March 2024

Beyond 2030 Technical Report

ESO

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Introduction

Context

One of our key responsibilities as the Electricity System Operator (ESO) is to assess Great Britain's future energy supply and demand needs and then design an electricity network that can meet those needs in a safe, efficient and affordable way.

To deliver the UK Government's 50 GW offshore wind ambition by 2030, coordinated electricity transmission network planning is essential. In 2020, we developed the first Holistic Network Design (HND1)[1], that considered how to best connect 23 GW of offshore wind to the onshore transmission network. Last year, the UK Government asked us to go further by connecting more offshore wind to the onshore electricity network and if the transmission assets can be delivered under the timeframes set out in the UK Government's *Transmission Acceleration Action Plan* (TAAP), this network plan combined with the timely delivery of additional generation and developer led offshore transmission will enable the Great Britain to meet its Sixth Carbon Budget.

The design facilitates the connection of an additional 21 GW of offshore wind as a result of the ScotWind leasing round, enabling Great Britain to have the second largest offshore wind fleet in the world by the mid-2030s, larger than the rest of Europe combined. This design also facilities the connection of a breadth of other low-carbon electricity generation.

Identifying and assessing future network needs

As the ESO we established possible future scenarios before assessing a "current vs future" projected network capability. Network Capability is assessed based on how much power needs to flow across the network. This is defined by electrical boundaries across Great Britain and is outlined every year in the *Electricity Ten Year Statement* (ETYS). Options required to meet a required transfer can be proposed from the Transmission Owners (TOs), Interested persons and we, the ESO, in the form of ESO-led alternative solutions.

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

A holistic approach

Our analysis has identified a recommended network design for connecting offshore wind farms by considering representative onshore reinforcements alongside offshore network designs. We have then used this offshore network to iterate and look in more detail at the onshore driven requirements. Both phases are described in this annex, and in both phases, we have used four network design objectives to make sure we are considering a broad range of factors in planning our future networks responsibly. These network design objectives are described in this document. In

[1] https://www.nationalgrideso.com/document/262676/download

brief, they are: economic and efficient; environmental impact; local community impact; and deliverable and operable.

The report provides an initial high-level view of future network requirements and provides a foundation for further detailed design exercises that are required prior to building the networks. The assessment that forms the basis of the report has identified a range of impacts, and constraints that need to be considered and mitigated in future design, development and construction phases.

In developing the Beyond 2030 report, we have collaborated closely with the Transmission Owners (TOs) and engaged with a range of interested parties including government departments, the regulator (Ofgem), wind farm developers, and environmental and community representatives. Feedback from these stakeholders has helped shape recommendations provided in this report.

Purpose of this document

This annex to the Beyond 2030 report provides further detail on the recommendations. It expands on the publication, explaining which offshore and onshore design options were considered, how these were assessed and how this led to a final recommendation.

This annex specifically presents the ScotWind elements of the HNDFUE. At the time of publication the other elements of HNDFUE, Celtic Sea and Innovation and Targeted Oil and Gas (INTOG), have not yet concluded, but these are not anticipated to impact the design recommendations in this annex. These final elements of HNDFUE will be published in due course as an extension to this document.

Reinforcement options presented in this annex meet a clearly defined need but have a variety of levels of maturity in their development. Following these recommendations, more detailed design and development is likely to be needed in all cases. This detailed design will also need to consider other statutory and regulatory responsibilities of license holders and so we expect the design to continue to evolve into the future.

Annex structure

This annex covers five 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 recommendation.
- **Identifying and assessing initial offshore network designs**, an explanation of the iterative process to identify and assess offshore designs whilst considering the high-level onshore network impact.
- **Determining the recommended network design for connecting offshore wind farms**, an explanation of how we determined the recommended offshore network design and considered the impact of onshore network reinforcements.
- **Determining the future electricity network needs for Great Britain**, an explanation of the process undertaken to determine the recommended future onshore and offshore network requirements.
- **Summary onshore options assessment table**, including optimal delivery dates per FES scenario, BRAG ratings per design criteria, and recommendations.

Overview of our design objectives and assessment approach

What design objectives did we consider?

To support the goal of achieving a net-zero energy system, the UK Government, the Regulator and the ESO have been evolving the way energy networks are designed. Previously, energy generated by offshore wind farms was connected sequentially, often in a radial point-to-point connections from the generator to the transmission system.

Following instruction from the UK Government, we have started to design networks using a more holistic approach. The ESO Offshore Coordination project began in 2020, contributing to the Offshore Transmission Network Review. Phase 1 of this project assessed the costs and benefits of a coordinated offshore transmission network, including the technical and procedural considerations required to achieve coordination. This resulted in the publication of our *Phase 1 Final Report*[2]. Phase 2 of this project then delivered a Holistic Network Design (HND) for a coordinated onshore and offshore network. This was published in July 2022[3], and provided a recommended offshore and onshore design for a 2030 electricity network that facilitates the Government's ambition for 50 GW of offshore wind by 2030.

Phase 3 of this project was then initiated to consider additional offshore wind farms in Scotland and the Celtic Sea. This Holistic Network Design Follow up Exercise (HNDFUE), as outlined in the HNDFUE terms of reference[4]**,** 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 beyond economics. The design objectives considered in this approach include:

- **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.

What was our approach to determining the network requirements?

The approach to determine the recommended design needed to consider the design objectives across both offshore and onshore networks.

The significant impact of offshore wind in the future energy system meant that it was crucial to establish how these wind farms would best connect to the onshore transmission system. Once the offshore network configuration had been established, it would be feasible to further assess the onshore network design to account for a range of future energy scenarios.

Considering the need to determine the offshore configuration first, the holistic onshore and offshore network design has been developed following three main phases shown in Figure 1.

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[2] https://www.nationalgrideso.com/document/183031/download
[3] https://www.nationalgrideso.com/future-energy/pathway-2030-holistic-network-design/holistic-network-design-offshore-wind
[4] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1181581/otnr-hnd-fue-tor.pdf

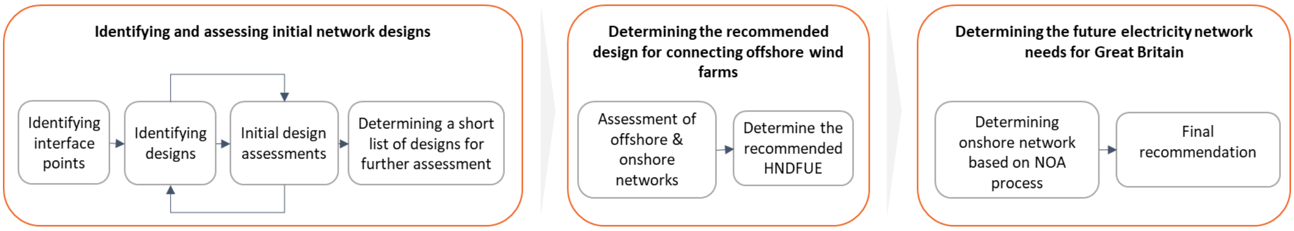

Figure 1 - overview of the design process

Identifying and assessing initial offshore network designs

We developed offshore network designs, which would connect the offshore wind farms to the onshore transmission network. A key factor to consider was where the wind farms would connect to the onshore network, known as the interface points. Once feasible interface points were established by the TOs, we identified and assessed numerous ways to connect the offshore generation to these interface points. Some designs included mainly radial point-to-point connections between wind farms and the onshore network, whereas other designs included significant interconnection between wind farms and multiple offshore links from Scotland to the South of England. Interconnection and coordination between wind farms and across the grid enables the best use of landfall sites and thus reduces the environmental and community impact, however it can lead to increased complexity in deliverability and operability, and potentially increase costs.

The assessment of designs considered both the offshore and onshore aspects. Devising a definitive onshore network to accommodate each offshore design was unrealistic at this stage given the number of designs to assess. However, the onshore network needed to be considered to some extent at this early stage, and so representative onshore reinforcements were determined and used for to account for the onshore aspect.

Following the assessment of over 140 options, 6 high performing designs were shortlisted to be considered for further development and assessment.

Determining the recommended design for connecting offshore wind farms

This phase focussed on assessing the shortlisted designs in greater detail, including the impact on onshore requirements. Six high performing designs were shortlisted with varying levels of offshore coordination, from a radial design to a highly coordinated design, before determining the recommended offshore network. The designs were assessed on their offshore and onshore performance against the design objectives, considering the potential onshore reinforcements required to support the connection of the offshore network. In addition to individual assessments, the designs were compared and ranked.

Following the ranking of designs there was an opportunity to develop a modified design which merged the two best performing designs. It adopted features of each deemed to have a net benefit. This hybrid design outperformed all six shortlisted designs.

Determining the future electricity network needs for Great Britain

The recommended design for connecting offshore wind farms considered one specific future energy scenario, that contained the in scope generation. However, to finalise the future network requirements, we needed to assess a range of future energy scenarios. This phase considered the recommended offshore network and built upon indicative onshore network needs, to determine the final design recommendations both onshore and offshore.

How were designs assessed against the design objectives?

As agreed with the Office of Gas and Electricity Markets (Ofgem) and government, the assessment process should consider the design objectives on equal footing across the onshore and offshore networks.

The assessment used 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 economics across each design. To assess and compare the deliverability and operability, environmental impact and community impact, we used BRAG (Black, Red, Amber, Green).

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 from an environmental/community/deliverability and operability perspective due to environmental/community/deliverability issues.
- Red – the design has a high level of constraints from an environmental/community/deliverability and operability perspective and is potentially viable, however will have to overcome many environmental/community/deliverability issues.
- Amber – the design has a medium level of constraints from an environmental/community/deliverability and operability perspective and is likely to be viable, however may have to overcome some environmental/community/deliverability issues.
- Green – the design has a low level of constraints from an environmental/community/deliverability and operability perspective and is likely to be viable without any major environmental/community/deliverability issues.

In some instances, it was hard to differentiate between designs using their BRAG ratings alone; a more granular scoring system was required to rank and carry forward recommendations. To provide more granularity and distinguish between designs that had the same BRAG ratings, we assigned a scale rating from one (best) to five (worst) with the BRAG ratings. The scale ratings were assigned to the overall offshore and onshore BRAG ratings, not to individual reinforcement BRAG ratings.

Identifying and assessing initial offshore network designs

What was the purpose of this phase?

The purpose of this phase was to identify network designs that connected 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 assessment process.

How did we identify and assess designs?

Interface points and key constraints

In determining how to connect wind farms to shore, it was important to identify suitable onshore interface points. Interface points provided by TOs typically consisted of coastal points where existing transmission infrastructure had space and/or capacity to accommodate new connections, however it could also include new substations or locations in early development. This assessment of interface points considered the objectives on equal footing and was performed in close collaboration with the Transmission Owners (TOs). In addition to determining suitable interface points, it was important to assess routes for connecting wind farms to shore, and routes that enable interconnection between wind farms and/or offshore interconnection between onshore regions.

Figure 2 shows an overview of the Holistic Network Design Follow up Exercise (HNDFUE) wind farms and interface points provided by Transmission Owners and considered for connections of offshore wind in scope for HNDFUE. Some interface points were excluded from consideration due to existing capacity constraints, for example limited physical space on a site. Environmental and community constraints are considered at a very high level when assessing interface points and revisited in more detail later in the process.

Error! Reference source not found. also shows the high number of wind farms located offshore in Scotland. For this generation to supply key demand centres, it is important to consider the most efficient methods to connect the two. Key onshore network boundaries and constraints that trigger onshore network reinforcement need to be considered. On the figure are a number of onshore boundaries that were assessed in the process and cover key regions and constraints across Great Britain. A comprehensive map of all onshore network boundaries can be found in the *Electricity Ten Year Statement 2023* (ETYS)[5]. For reference Figure 2 also includes a sample of environmental features that have been considered at the later stages of our assessment to show how interface points and subsequent designs may interact with some of these features.

