of PDA 1 – discounted on the same grounds as C_011f.

Design and overall BRAG	Description	Rationale for discounting
C_011m	All radial connections to Pembroke, Carmarthenshire, and Baglan Bay.	All capacity to South Wales does not perform well and cost of reinforcements in South Wales may be underestimated adding risk and uncertainty, meaning economic benefits may be overstated. Very poor performance on environment.
C_011n	All radial connections to South Wales with bootstrap between Baglan Bay and North Devon.	Radials with bootstrap designs deferred to the final strategic options appraisal (FSOA).
C_011o	All radials to South West to Cornwall and North Devon.	All capacity to the South West does not perform well and this design has a poor performance on community.
C_011p	All radials to the South West with bootstrap between Carmarthenshire and North Devon.	Radials with bootstrap designs deferred to FSOA.
C_011t	Coordinated connections to Baglan Bay and HVAC connection to Carmarthenshire.	All capacity to South Wales does not perform well (against the environmental design objective in particular) and cost of reinforcements in South Wales may be underestimated so this option may be high risk.