[5] Electricity Ten Year Statement (ETYS) | ESO (nationalgrideso.com)

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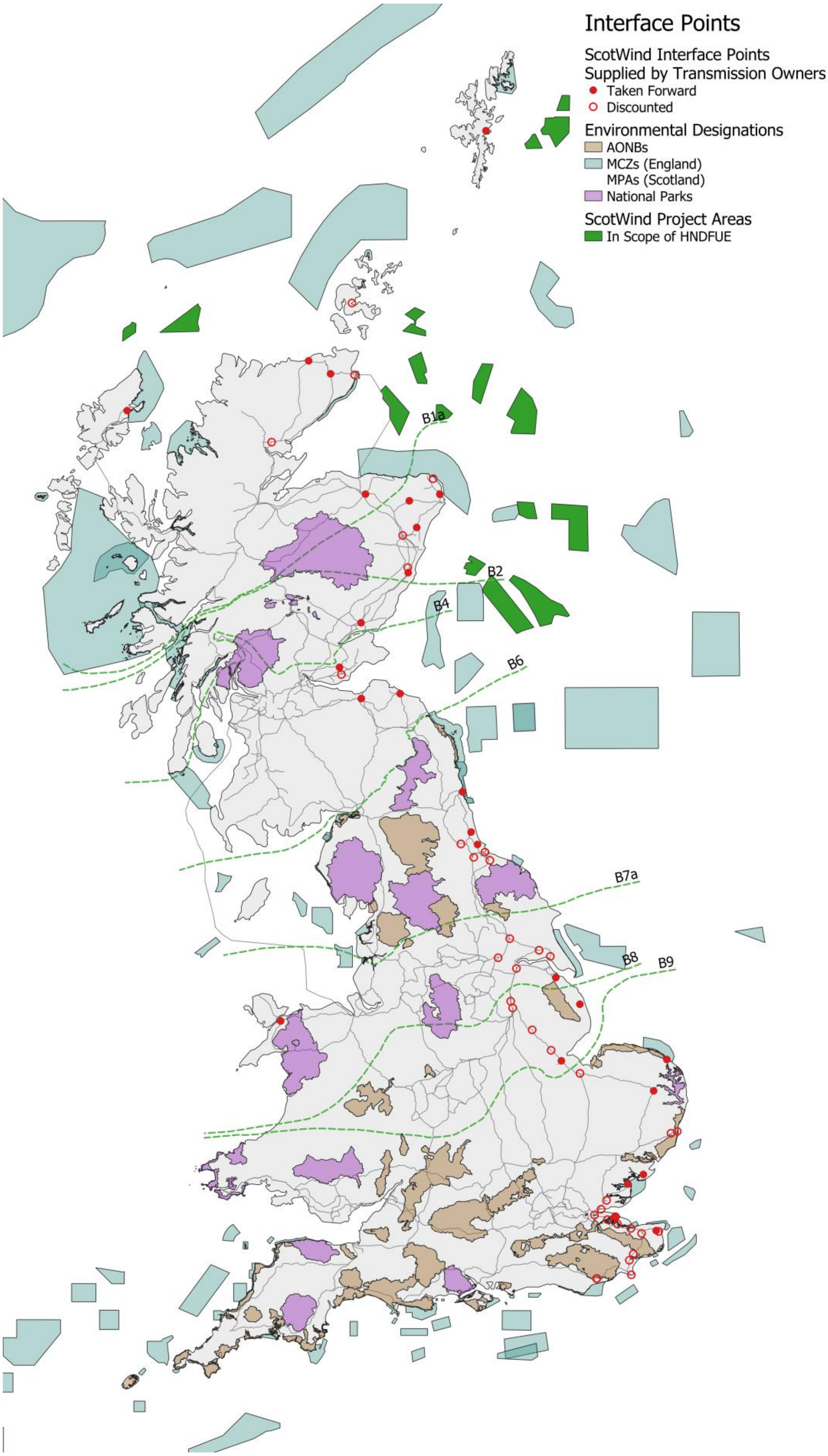


Figure 2 - overview of wind farms, interface points and key constraints

Offshore design option creation

After identifying interface points, we explored different offshore designs to connect the offshore wind generation to the main transmission system via a selection of these interface points. Each offshore design was appraised individually for the community, environment, deliverability & operability, and economic design objectives. The designs were reviewed and scrutinised considering the design objectives on equal footing. Based on the collective performance against design objectives, we decided whether to iterate further by changing features, e.g. interface points, interconnection, capacity of infrastructure etc., or to not take the design forward.

During the initial development, we identified 16 design groups that considered a wide variety of key features. Some designs included mainly radial point-to-point connections between wind farms and the onshore network, whereas others included significant interconnection between wind farms and multiple offshore links from Scotland to the South of England. The assessment of a broad range of designs enabled us to determine if and how varying features would strengthen or worsen the performance. A description of the design groups is shown in Table 1. To keep track of the variations, each design received a unique reference, e.g. S_009k-1, that enabled us to logically follow common and distinguishing features through the exercise.

Design groups can broadly be categorised into four levels of electrical interconnection: (1) radial designs which have little to no additional interconnection; (2) designs with low levels of additional interconnection (1-2 links); (3) designs with medium levels of additional interconnection (3 – 4 links); and (4) designs with high levels of additional interconnection (more than 5 links). It is important to note that the varying levels of interconnection are in addition to interconnection recommended as a result of the HND. Figure 3 shows examples of varying levels of interconnection between wind farms and offshore interconnection between Scotland and England.

Table 1 - Overview of designs groups

Design Group	Levels of offshore interconnection	Description
1	Radial	Radial connections from all offshore wind farms to onshore substations
2	Radial	Radial connections from all offshore wind farms to onshore substations – considers connections further south
3	Radial	Radial connections from all offshore wind farms to onshore substations – variation to hydrogen electrolysis demand sensitivity scenarios
4	Radial	Mainly radial connections from offshore wind farms to onshore substations, with some interconnection and sensitivities around Shetland
5	Low	Low levels of offshore interconnection with one additional HVDC subsea cable across key constraint boundaries in Scotland
6	Low	Low levels of offshore interconnection with one additional HVDC subsea cable across the Anglo-Scottish Border
7	Low	Low levels of offshore interconnection with two additional HVDC subsea cables across the Anglo-Scottish Border
8	Medium	Medium levels of offshore interconnection with three additional HVDC subsea cables across the Anglo – Scottish Border
9	Medium	Medium levels of offshore interconnection with four additional HVDC subsea cables across the Anglo – Scottish Border, but some sensitivities considering HVDC subsea cables coordinating in Scotland
10	Medium	Medium levels of offshore interconnection with four additional HVDC subsea cables, across the Anglo – Scottish Border, with the HVDC subsea cables connecting further South in England
11	High	High levels of offshore interconnection with five additional HVDC subsea cables across the Anglo Scottish Border
12	High	High levels of offshore interconnection with six additional HVDC subsea cables the Anglo Scottish Border
13	High	High levels of offshore interconnection with seven additional HVDC subsea cables across the Anglo Scottish Border
14	High	High levels of offshore interconnection with eight additional HVDC subsea cables, across the Anglo Scottish Border
15	Medium	Medium levels of offshore interconnection with three additional HVDC subsea cables the Anglo – Scottish Border. Different from design group 8 due to the removal of some wind farm interconnection in Scotland.
16	Medium	Medium levels of offshore interconnection with four additional HVDC subsea cables across the Anglo – Scottish Border. Includes a West Coast HVDC subsea cable and three East Coast HVDC subsea cables (and is therefore different from design group 10)

Figure 3 shows four examples of varying levels of interconnection between wind farms and across regions.

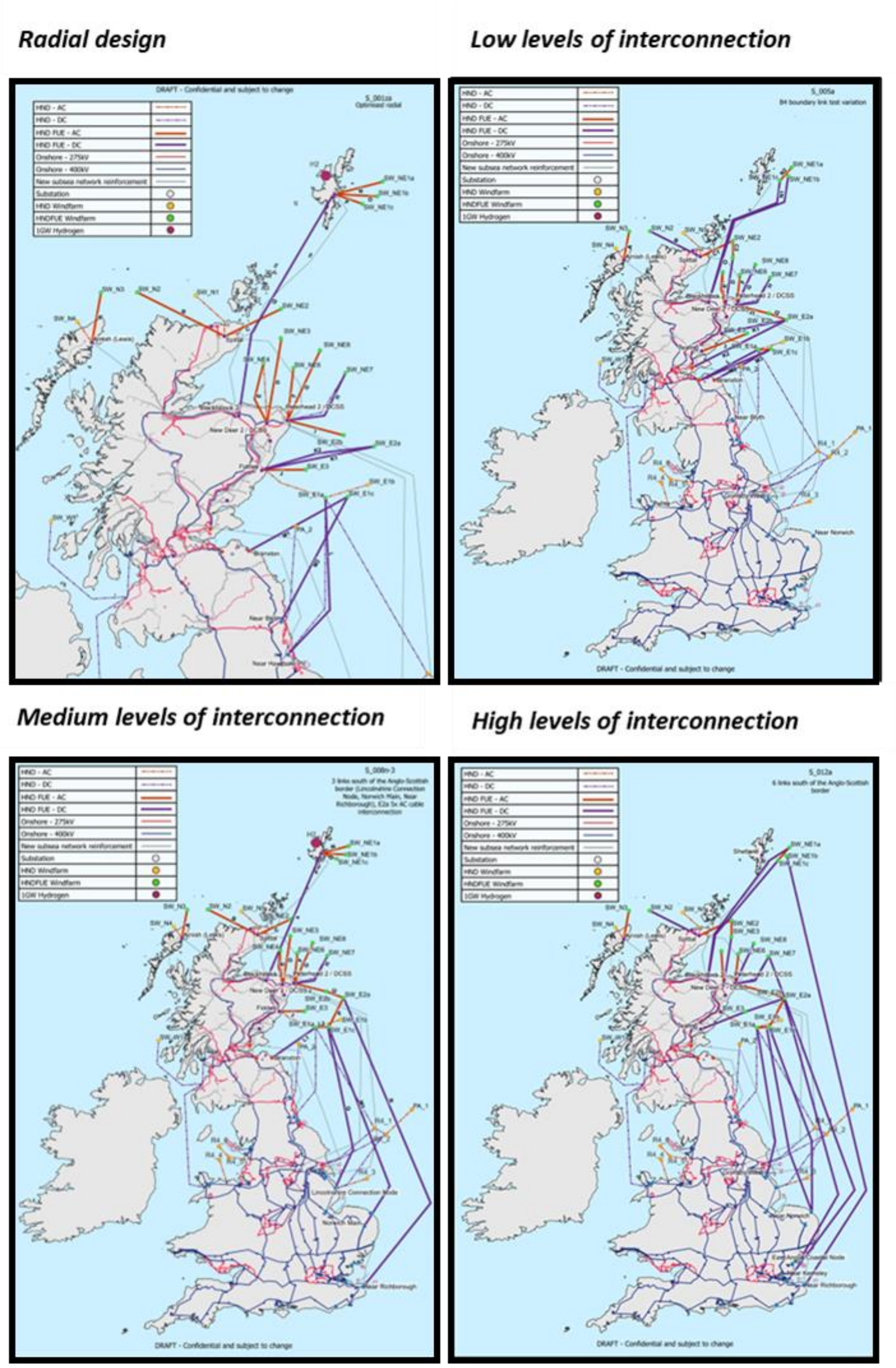


Figure 3 - Maps showing varying levels of interconnection.

How did we determine the shortlisted designs?

Following the initial assessment, we selected a shortlist of designs to assess and optimise in further detail before determining the recommended offshore network.

Table 2 provides an overview and comparison across the design groups. Where designs were discounted early in the process, e.g. design groups 2 to 4, and no further assessment was completed, these groups have been omitted from the table. For each design group, the table presents the assessment for one or two designs in the group. In some cases, the design presented in the table is the only design developed and assessed in the design group, in other cases, it is the best performing design within the group. For design group 9, two designs were assessed to perform well across the objectives (and taken forward to the shortlist), hence these two are presented in the summary table.

The summary table includes the BRAG assessment for the community, environment, and deliverability and operability objectives. In addition, the table includes the economic assessment for each design, which has been broken down into key cost categories. While costs were calculated to compare performance, these were initial assessments using some approximations before more detailed analysis was performed on the shortlisted designs. Each category of cost has been assigned a high, medium or low rating within the table below. The design with the highest and lowest cost in each category has also been identified. Moreover, the net present value (NPV) has been rounded to the nearest £500m.

Definition of cost categories:

- NPV: differential in cost between the design in question, and the most economic design, which is S_016e-1.
- Offshore infrastructure costs: the estimated cost of building, operating and maintaining the offshore network (for this purpose, this is all infrastructure between the interface point and offshore wind farms, in addition to costs associated with each interface point).
- Onshore infrastructure costs: the estimated cost of reinforcing the onshore transmission network to transport power to where it is needed, where it is economic to do so.
- Operational costs: includes the costs to operate and balance the system.

Table 2 - Network Design Assessment Overview – shortlisted designs highlighted in green and bold.

Design Group	Level of offshore interconnection	Description*	Key design	BRAG assessment			Economic costs (£m)			
				Environment	Community	Deliverability and Operability	**NPV** (cost difference to most economic design) **(£bn)**	Offshore network	Onshore boundary reinforcement	Market
1	Radial	Radial connections from all offshore wind farms to onshore substations	S_001za	A	G	G	+£2.5	Lowest	Highest	M
5	Low	One additional link across key constraint boundaries in Scotland	S_005a	A	A	A	+£9.0	M	H	M
6	Low	One additional link south	S_006c	R	A	R	+£9.0	M	H	L
7	Low	Two additional links south	S_007a	R	A	A	+£9.5	M	H	L
8	Medium	Three additional links south	S_008n-3	R	G	R	+£1.0	M	L	H
9	Medium	Four additional links south, some sensitivities considering links coordinating in Scotland	S_009i-1	R	A	R	+£0.5	M	L	H
	Medium	Three additional links south, with the links connecting further south in England	S_009k-1	A	A	R	+£2.0	M	L	H
10	Medium	Four additional links south	S_010b	R	A	R	+£6.0	H	L	M
11	High	Five additional links south	S_011d	R	A	R	+£4.0	H	L	M
12	High	Six additional links south	S_012a	B	R	R	+£9.0	H	L	L
13	High	Seven additional links south	S_013a	B	R	R	+£10.0	H	L	L
14	High	Eight additional links south	S_014a	B	R	R	+£11.0	Highest	L	Lowest
15	Medium	Three additional links south. Different from design group 8 due to the removal of some wind farm interconnection in Scotland.	S_015h	R	A	R	+£7.0	M	L	Highest
16	Medium	Four additional links south. Includes a West Coast link (and is therefore different from design group 10)	S_016g	R	A	R	+£0.5	M	Lowest	M

More detailed descriptions of design groups are found in Table 1

H = High, M = Medium, L = Low

Initial options assessment

The assessment at this early stage considered environmental, deliverability and operability and community constraints between the offshore wind farms and onshore substations – it did not consider the impacts of any further onshore works. These further onshore works were assessed for the shortlisted designs in the subsequent phase. Generally, designs with less interconnection and less offshore infrastructure performed better from an environmental, deliverability and operability and community perspective; however it was important to note that these designs tend to have greater requirements for onshore boundary reinforcement, which are likely to trigger new infrastructure needs that will have to overcome onshore environmental issues.

When considering the environment, the designs varied in assessment from those that were unlikely to be viable (Black rated) to those that were likely to be viable (Amber rated) but had issues to overcome. Due to the extent of infrastructure required to connect the wind farms to shore it is expected that some level of environmental constraints will need to be overcome.

The community assessment identified that designs vary in terms of being potentially viable (Red rated) from a community perspective to likely to be viable (Green rated) from a community perspective.

The deliverability and operability assessment determined that the radial design was likely to be viable (Green rated), however increasing the level of offshore interconnection and infrastructure would result in many deliverability and operability issues. A specific concern with designs that include large numbers of interconnected high voltage direct current (HVDC) subsea cables was the supply chain availability of novel equipment required to manage the interconnection and control of HVDC technology.

The economic assessment shows how the levels of offshore and onshore costs vary significantly between radial designs and highly interconnected designs. The assessment shows that medium levels of interconnection (three to four additional offshore HVDC subsea cables) perform best from an economic perspective. Designs with one or two additional HVDC subsea cables do not offset the need for significant onshore reinforcement and designs with six or more additional HVDC subsea cables south did not provide additional reduction in onshore works compared to three to five additional links. Economic performance was impacted by the cost of offshore assets (with longer links and offshore infrastructure adding cost), and the benefit that these assets can provide to the network (by reducing market costs and/or reducing the need for onshore reinforcements).

Final options shortlisting

Following the assessment of over 140 designs and considering the objectives on equal footing, we decided to progress several high performing designs for further appraisal.

The designs selected were:

- **S_001za** – the optimised radial
- **S_008n-3** – three HVDC subsea cables across the Anglo – Scottish Border
- **S_009i-1** – four HVDC subsea cables across the Anglo – Scottish Border
- **S_009k-1** – four HVDC subsea cables across the Anglo – Scottish Border (variation in where HVDC subsea cables are connecting on the East Coast)
- **S_011d** – six HVDC subsea cables across the Anglo – Scottish Border
- **S_016g** – three HVDC subsea cables on the East Coast Anglo – Scottish Border and one HVDC subsea cables across the West Coast Anglo – Scottish Border

The six selected have several features or connections that are consistent, but also provide a spread from designs that are fully radial to designs that include significant amounts of interconnection offshore.

Determining the recommended network design for connecting offshore wind farms

What was the purpose of this phase?

The purpose of this phase was to determine a recommended offshore network design by assessing the shortlisted designs in further detail. Specifically, the phase aimed to assess the impact of offshore network designs on the onshore network in greater detail.

How did we determine the recommended offshore network design?

To understand the overall impact of each of the six shortlisted designs, we worked closely with the Transmission Owners (TOs) to understand the representative onshore reinforcement requirements for the designs in further detail. At this stage of the process, the works are identified from a single scenario considering the connection of the offshore wind generation. The process involved an exercise to find the optimal combination of reinforcements for each shortlisted design, considering the four network design objectives. This in turn created a number of final strategic designs with a representation of offshore network requirements, and onshore network requirements which can then be assessed against each other in more detail than the previous stages.

Onshore reinforcements

Through our design process, we try to establish how much new onshore infrastructure may be needed alongside the new offshore infrastructure. When considering the design to connect the offshore wind farms in the scope of the Holistic Network Design Follow up Exercise (HNDFUE), we used representative enabling works (to enable a generator to connect to the network safely and efficiently) and representative wider works (to reinforce capability across the wider network).

Enabling works in this context are works which are needed to meet the Security and Quality of Supply Standards for a specific generator to connect to the system (for example to make an electrical connection, or to avoid unacceptable overloads on the network following a fault) and are analysed with a specific scenario for that generator to provide the right level of ‘stress test’ for the relevant infrastructure. These may also provide other wider network benefits, such as improved power flows in the wider network, but this is not always the case. At this early stage, studies were carried out to produce representative versions of these works to allow for designs to be appraised and compared.

Further detailed design work is needed following our recommendations which includes the connection studies for each individual generator in scope of HNDFUE. Once these studies are completed, the relevant enabling works will be determined and inserted into that generator’s connection agreement.

For onshore work that provides wider system benefit, these are then assessed further across different scenarios and given investment recommendations as described in section 5 of this annex. It is possible that some of the representative wider works considered in arriving at the design to connect the offshore wind are superseded when looking across these other scenarios. As a result, these may not be ultimately recommended, for example if a different configuration offers a better outcome across the network design objectives.

Final options appraisal

The onshore reinforcement options were appraised across the four design objectives, and the different combinations of reinforcement options, or pathways, assigned cumulative BRAG (Black, Red, Amber, Green) ratings and severity ratings by us. This approach led to each shortlisted offshore network design having an associated onshore reinforcement pathway. In determining the BRAG ratings, we considered opportunity of high-level mitigation actions that could be implemented to reduce the impact and improve the viability of designs.

Once the shortlisted designs were individually assessed to determine the potential onshore component of each design, we assessed the designs across the objectives on equal footing to recommend a final design. To support the comparison and assessment across each objective, we ranked each shortlisted design for each design objective.

In the process of determining the recommended design we considered opportunities to iterate and refine designs based on the outcomes of the detailed assessments. Based on stakeholder feedback, we identified a few optimisations that further improved the performance of the design against the four design objectives. These minor adjustments were discussed with impacted parties, who were supportive of the adjustments.

What is the recommended offshore network design?

Following the assessment of the shortlist, we identified a modified design (designated S_009s) that formed a hybrid of two shortlisted designs (S_009i-1 and S_008n-3).

Recommended design: **S_009s**

Design S_009s shown in Figure 4 was determined to be the best performing when considering all objectives on an equal footing.

This design performs well across all four network design objectives when compared to the other shortlisted designs, and transfers power efficiently across the network to centres of demand.

Whilst the radial design (S_001za) was slightly more economic than this recommended design, the recommended design performed substantially better when considering the community impact, environmental impact and deliverability and operability factors. This is due to the radial design requiring significantly more onshore infrastructure, whilst still also needing a large amount of infrastructure in the marine environment, resulting in more reinforcement overall when compared to this recommendation.

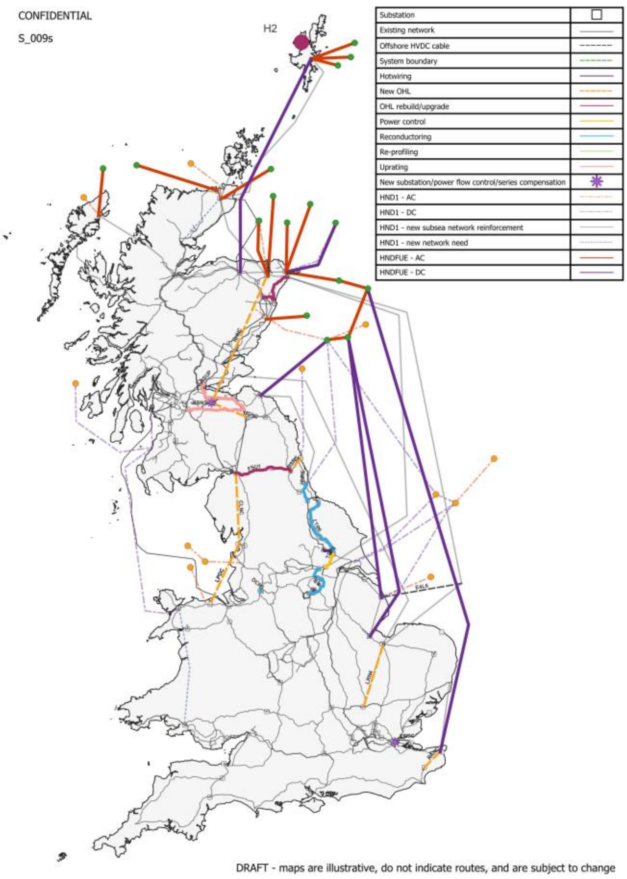


Figure 4 - overview of recommended offshore design

Table 3 below shows the representative connection works and wider works considered in arriving at the recommendation for the final design S_009s. Some of these have been superseded by the subsequent stage of our analysis where more options may have been presented or more detail may have been available. For the full list of wider works recommendations please refer to Table 16 at the end of this annex.

Table 3 - Onshore works[6] for the final HNDFUE design

Code	Description	Enabling Works	Wider Works
BTR2	Upgrade the existing circuits between Brinsworth and Thorpe Marsh to allow for more capacity	Y	Y
CLN2	New circuit across North West England	Y	Y
DCR4	Replace the conductors on the existing circuits between Carrington and Daines with higher capacity conductors	Y	N
DSUP	Establish further connection capacity between Dounreay, Banniskirk (Spittal), and Thurso.	Y	N
E4L6	Refine an existing offshore HVDC link planned between Central Scotland and eastern England with a third connection into Lincolnshire	Y	N
ECSC	Install voltage support equipment within East Anglia	N	Y
ETRE	Upgrade the existing circuits between Eggborough and Thorpe Marsh to allow for more capacity	Y	Y
FSU1	Upgrade the existing network to a higher voltage between Harker and Stella West	Y	Y
HGNC	New circuit between Harburn and Gala North	N	Y
HNRE	Replace the conductors on the existing circuits between Hawthorn Pit and Norton with higher capacity conductors	Y	N
JTHW	Carry out thermal upgrading on the existing circuit between Thurcroft and West Melton	N	Y
LCU2	Upgrade the existing network to a higher voltage between Kincardine North, Strathaven and Smeaton	N	Y
LPDC	New offshore HVDC link between North West England and Wales	N	Y
LRN6	New transmission capacity between the South Lincolnshire area to Hertfordshire	Y	Y
LTRE	Upgrade the existing circuits between Lackenby and Thornton to allow for more capacity	Y	Y
NHNC	New circuit from North East Scotland to the Central Belt	Y	Y

[6] The relevant TO also identified a further issue which needs to be resolved, potentially by a new circuit in the North East (BSNC). It is not included in this plan as further work is required to clarify the specific driver behind this reinforcement, its timing and the best solution.

Code	Description	Enabling Works	Wider Works
NNNC	New circuit between New Deer and Greens (New Deer 2)	Y	N
OTHW	Carry out thermal upgrading on the existing circuit between Osbaldwick and Thornton	Y	N
PKUP	Upgrade and/or rebuild the circuits and equipment between Longside (Peterhead 2), Peterhead, Persley, Kintore, Fetteresso, Alyth, and Kincardine	Y	Y
RANC	New circuit within Southeast England	Y	N
TDP4	Add power control devices to the existing circuit between Drax and Thornton	Y	N

How did other shortlisted designs perform?

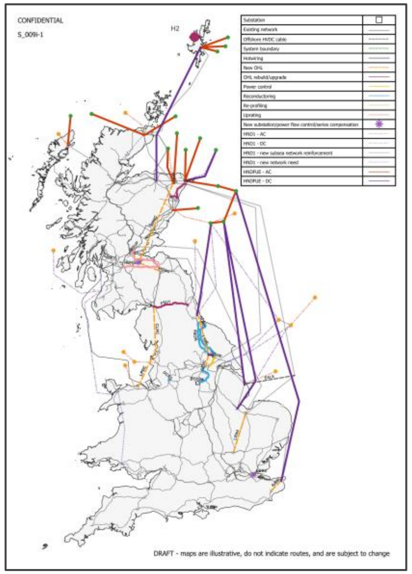
The final strategic options appraisal compared all of the shortlisted options against each other considering the four network design objectives.

Figure 5 provides an overview of the six shortlisted designs, and an overview of the assessment is shown in Table 4. The final recommendation was a combination of designs in the shortlist and so is not shown in Figure 5.

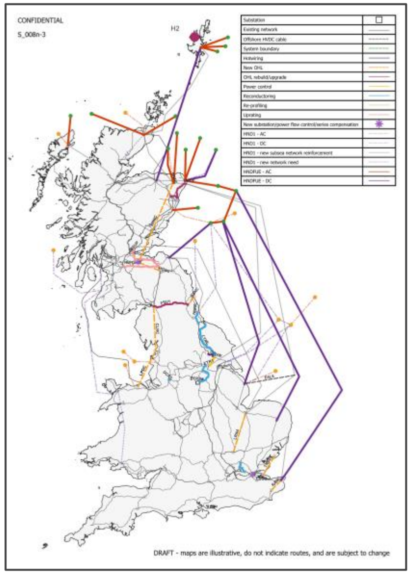
Below is a summary of how each of the shortlisted designs performed in the assessment. Table 4 shows the relative ranking of each of the shortlisted design for each of the four network design objectives. These were determined following more detailed comparison and to inform the final recommendation.

ESO

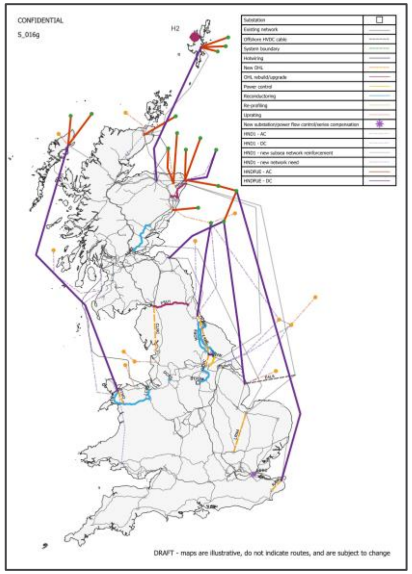
S_009i-1



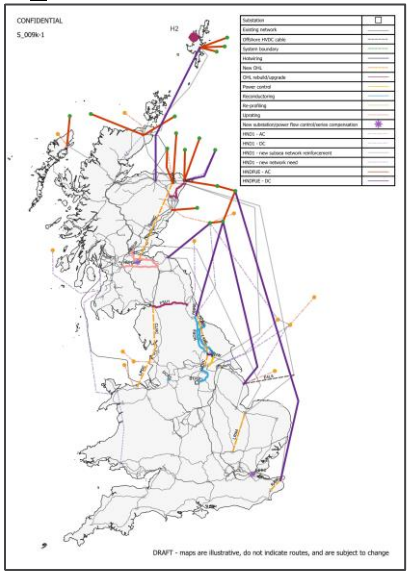
S_008n-3



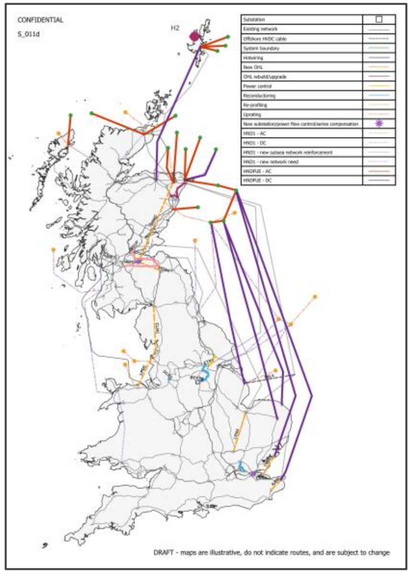
S_016g



S_009k-1



S_011d



S_001za

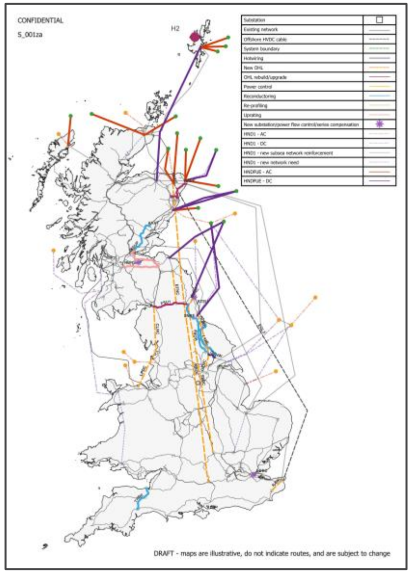


Figure 5 - an overview of shortlisted network designs

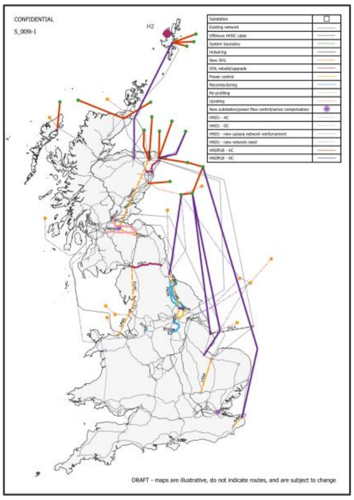
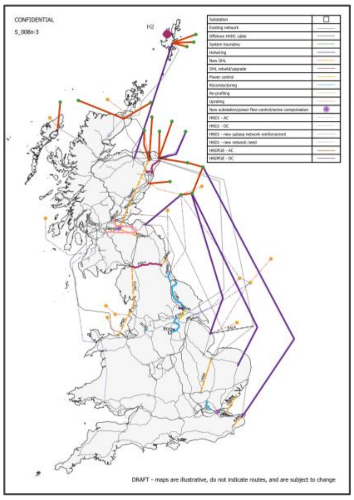
Table 4 - Design assessment overview and comparison

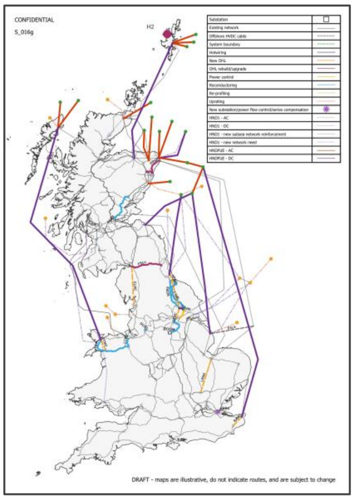
Rank	Design	Ref.	Economic and Efficient				Deliverability and Operability			Environment			Community		
			Total offshore cost	Total onshore cost	Constraint cost (delta)	Rank	Offshore BRAG	Onshore BRAG	Rank	Offshore BRAG	Onshore BRAG	Rank	Offshore BRAG	Onshore BRAG	Rank
1st	**S_009s**	**Three links south (hybrid)**	**M**	**M**	**M**	**2nd**	**R1**	**R1**	**1st**	**R1**	**R4**	**2nd**	**G4**	**R3**	**2nd**
2nd	S_009i-1	Four links south	M	M	M	3rd	R1	R3	4th	R3	R4	4th	A1	R3	4th
3rd	S_008n-3	Three links south	M	M	M	4th	R1	R2	2nd	R3	R4	5th	A2	R3	5th
4th	S_016g	Four links south (West Coast link)	H	Lowest	H	6th	R2	R2	5th	R3	R3	1st	A2	R2	1st
5th	S_009k-1	Three links south	L	M	Highest	7th	R1	R3	3rd	R1	R4	3rd	G4	R3	3rd
6th	S_011d	Five links south	Highest	M	Lowest	5th	R2	R2	6th	R4	R4	6th	A3	R3	6th
7th	S_001za	Radial	Lowest	Highest	L	1st	G3	R5	7th	A4	R5	7th	G4	R4	7th

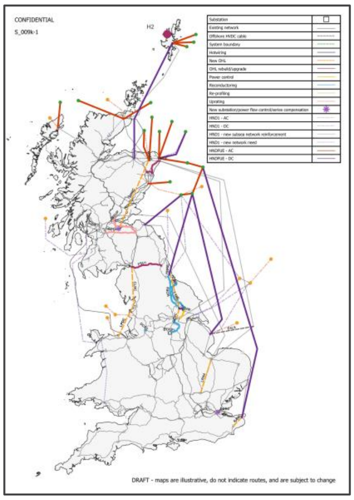
H=High, M=Medium, L=Low

Severity ratings included in the BRAG to differentiate between same BRAG ratings, 1 (lowest severity rating)-5 (highest severity rating)

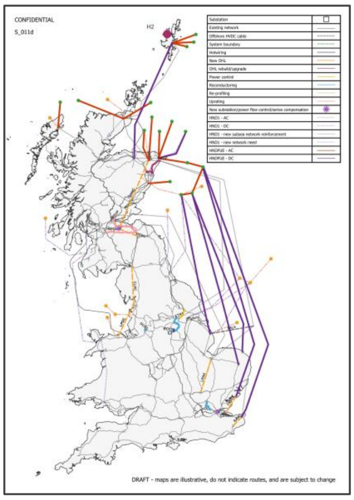
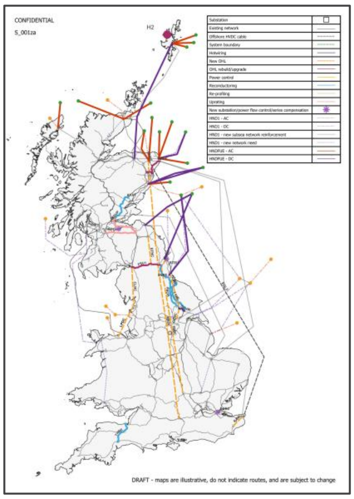
The recommendation is based on a strategic assessment of works both offshore and onshore. Each project will still need to be developed by the relevant parties to find the best solutions for each part of the overall design.

Design	Overview	Assessment commentary
S_009i-1		This design, which is ranked second overall, has four additional links south of the Anglo-Scottish border that terminate in Lincolnshire (two links), County Durham, and Kent. The design performs mid-range across all design objectives but performs better overall than all designs except S_009s, with which it shares many key features. The design performs slightly worse economically than S_009s, and worse in all three remaining objectives. For the environmental and community objectives, this poorer performance is primarily driven by the higher amount of onshore works required in the Northeast England. From a deliverability and operability perspective, the offshore design has longer HVDC cable lengths and more complex onshore works; therefore it ranks behind design S_009s.
S_008n-3		This design, which is ranked third, has three additional links south of the Anglo-Scottish border that terminate in Lincolnshire, Norfolk, and Kent. Although the design performs relatively well across all design objectives, the relatively poor performance against the environmental objective significantly impacts the overall ranking, with the design performing worse than design S_009s, which is ranked second. The design also encounters several sensitive onshore and offshore areas including challenging environmental constraints surrounding East Anglia, and in the North East of England.

<table>
<tr><th>Design</th><th>Overview</th><th>Assessment commentary</th></tr>
<tr><td>S_016g</td><td>
</td><td>This design, which is ranked fourth, has four additional links south of the Anglo-Scottish border that terminate in County Durham, Lincolnshire and Kent, with a link on the West Coast of Great Britain terminating in North Wales.

This design performs strongly within the environment and community design objective, due to the link on the west spreading both the onshore and offshore impact across a wider area, and reducing the onshore works required in the process, particularly extensive works required in Scotland in other designs. These environmental and community benefits are however outweighed by the other two design objectives. It is one of the highest cost designs due to the extensive amount of offshore work required. In addition to this, it has greater deliverability and operability challenges when compared to other shortlisted designs, again due to the challenging offshore network required.</td></tr>
<tr><td>S_009k-1</td><td>
</td><td>This design, which was ranked fifth, has three additional links south of the Anglo-Scottish border that terminate in County Durham, Lincolnshire, and Kent.

The design performs worst in the economic and efficient objective, due to substantially higher constraint costs than the other shortlisted designs. Across the other three design objectives, this design performs very similarly to the other coordinated designs with three links south of the Scottish border, but at a much higher cost and is therefore ranked lower.</td></tr>
</table>

Design	Overview	Assessment commentary
S_011d		This design, which is ranked sixth, is a highly coordinated offshore design which has the highest amount of offshore infrastructure out of all the shortlisted designs. This design has five additional links south of the Anglo-Scottish border that terminate in Lincolnshire, twice in Norfolk, Essex, and Kent. This design performs worst out of the coordinated designs from an environmental and community point of view due to the large number of links south, and the associated number of landfall sites that arise from this. This increase in landfalls also then creates an increased environmental impact as there is an increased amount of onshore infrastructure required to transport the power to major demand centres located further inland. This design also performs worst out of the coordinated designs against the deliverability and operability objectives, again due to the complexity of delivering the proposed HVDC network topology, which relies on novel technology with a less mature supply chain.
S_001za		This design, which ranked seventh, is the optimised radial design, with minimal offshore coordination. This design performed the best economically due to a low amount of offshore infrastructure required, however this then resulted in extensive onshore network required to transport the power from Scotland and North East England down to major demand centres further south. This onshore infrastructure results in this design performing worst overall in the environmental objective, as it required a substantial number of new circuits to be built along the length of the country. This would have caused significant impact to the onshore environment, including several national parks. This extensive onshore infrastructure causes the design to also perform worst in the community design objective, due to the widespread community impact of these new circuits being constructed. Lastly, the design also performed worst in the deliverability and operability objective, due to the challenge of coordinating and delivering the volume of onshore work required.

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 further onshore reinforcement needs to be considered taking into account a range of future energy scenarios.

Determining the future electricity transmission network needs for Great Britain

What was the purpose of this phase?

The purpose of this phase was to determine the recommended onshore network requirements that complement the offshore network design presented in design S_009s. In determining the recommendations, we considered how varying future energy scenarios (FES) impact the requirement for onshore reinforcement.

How did we assess options to make a recommendation?

We provided the Transmission Owners (TOs) with power transfer requirements for design S_009s across the future energy scenarios. Based on the power transfer requirements, the TOs determined a range of network reinforcements that would achieve the identified future requirements of the system. These could include upgrading existing circuits and substations in the first instance, and building new circuits and substations if further capacity is required. In some cases, several network reinforcement options could be considered to achieve similar power transfers. The options predominantly include onshore reinforcements, however, if TOs determined that offshore links additional to those recommended in design S_009s were needed, these were also considered. These options are assessed and recommended onto a base network consisting of the current electricity transmission system, including projects which are part of Ofgem's Accelerated Strategic Transmission Investment (ASTI) framework.

As previously mentioned, the onshore reinforcements can be categorised as:

- **Enabling works** that are tied to enabling the connection of generators.
- **Wider works** that enable the wider power transfer across Great Britain's transmission system; and
- **Wider and enabling works**, defined as wider works that also enable the connection of generators.

Overall, the TOs identified 55 options to be assessed in the process (47 wider works options, and 8 wider and enabling works options). These options were considered on the background of design S_009s as presented in section 4, including the representative enabling works considered in that design. These options were assessed using BRAG (Black, Red, Amber, Green) ratings for the environmental, community, deliverability and operability criteria. The TOs submit the Earliest in Service Date (EISD), cost profiles and network capability provided by each option. They are then assessed by us against the four design criteria mentioned above to determine the recommendation of which projects should receive investment.

To deliver the power transfer capabilities required across Great Britain, several reinforcement options are combined to form a recommended pathway that delivers the future electricity network needs.

Based on the assessment of options, they were recommended to either Proceed, Hold, or Stop. The definitions of these recommendations are listed below: In this document we only make recommendations on wider works. Enabling works and offshore infrastructure to enable connections are defined in the connection offer process.

- **Proceed – Critical** – the option is required on its Earliest in Service Date (EISD) in at least one scenario and provides the most benefit when delivered on its EISD. The EISD is the earliest year an option can be delivered and operational.
- **Proceed – Maintain** – Where the option provides the most benefit when delivered on its EISD in only one scenario or the option was optimal in at least two scenarios within three years of its EISD. Optimal means that an option is found to provide economic benefit and is required in at least one Future Energy Scenario.
- **Hold** – Where the option was found to be optimal, but not critical in any scenario or optimal in at least two scenarios within three years of its EISD. Hold options are still required however, economically speaking the need to invest right now is not essential but planning activities to continue their ongoing development should continue.
- **Stop** – Where the option was not found to be optimal, delivery should be stopped and not be continued.
- **Do not start** – Where the option was not found to be optimal, delivery work should not begin.

In the next section we will present findings of specific reinforcements in a common format as shown in the table below. Certain reinforcements were received at a late stage and for us to continue the cost benefit analysis process, it used some interim environment and community scores until the TO provided the appraisals. The reinforcements affected are noted in the tables.

Table 5 - provides an illustrative overview of the assessment for these options.

Code	Description	Eco	Env	Com	D&O	Recommendation
XYNC	New circuit between point X and point Y	0	R	A	G	**Stop**
YZUP	Upgrade the existing network to a higher voltage between point Y and point Z	4	R	A	G	**Proceed – Critical**

In these tables:

- 'Option' gives a four letter short-code which will be unique to each reinforcement assessed
- 'Name' provides a short description of the reinforcement used in this assessment
- 'Eco' represents the economic and efficient output for that reinforcement. The economic and efficient number for each option indicates the number of FES scenarios for which the option delivers a positive business case.
- 'Env' represents the BRAG rating for this reinforcement from the appraisal of environmental impact
- 'Com' represents the BRAG rating for this reinforcement from the appraisal of community impact
- 'D&O' represents the BRAG rating for this reinforcement from the appraisal of deliverability and operability
- 'Recommendation' gives the final recommendation of the investment following the assessment

What is the recommended design considering all FES scenarios?

Overview

The description of the recommended network requirements has been broken down into three key regions; North, Central, and South. The regional descriptions provide an overview of how power is transferred across the region and key considerations in determining the recommended design. These regions are not strict boundaries, and they were not considered in the methodology. Some options span two regions, in which case they may be described in one of the regional narratives.

For a full list of options, including the recommendations and BRAGs against each design criteria, please see Table 15 and page 40.

Figure 7 provides an overview of the three regions and the recommended network.

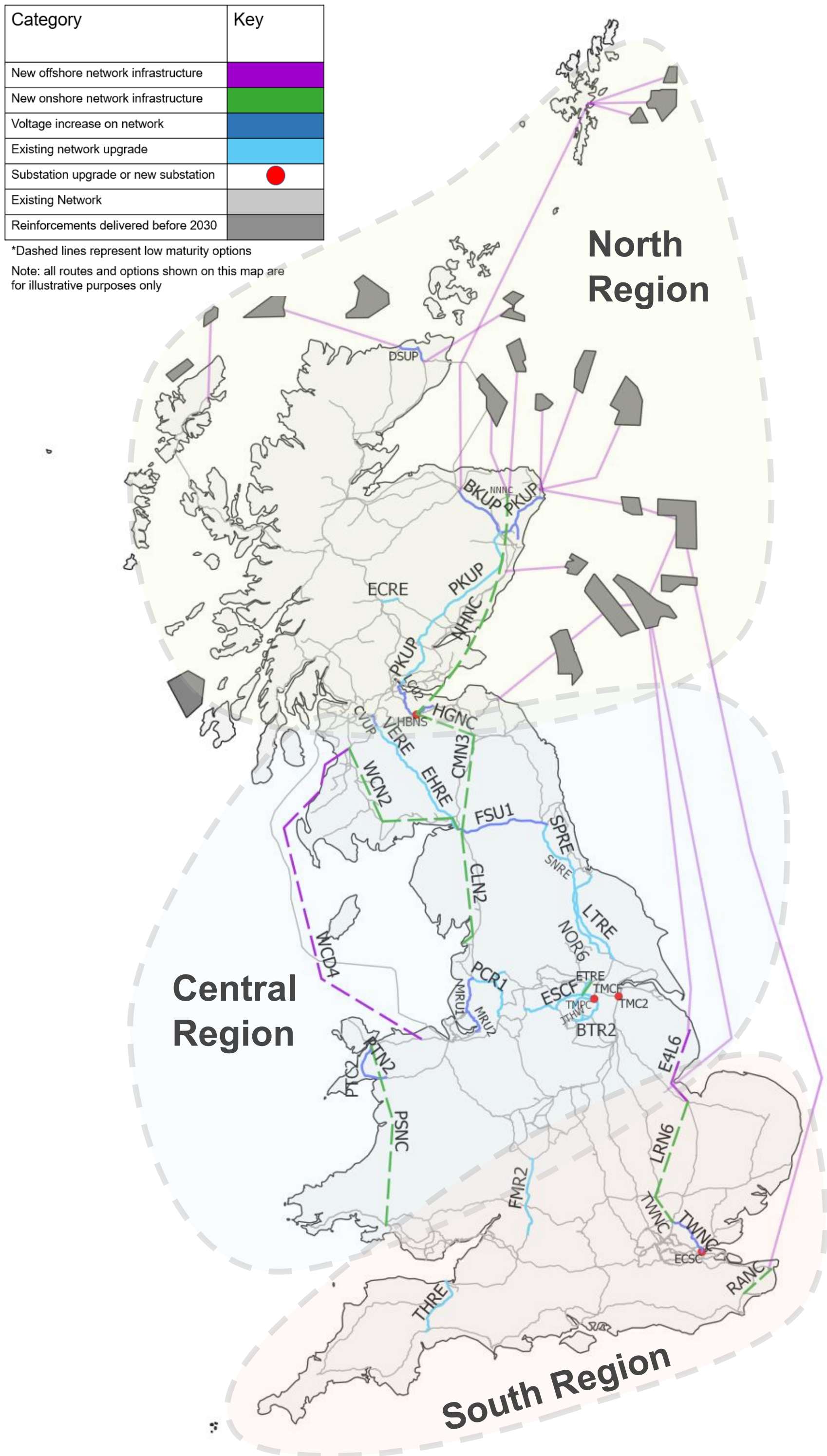


Figure 6 - Overview of the three regions and recommended network

North Region

Design S_009s recommends a significant number of wind farms connecting in the North of Scotland, therefore it's important to consider how power is transferred from the interface points to demand centres across Great Britain. This section focuses on the initial connections in the North of Scotland. Figure 8 provides an overview of the options considered and recommended network design in this region.

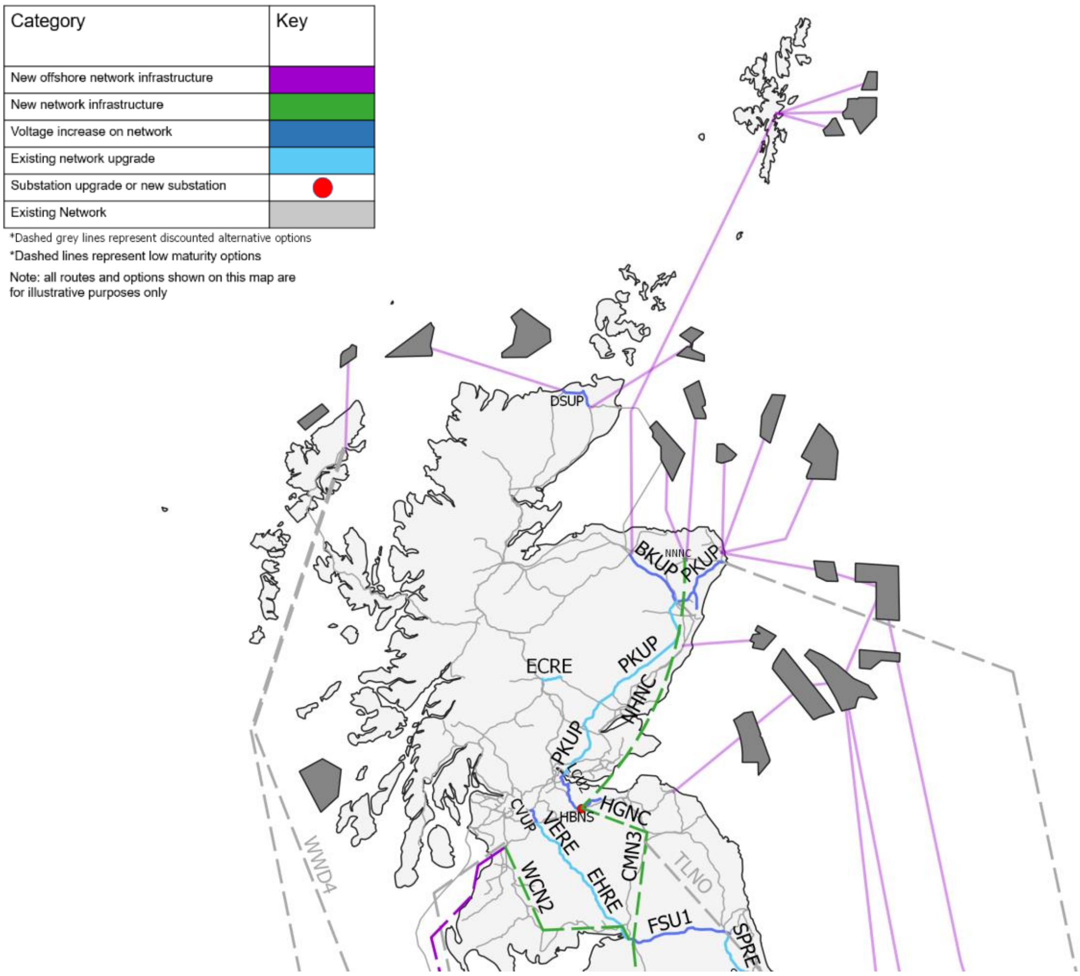


Figure 7 - overview of the options considered and recommended network design in this region.

To support the S_009s offshore design in North Scotland, the following enabling works have been considered and will be further assessed as part of the connections process that follows in the detailed network design process.

- New circuit between New Deer and Greens (New Deer 2) (known as NNNC).
- Establish further connection capacity between Dounreay, Banniskirk (Spittal), and Thurso to meet the compliance requirements of connections in the North of Scotland as well as providing capacity to allow this power to be transferred from the north to demand centres further south. (DSUP).

Referring to wider works, a circuit capacity upgrade is required near where the Scottish Highlands meets central Scotland, involving a reconductoring of a short section of 132 kV line between Errochty and Clunie, (known as ECRE). It helps manage East-West (and West-East) flows on the network from generation sources in the East and North of Scotland.

During the analysis of options and pathways, two options were identified (known as BKNC and BKUP) to transfer power from Coachford (Blackhillock 2) and Kintore. BKNC involves building a new circuit which will be in addition to the existing route, whereas BKUP involves upgrading the existing asset to a higher voltage while building a new substation. A comparison of these two options is presented in Table 6.

Table 6 - provides an overview of the assessment for these options.

Code	Description	Eco	Env	Com	D&O	Recommendation
BKNC	New circuit between Kintore and Coachford	0	R	A	G	**Do not start**
BKUP	Upgrade the existing network to a higher voltage between Kintore and Blackhillock	4	R	A	A	**Proceed – Critical**

Since BKUP involves upgrading the existing network to a higher voltage as well as building a new substation, the disruption involved with this project was comparable to building new circuit along the existing route proposed by BKNC. Both schemes were scored as a Red rating for Environmental impact and an Amber for Community impact in our assessment. The consenting needed for the new assets for BKNC result in more challenges than BKUP. Following further engagement with TOs, creating the new substation for BKUP is strategically more beneficial than BKNC for future connections in the area due to the additional network interface points it creates.

In some cases, enabling works also provide wider system benefits providing an efficient means to meet multiple network drivers. It is recommended to upgrade and/or rebuild the circuits and equipment between Longside, Peterhead, Persley, Kintore, Fetteresso, Alyth, and Kincardine (known as PKUP). Moreover, it is recommended to develop a new circuit from North East Scotland to the Central Belt (known as NHNC). The NHNC option forms part of the new north to south electrical spine. It provides the greatest transfer capability of all those assessed. Based on initial assessments, alternative offshore options considered on the West and East Coast between Scotland and England or Wales have significant environmental constraints, excessive costs and offer less network capability. These and other alternative options will continue to be assessed and developed to ensure optimal future reinforcement strategy for the Great Britain electricity transmission system. This option is also currently required to enable the development of a robust and reliable offshore network connection and will be reappraised in the detailed design stage.

As a continuation of this onshore spine facilitating the further transfer of power beyond Harburn, it is recommended to develop a new circuit from Harburn to Gala North (HGNC). This infrastructure is vital for the transfer of abundant renewable energy resources in Scotland down to the North of England. Table 7 provides the assessment of these recommended options.

Table 7 - provides an overview of the assessment for these options.

Code	Description	Eco	Env	Com	D&O	Recommendation
NHNC	New circuit from North East Scotland to the Central Belt	3	R	R	A	**Proceed - Critical**
HGNC	New circuit between Harburn and Gala North	3	R	R	G	**Proceed - Maintain**
PKUP	Upgrade and/or rebuild the circuits and equipment between Longside (Peterhead 2), Peterhead, Persley, Kintore, Fetteresso, Alyth, and Kincardine	4	G	A	A	**Proceed - Critical**

Several alternative options were assessed for Anglo-Scottish cross-border capability. However, environment and community challenges prompted us to review the initial options. The new circuit between South West Scotland and Lancashire (known as WCNC) was shortened to go no further south than a new substation in North West England; this shortened option is WCN2. An amended option, (known as CLN2) would go southwards from the new substation to Lancashire rather than the initial CLNC option starting from Harker. This combination reduces the environmental and community impacts and optimises existing options for the best capability in transporting power south on either side of the country. The assessment and alternatives explored for these reinforcements are detailed in the subsequent paragraphs and tables.

Several alternative options were assessed to increase network capability across the Anglo-Scottish border. We have previously recommended a new circuit between South West Scotland and Lancashire (WCNC). This recommendation has been superseded by a refinement to this option, WCN2. This terminates the southern section of the circuit in the North West, close to the Anglo-Scottish border, reducing the volume of new infrastructure in the North West of England. Another amended option, (known as CLN2) would go southwards from the new substation to Lancashire rather than the initial CLNC option starting from Harker. This combination reduces the environmental and community impacts and optimises existing options for the best capability in transporting power south on either side of the country. The assessment and alternatives explored for these reinforcements are detailed in the subsequent paragraphs and tables.

To continue the spine from Gala North, we considered four options to transfer power further south. The first option consisted of a new circuit from Gala North to Harker via Teviot (CMNC). The second option established a new circuit from Gala North to Fourstones via Teviot (known as CMN2). The third option considered further power transfer from Gala North to Teesside (known as TLNO), but found to provide insufficient benefit to justify its significant cost. The final option superseded CMNC and CMN2 by proposing to terminate the new circuit at the new substation in the north west of England (known as CMN3). CMN3 was developed through TO collaboration in order to manage the impact in this area, and to improve system resilience. Figure 9, below, shows that CMN3 connects into the new substation in North West England. By planning this substation to be on the western side of the country, it enables the development of WCN2 and CLN2. These new options have successfully reduced the need for two circuits further south down to one, CLN2. Furthermore, it has been recommended to reinforce routes for power across the North of England by upgrading the existing network to a higher voltage between Harker and Stella West (known as FSU1).

As shown in Table 8, the BRAG ratings were the same across CMNC, CMN2 and CMN3, however the cumulative assessment considered the environmental and community impact to be better for CMN3 as the alternatives would not avoid a second new circuit past the Lake District and Yorkshire Dales National Parks.

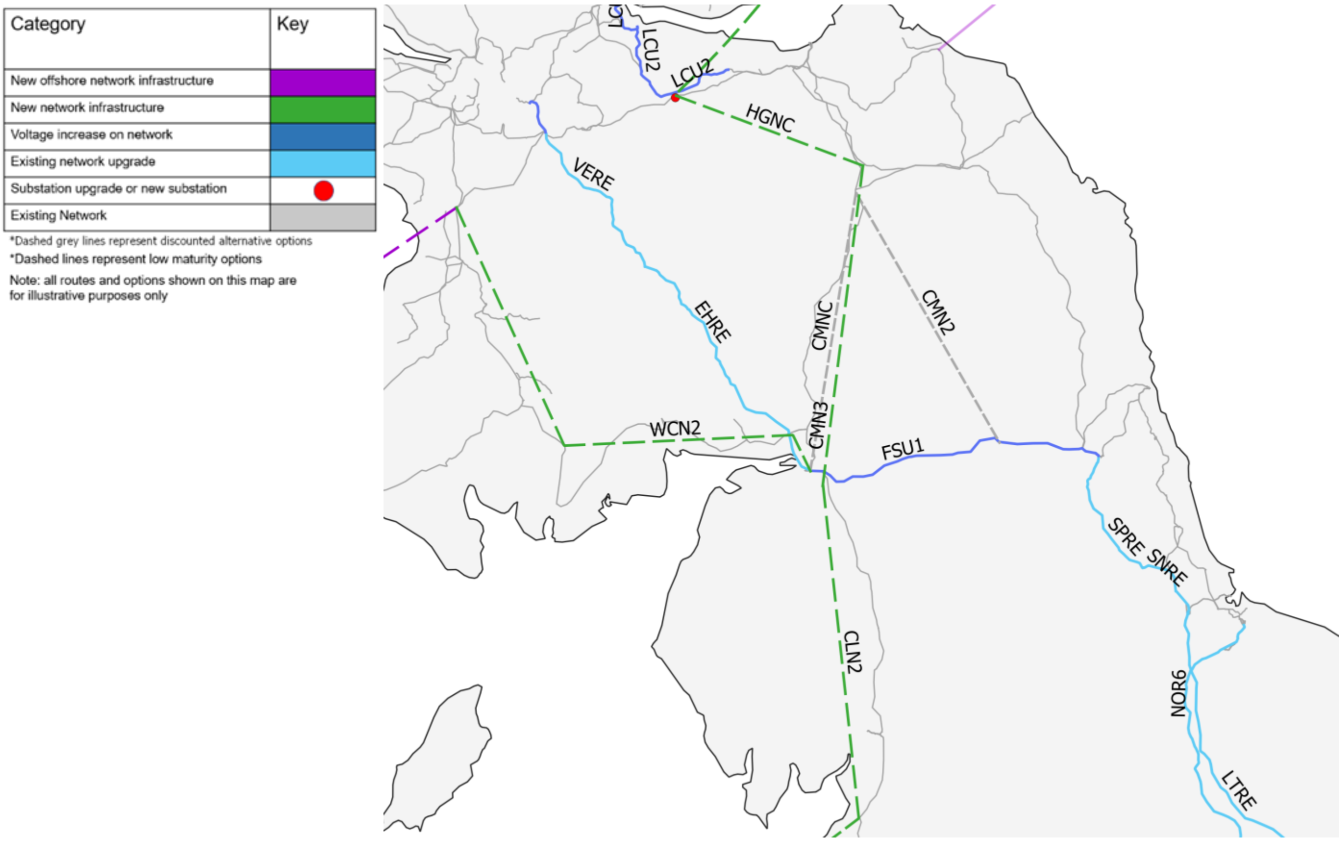


Figure 8 - comparison of CMN3 with CMNC and CMN2.

Table 8 - provides an overview of the assessment for these options.

Code	Description	Eco	Env	Com	D&O	Recommendation
CMNC	New circuit from South East Scotland to North West England	0	R	R	A	**Stop**
CMN2	New circuit between South East Scotland and North East England	0	R	R	A	**Do not start**
CMN3	New circuit between South East Scotland and North West England	4	R*	R*	A	**Proceed – Maintain**
TLNO	New circuit from eastern Scotland to North East England	0	R	R	R	**Stop**

*denotes interim ESO scores

Considering the economic value across FES scenarios and the environment, community, and operability assessments, it was recommended to Proceed with CMN3. The CMNC/2/3 variations are thought to have the same levels of consenting risk at this stage in the strategic option selection process. However, when taken as a whole with other reinforcement requirements in the cumulative appraisal stage, CMN3 is the variation that utilises the new substation in North West England. This in turn means that the onshore requirement is just one new onshore circuit through North West England to the Lancaster/Heysham area and past the Lake District and Yorkshire Dales National Parks. On this basis, CMN3 was recommended to Proceed for further development as it facilitates reinforcements WCN2 and CLN2 whereas the alternatives would have seen two reinforcements proposed past the National Parks which would have more significant community and environmental impact.

The spine recommended (which includes the projects NHNC, HGNC, CMN3 and CLN2) achieves significant transfer capacity. However, further transfer capacity is needed from Scotland to further south. To achieve this additional transfer capacity, we explored a new circuit between South West Scotland and Lancashire (known as WCNC). In addition, we also explored altering WCNC to connect into a substation in North West England (known as WCN2).

Table 9 - provides an overview of the assessment for these options.

Code	Description	Eco	Env	Com	D&O	Recommendation
WCNC	New circuit between South West Scotland and Lancashire	0	R	R	R	**Stop**
WCN2	New circuit between South West Scotland and North West England	4	R*	R*	R	**Proceed – Critical**

*denotes interim ESO scores

It was found that WCN2 is an effective alternative to WCNC, as it stops at the substation in the North West of England. Although the BRAG ratings remain similar, WCN2 does mitigate some of the environmental and consenting challenges associated with the initial option being in the vicinity of the National Parks. WCN2 also delivers value across all FES and alleviates some of the need to transfer power along the West Coast, therefore is recommended for further development.

Both CMN3 and WCN2 have been designed to meet both wider and local system requirements. Both provide transfer capability from Scotland to the North of England and also integrate onshore generation customers efficiently and economically.

In addition to developing the ‘onshore spine’, the following wider works are recommended to Proceed to further development to facilitate the power transfer across the region. To increase capacity in the Central Belt area, it is recommended to upgrade the existing network to a higher voltage between Clydesmill and Strathaven (known as CVUP). In addition, it is recommended to adjust the existing network to form a circuit from Kincardine North towards Strathaven and Smeaton using existing pylon routes (known as LCU2). To further increase capacity transfer between Scotland and the North of England, it is recommended to replace the conductors on the existing circuit between Elvanfoot and Harker with higher capacity conductors (known as EHRE). To manage the east to west flows it is recommended to replace the conductors on a short section of the existing circuit between Errochty and Clunie with higher capacity conductors (known as ECRE). To provide increased network capacity in the south of Scotland it is recommended replace the conductors on the existing circuit between Strathaven and Elvanfoot with higher capacity conductors (known as VERE).

In addition to these reinforcements there is an option which amends the West Coast offshore HVDC link between Scotland and Wales proposed in the HND. This option and its alternatives are discussed in the next section.

Central Region

To facilitate the S_009s offshore design in North Scotland and the Central Belt, the following enabling works have been considered and will be further assessed as part of the connections process that follows in the detailed network design process.

- Replace the conductors on the existing circuits between Carrington and Daines with higher capacity conductors (known as DCR4).
- Replace the conductors on the existing circuits between Hawthorn Pit and Norton with higher capacity conductors (known as HNRE).
- Carry out thermal upgrading on the existing circuit between Osbaldwick and Thornton (known as OTHW)
- Add power control devices to the existing circuit between Drax and Thornton (known as TDP4).
- Refine an existing offshore HVDC link planned between Scotland and Norfolk with a multi-terminal connection into Lincolnshire (known as E4L6).

The optioneering process in the North of England considers the requirement to transfer power from Scotland to the rest of Great Britain. In addition to onshore reinforcements, we and the TOs considered additional offshore links on the West Coast. Figure 10 provides an overview of the options considered and the recommended network design.

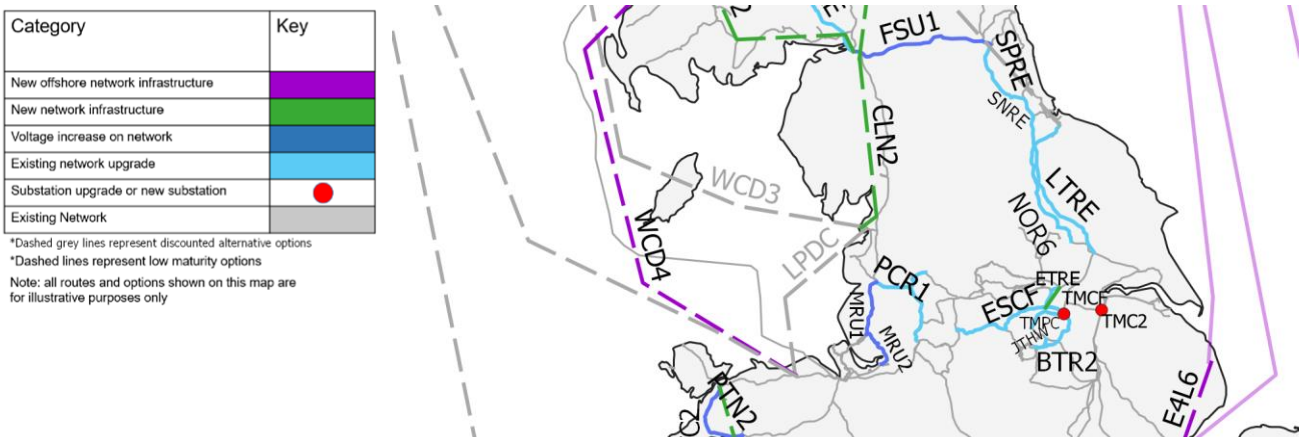


Figure 9 - overview of the options considered and recommended network design in this region.

As presented in the previous section, the offshore alternatives to WWD4 were based on variations of design S_016g, and variations of WCD4 propose amending the HND1 western multi terminal design from Ayrshire to North Wales. The variations considered would change the technology type, doubling the capacity of the existing proposal to 4 GW. Different southern end landing points were considered - to Heysham (near Lancaster) with a second HVDC link between Heysham and North Wales, or to connect directly to North Wales.

The offshore options included amendments to the first Holistic Network Design (HND) connections and could provide:

- Increase the capacity of the proposed HND1 West Coast offshore HVDC link between Scotland and Wales (known as WWD4) and other variations landing in South Wales (WWD5) and South West England (WWD6)
- Enhance the proposed HND1 West Coast offshore HVDC link between Scotland and Wales (known as WCD4)

- Enhance the proposed HND1 West Coast offshore HVDC to 4 GW from Ayrshire to North West England (known as WCD3), and a follow on new offshore HVDC link between North West England and Wales (known as LPDC).

Other variations landing in South Wales (WCD5) and Southwest England (WCD6) were considered and further optioneering is required to determine the best landing point in North Wales.

Table 10 - provides an overview of the assessment for these options.

Code	Description	Eco	Env	Com	D&O	Recommendation
WWD4	Amend the proposed West Coast offshore HVDC link to have an additional terminal in North Wales	1	R	A	R	**Do not start**
WCD4	Increase the capacity of the proposed HND1 West Coast offshore HVDC link between Scotland and North Wales	3	A	G	R	**Proceed – Maintain**
WCD3	Enhance the proposed HND1 West Coast offshore HVDC link between South West Scotland to North West England	0	R	G	R	**Do not start**
LPDC	New offshore HVDC link between North West England and Wales	0	R	A	R	**Stop**

During the assessment through working with TOs we identified significant environmental and deliverability challenges in connecting power generated in Scotland to North Wales. Significant marine environmental concerns around Lancashire were identified for WCD3 if combined with LPDC. Considering these factors, and that WCD4 demonstrated economic value across three of the FES scenarios, it was recommended to proceed for further development.

In addition to developing further onshore transfer capacity off the West Coast it was determined that additional onshore capacity would provide an optimal balance between offshore and onshore transfer capacity.

Our analysis identified the need for a new reinforcement in close proximity to the Lake District and Yorkshire Dales National Parks – Cumbria to Lancashire (known as CLNC). To solve this, other alternative options in North West England were explored which included altering CLNC to connect to a substation in the North West of England instead of Lancashire (option known as CLN2).

Table 11 - provides an overview of the assessment for these options.

Code	Description	Eco	Env	Com	D&O	Recommendation
CLNC	New circuit across North West England	0	R	R	A	**Stop**
CLN2	New circuit across North West England	4	R*	R*	A	**Proceed – Critical**

*denotes interim ESO scores

Furthermore, CLN2 delivers better economic value across the FES whilst performing similarly to CLNC across environmental, community, deliverability and operability design criteria. Therefore, CLN2 is recommended to proceed for further development. Note that CLN2 was identified as possible enabling works for connecting Holistic Network Design Follow up Exercise (HNDFUE) wind farms and it provides wider works capacity.

To enable power transfer from the North West of England to areas further south, the TOs explored upgrading the existing circuits and substations near Mersey to a higher voltage (known as MRU1 and MRU2), and reconfiguring Thorpe Marsh substation (known as TMCF). These circuit and substation upgrades provide extra capacity on the network on the west side of the country. This was seen as a possible alternative to LPDC, which as previously highlighted has significant marine environmental concerns.

Table 12 - provides an overview of the assessment for these options.

Code	Description	Eco	Env	Com	D&O	Recommendation
MRU1	Upgrade the Mersey ring of circuits and substations (Phase 1 of 2)	4	R*	R*	A	**Hold**
MRU2	Upgrade the Mersey ring of circuits and substations (Phase 2 of 2)	1	R*	R*	A	**Hold**
TMC2	Reconfigure the network between Keadby and Thorpe Marsh	1	G*	G*	A	**Hold**
TMCF	Reconfigure Thorpe Marsh substation	4	A*	A*	A	**Proceed - maintain**

*denotes interim ESO scores

Based on the assessment of MRU1 and MRU2, our recommendation is Hold. We also recommend a Hold for reconductoring of further circuits between Carrington and Penwortham (PCR1).

In addition to delivering the West Coast links (WCD4) and onshore spine (CLN2), it is recommended to upgrade the existing network to a higher voltage between Harker and Stella West (known as FSU1). This connection enables the transfer for power from the West Coast to circuits along the East Coast. Although previous optioneering did not recommend a new onshore circuit along the North East Coast (TLNO), the FSU1 upgrade combined with replacing conductors on the existing circuits between Norton to Spennymoor to Stella West (known as SPRE and SNRE), Norton to Osbaldwick (known as NOR6), and Lackenby to Thorton (known as LTRE), with higher capacity conductors delivers further capacity to transfer power south. This additional capacity also reduces the need for further offshore circuits on the West Coast (LPDC).

Table 13 - provides an overview of the assessment for these options.

Code	Description	Eco	Env	Com	D&O	Recommendation
LTRE	Upgrade the existing circuits between Lackenby and Thornton to allow for more capacity	4	A	A	A	**Proceed – critical**
NOR6	Upgrade the capacity of the circuit between Norton and Osbaldwick	4	G	A	A	**Proceed - critical**
SPRE	Replace the conductors on the existing circuit between Spennymoor to Stella West with higher capacity conductors	4	A	A	A	**Hold**

SNRE	Replace the conductors on the existing circuit between Spennymoor to Norton with higher capacity conductors	4	A	A	G	**Hold**

We are giving a Proceed (critical) recommendation to enhancing an HND1 reinforcement (known as PTNO). PTNO would create a second circuit in North Wales on an existing route. PTN2 enhances it by amending PTNO to use higher rated conductors and cables. By upgrading the capacity of cable sections on the existing Pentir to Trawsfynydd circuit on the same route (known as PTC2), works with PTN2 enable better transfer capability and facilitates power transfer from new HVDC link (WCD4) to the south. Furthermore, we continue to see the need to develop a new circuit from North Wales to South Wales (known as PSNC).

In the eastern region it is recommended to Proceed with the reconfiguration of Thorpe Marsh substation, which will unlock capacity and provide higher transfer capacity across the North of England whilst removing the need for additional infrastructure (known as TMCF). In addition, reconfiguring the network between Keadby and Thorpe Marsh (known as TMC2) received a recommendation of Hold.

In the Midlands it is recommended to Hold the options of upgrading the existing circuits between Brinsworth and Thorpe Marsh to allow for more capacity (known as BTR2), and reconductoring both Brinsworth to Chesterfield and Chesterfield to Ratcliff (known as EDN3).

These options have a Hold recommendation due to the gap between their EISD and their optimal year. The following table shows the optimal year per scenario for each option and their respective EISD. This shows that we do require these options in the future, but due to their project development times, they have been given a Hold recommendation. We have highlighted to the TOs and Ofgem that these projects should be progressed in the short term in order to mitigate unforeseen project delays.

Table 14 - Optimal delivery year per FES scenario for PCR1, TMCF, TMC2 and BTR2.

Code	EISD	FES Scenario			
		Leading the Way	Consumer Transformation	System Transformation	Falling Short
PCR1	2030	2036	2036	2036	2036
TMCF	2032	2034	2035	2034	2035
TMC2	2032	Not optimal	2037	Not optimal	Not optimal
BTR2	2027	2034	2035	2035	2035

In addition to the options recommended above, to enable wider power transfer across the region, the following options are recommended to Proceed:

- Reconfigure the network between Stalybridge and Thorpe Marsh (known as ESCF)
- Add power flow control devices to the existing circuit between Thorpe Marsh and West Melton (known as TMPC)
- Upgrade the existing circuits between Eggborough and Thorpe Marsh to allow for more capacity (known as ETRE)
- Carry out thermal upgrading on the existing circuit between Thurcroft and West Melton (known as JTHW).

South Region

Capability in the South is required to allow power to flow into large demand centres, such as London.

Figure 10: overview of the options considered and recommended network design in this region.

Works are required below the Anglo-Scottish border that complement the connection of the S_009s offshore design. A new circuit within South East England is recommended to increase network capacity in the South East and around existing interconnector terminals (known as RANC). RANC enables a link from a wind farm in Scotland into Kent. It increases local network capacity to an area which is currently congested, whilst increasing network resilience and alleviating issues associated with faults. This reinforcement was identified as representative enabling works; however this will need to be further considered in detailed design.

There are two new circuits in the south which are required. a new circuit between the South Lincolnshire, Cambridgeshire and North West Norfolk boundary to Hertfordshire (LRN6). This recommendation supersedes the previous recommendation (LRN4) and a new circuit between Wymondley and Waltham Cross and increase operating voltage of the network within the area (known as TWNC).

LRN6, is a variation of the previously recommended LRN4, and provides new transmission capacity between the South Lincolnshire, Cambridgeshire and North West Norfolk boundary to Hertfordshire. This revised recommendation shortens the length of the circuit through Lincolnshire reducing the impact on communities within the county.

The need for the new network capacity provided by this option has been reconfirmed through our analysis and we still see a strong need for this new circuit. It prevents overloading of the existing network in the region and enables offshore wind connections in the region. LRN6 was compared to four alternative variations; this option reduces the amount of network build and the impact on communities. Alternative options included a range of onshore options and an offshore option however these options were found to have greater impacts on the environment and were more costly to consumers.

TWNC has been previously recommended and helps manage east to west (and west to east) flows on the network from wind and nuclear generation sources in the east and north. The second element of this scheme upgrades the voltage of existing infrastructure between the North of London and Essex which provides a number of benefits similar to creating a new circuit route, with less of the environmental and community impacts.

Further wider works in the South of England are comprised of fewer network upgrades, required to increase network capabilities. These include:

- Replace the conductors on the existing circuit between Feckenham and Minety with higher capacity conductors (known as FMR2) to relieve overloaded circuits in the West of England;
- Replace the existing conductors between Grendon to Sundon with higher capacity conductors (this work is now known as SGRE having previously been recommended under another name) to provide increased network capability in Central England; and
- Replace the conductors on the existing circuits between Hinkley Point, Taunton and Exeter with higher capacity conductors (known THRE) to provide increased network capability in the South West of England.

Moreover, it is recommended to Proceed with installing power flow control equipment within East Anglia (known as ECSC) to better manage the balancing of power within the wider region. This small This small investment helps to support the system in case of faults within the region which increases the ability to export power without developing new circuits. Further analysis will be conducted by the Transmission Owner to reflect the outcomes of the East Anglia Networks Study

Conclusions and next steps

This document is the technical annex to the Beyond 2030 report produced to deliver on the Climate Change Committee's Sixth Carbon Budget and Crown Estate Scotland's leasing round and mapping the way to a clean, secure and affordable energy future. Each phase has summarised how we have:

- Outlined our overall design objectives and assessment approach.
- Explained how we have identified and assessed initial offshore network designs and determined the recommended network design for connecting offshore wind farms.
- Explained how we have determined the future electricity transmission needs for Great Britain.

Designing a holistic electricity network does not just mean building more network infrastructure. We are working to find innovative solutions that ensure the system is designed securely and affordably, negating the need for more network infrastructure, in some circumstances, through utilising existing route corridors and, where possible, existing infrastructure.

Looking out to the late 2030s, there will be more solutions that could cater for Great Britain's rising energy needs. These vary from potentially faster network delivery enabled by competition, the creation of a spatial energy plan directing the optimal locations of generation and demand assets as well as potential reforms to the wholesale electricity market. Our recommended network should be implemented to enable our ambitious decarbonisation targets while providing maximum value to consumers.

Options assessment table

Options that formed part of the Phase 2 that delivered a Holistic Network Design (HND1) for a coordinated onshore and offshore network, published in July 2022, are not included in the tables below. The recommended options for the onshore design for a 2030 electricity network that facilitates the Government's ambition for 50 GW of offshore wind by 2030 can be found in our *NOA Refresh* Report.[7]

The options included in *Table 15* below are the representative connection works for the final design S_009s.

Table 15 – Onshore works for the final HNDFUE design

Code	Description
DCR4	Replace the conductors on the existing circuits between Carrington and Daines with higher capacity conductors
DSUP	Establish further connection capacity between Dounreay, Banniskirk (Spittal), and Thurso
E4L6	Refine one of the proposed offshore HVDC link planned between Scotland and Eastern England with a third connection into Lincolnshire
HNRE	Replace the conductors on the existing circuits between Hawthorn Pit and Norton with higher capacity conductors
NNNC	New circuit between New Deer and Greens (New Deer 2)
OTHW	Carry out thermal upgrading on the existing circuit between Osbaldwick and Thornton
RANC	New circuit within South East England
TDP4	Add power control devices to the existing circuit between Drax and Thornton

The options included in Table 16 below are the representative wider works beyond 2030 including the optimal delivery date of the option across each of the FES scenarios: Leading the Way (LW), Consumer Transformation (CT), System Transformation (ST) and Falling Short (FS).

[7] NOA Refresh Report

Table 16 - Recommendations for onshore wider works options beyond 2030

Code	Description	EISD	LW	CT	ST	FS	Eco	Env	Com	D&O	Recommendation
BKNC	New circuit between Kintore and Coachford	2035	N/A	N/A	N/A	N/A	0	R	A	G	**Do not start**
BKUP	Upgrade the existing network to a higher voltage between Kintore and Blackhillock	2034	2034	2034	2037	2037	4	R	A	A	**Proceed - Critical**
BTR2	Upgrade the existing circuits between Brinsworth and Thorpe Marsh to allow for more capacity	2027	2034	2035	2035	2035	4	A	A	G	**Hold**
CLN2	New circuit across North West England	2036	2036	2036	2036	2036	4	R*	R*	A	**Proceed - Critical**
CLNC	New circuit across North West England	2036	N/A	N/A	N/A	N/A	0	R	R	A	**Stop**
CLNS	New substation at Cousland	2031	N/A	N/A	N/A	N/A	0	A	A	G	**Do not start**
CMN2	New circuit between South East Scotland and North West England	2033	N/A	N/A	N/A	N/A	0	R	R	A	**Do not start**
CMN3	New circuit between South East Scotland and North West England	2033	2035	2035	2036	2035	4	R*	R*	A	**Proceed - Maintain**
CMNC	New circuit between South East Scotland and North West England	2033	N/A	N/A	N/A	N/A	0	R	R	A	**Stop**
CVUP	Upgrade the existing network to a higher voltage between Clydes Mill and Strathaven	2031	2033	N/A	2039	N/A	2	G	A	G	**Hold**
ECRE	Replace the conductors on a short section of the existing circuit between Errochty and Clunie with higher capacity conductors	2029	2034	2032	2033	2033	4	A	G	G	**Proceed - Maintain**
ECSC	Install power flow control devices within East Anglia	2027	2034	2034	2034	2034	4	G	G	A	**Proceed - Maintain**

ESO

Code	Description	EISD	LW	CT	ST	FS	Eco	Env	Com	D&O	Recommendation
EDN3	Replace the conductors on the existing circuits between Brinsworth and Thorpe Marsh, Brinsworth and Chesterfield, and Chesterfield and Ratcliffe with higher capacity conductors	2032	N/A	2037	N/A	N/A	1	A*	A*	A	**Hold**
EHRE	Replace the conductors on the existing circuit between Elvanfoot and Harker with higher capacity conductors	2030	2034	2031	2031	2031	4	G	A	G	**Proceed - Critical**
ESC2	Additional network upgrades within South Yorkshire	2033	N/A	N/A	N/A	N/A	0	R*	R*	A	**Do not start**
ESCF	Reconfigure the network between Stalybridge and Thorpe Marsh	2033	2033	2034	2033	2033	4	R	A	A	**Proceed - Critical**
ETRE	Upgrade the existing circuits between Eggborough and Thorpe Marsh to allow for more capacity	2029	2031	2031	2031	2031	4	A	A	A	**Proceed - Critical**
FMR2	Replace the conductors on the existing circuit between Feckenham and Minety with higher capacity conductors	2029	2031	2031	2031	2033	4	A	A	A	**Proceed - Critical**
FSU1	Upgrade the existing network to a higher voltage between Harker and Stella West	2035	2035	2035	2035	2035	4	R	R	A	**Proceed - Critical**
FWRE	Replace the conductors on the existing circuit between Feckenham and Walham with higher capacity conductors	2030	N/A	N/A	N/A	N/A	0	A	A	G	**Stop**
HGNC	New circuit between Harburn and Gala North	2036	2038	N/A	2038	2041	3	R	R	G	**Proceed - Maintain**
HONC	New circuit between County Durham and North Yorkshire	2025	N/A	N/A	N/A	N/A	0	R	R	A	**Do not start**

ESO

Code	Description	EISD	LW	CT	ST	FS	Eco	Env	Com	D&O	Recommendation
JTHW	Carry out thermal upgrading on the existing circuit between Thurcroft and West Melton	2027	2034	2035	2034	2034	4	G	G	G	**Proceed - Maintain**
LCU2	Adjust the existing network to form a circuit from Kincardine North towards Strathaven and Smeaton using existing pylon routes	2033	2037	N/A	2037	2037	3	R	R	A	**Hold**
LPDC	New offshore HVDC link between North West England and North Wales	2037	N/A	N/A	N/A	N/A	0	R	A	R	**Stop**
LRN6	New transmission capacity between the South Lincolnshire, Cambridgeshire and North West Norfolk boundary to Hertfordshire	2034	2034	2034	2034	2034	4	R	R	A	**Proceed - Critical**
LTRE	Upgrade the existing circuits between Lackenby and Thornton to allow for more capacity	2030	2033	2031	2034	2034	4	A	A	A	**Proceed - Critical**
MRU1	Upgrade the existing Mersey ring of circuits and substations to allow for more capacity (Phase 1 of 2)	2031	2036	2036	2036	2037	4	R*	R*	A	**Hold**
MRU2	Upgrade the existing Mersey ring of circuits and substations to allow for more capacity (Phase 2 of 2)	2033	N/A	2037	N/A	N/A	1	R*	R*	A	**Hold**
NHNC	New circuit from North East Scotland to the Central Belt	2038	2038	2038	2038	N/A	3	R	R	A	**Proceed - Critical**
NOR6	Replace the conductors on the existing circuit between Norton and Osbaldwick with higher capacity conductors	2029	2033	2031	2034	2035	4	G	A	A	**Proceed - Critical**
OENC	New circuit within North Yorkshire	2035	N/A	N/A	N/A	N/A	0	R	A	A	**Do not start**

ESO

Code	Description	EISD	LW	CT	ST	FS	Eco	Env	Com	D&O	Recommendation
OPN1	Upgrade the voltage of the network following Yorkshire Green	2033	N/A	N/A	N/A	N/A	0	R*	R*	A	**Do not start**
PCR1	Replace the conductors on the existing circuits between Carrington and Penwortham and Penwortham and Padiham with higher capacity conductors	2030	2036	2036	2036	2036	4	A	A	A	**Hold**
PKUP	Upgrade and/or rebuild the circuits and equipment between Longside (Peterhead 2), Peterhead, Persley, Kintore, Fetteresso, Alyth, and Kincardine	2033	2033	2033	2033	2033	4	G	A	A	**Proceed - Critical**
PSNC	New circuit between North Wales and South Wales	2037	2037	2037	2037	2037	4	R	R	R	**Proceed - Critical**
PTC2	Replace the conductors on the existing circuit between Pentir and Trawsfynydd with a higher capacity then was previously recommended	2028	2031	2031	2031	2031	4	R	A	G	**Proceed - Critical**
PTN2	New circuit in North Wales with a higher capacity then was previously recommended"	2028	2037	2037	2037	2037	4	R	R	A	**Proceed - Critical**
SGRE	Replace the conductors on the existing circuit between Grendon and Sundon with higher capacity conductors	2029	2031	N/A	2031	N/A	2	A	A	A	**Proceed - Critical**
SNRE	Replace the conductors on the existing circuit between Spennymoor to Norton with higher capacity conductors	2029	2035	2036	2036	2037	4	A	A	G	**Hold**
SPRE	Replace the conductors on the existing circuit between Spennymoor to Stella West with higher capacity conductors	2029	2035	2036	2036	2037	4	A	A	A	**Hold**

Code	Description	EISD	LW	CT	ST	FS	Eco	Env	Com	D&O	Recommendation
SXHW	Carry out thermal upgrading on the existing circuit between Smeaton and Branxton	2028	N/A	N/A	N/A	N/A	0	G	G	G	**Do not start**
THRE	Replace the conductors on the existing circuits between Hinkley Point, Taunton and Exeter with higher capacity conductors	2029	2031	2031	2031	2033	4	A	A	G	**Proceed - Critical**
TLNO	New circuit from Eastern Scotland to North East England	2040	N/A	N/A	N/A	N/A	0	R	R	R	**Stop**
TMC2	Reconfigure the network between Keadby and Thorpe Marsh	2032	N/A	2037	N/A	N/A	1	G*	G*	A	**Hold**
TMCF	Reconfigure Thorpe Marsh substation	2032	2034	2035	2034	2034	4	A*	A*	A	**Proceed - Maintain**
TMPC	Add power flow control devices to the existing circuit between Thorpe Marsh and West Melton	2030	2031	2031	2031	2031	4	G	G	A	**Proceed - Critical**
TWNC	New circuit between Wymondley and Waltham Cross and increase operating voltage of the network within the area	2033	2034	2034	2034	2035	4	R	R	A	**Proceed - Maintain**
VERE	Replace the conductors on the existing circuit between Strathaven and Elvanfoot with higher capacity conductors	2030	2035	2031	2031	2031	4	A	A	G	**Proceed - Critical**
WCD3[7]	Enhancement of HND1 Western Offshore HVDC to 4 GW from Ayrshire to North West England	2036	N/A	N/A	N/A	N/A	0	R	G	R	**Do not start**
WCD4[8]	Enhancement of HND1 Western Offshore HVDC to 4GW from Ayrshire to North West England	2036	2037	2037	N/A	2037	3	A	G	R	**Proceed - Maintain**

[8] Other landing points were explored at a high level (WCD5/6) and other options will be considered in the detailed network design.
[8] Other landing points were explored at a high level (WWD5/6) and other options will be considered in the detailed network design.

Code	Description	EISD	LW	CT	ST	FS	Eco	Env	Com	D&O	Recommendation
WCDC[8]	Enhance the proposed HND1 West Coast offshore HVDC link between Scotland and Wales	2036	N/A	N/A	N/A	N/A	0	R	G	R	**Do not start**
WCN2	New circuit between South West Scotland and North West England	2036	2036	2036	2036	2036	4	R*	R*	R	**Proceed - Critical**
WCNC	New circuit from Ayrshire to Northwest England	2036	N/A	N/A	N/A	N/A	0	R	R	R	**Stop**
WWD4[9]	Increase the capacity of the proposed HND1 West coast offshore HVDC link between North West Scotland and Wales	2031	N/A	N/A	2037	N/A	1	R	A	R	**Do not start**

*denotes interim ESO score

[9] Other landing points were explored at a high level (WWD5/6) and other options will be considered in the detailed network design.