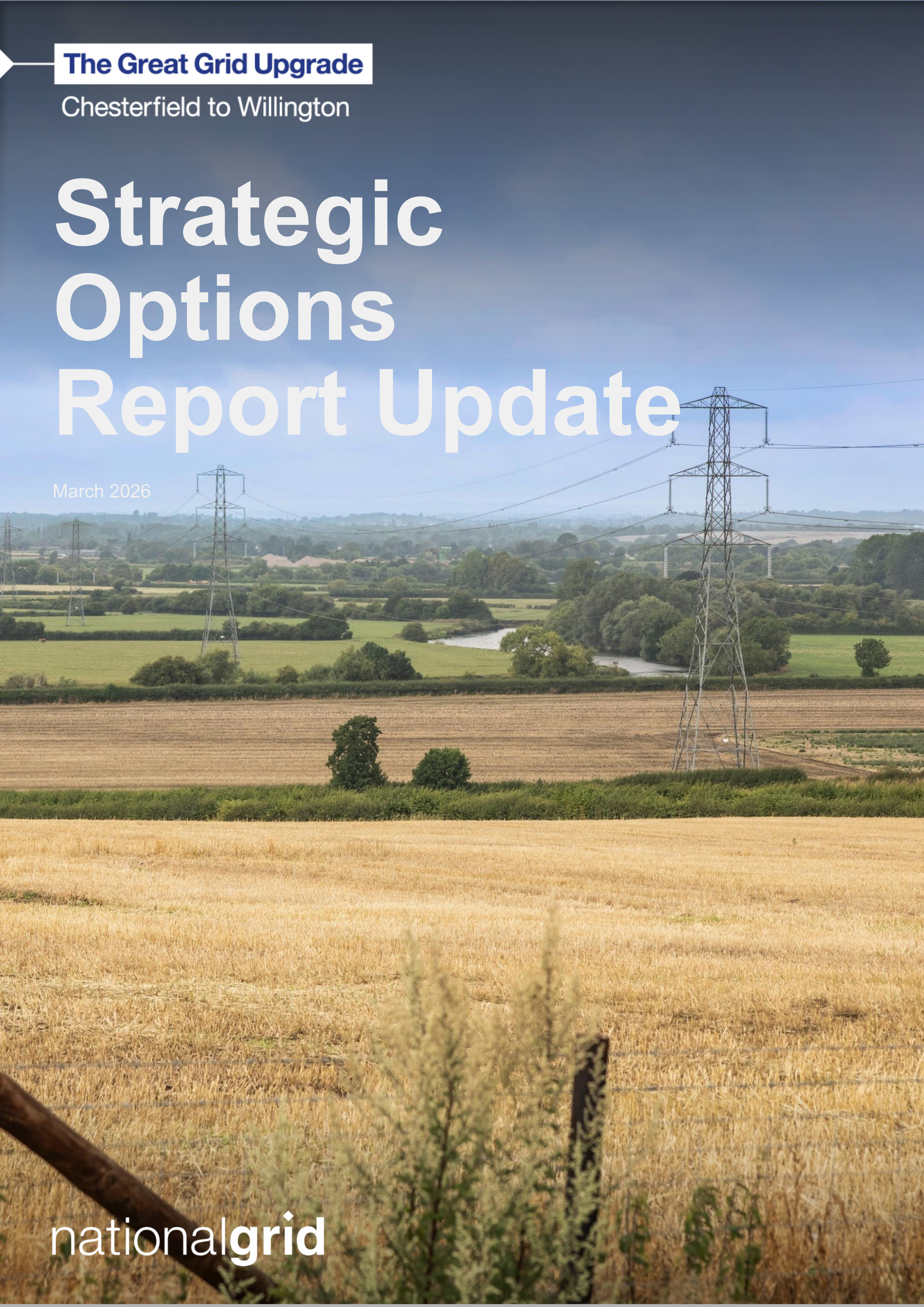
The Great Grid Upgrade

Chesterfield to Willington

Strategic Options Report Update

March 2026



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Contents

Chesterfield to Willington Document control

Version History

Document	Version	Status	Description / Changes
March 2024	0.4	Final Issue	Final Issue
March 2026	0.5	Final Issue	SOR Update publication for statutory consultation

Updates to the Initial Strategic Options Report (SOR)

The SOR is the output of the Strategic Proposal stage. Although this will be the initial report prepared as part of the Approach to Consenting process, the strategic options assessment is conducted at a specific point in time, while project development progresses over several months and years. Project development is an ongoing process that is influenced by changing internal and external factors, such as customer connections, network planning processes and plans (such as Centralised Strategic Network Plan (CSNP) and Holistic Network Design (HND)/ Network Options Assessment (NOA)) and legislative / policy changes.

As a result of factors such as these, it will be necessary during project development to revisit the Strategic Proposal, leading to an updated SOR. As the project progresses, further studies are naturally undertaken, including preliminary routeing and siting of the preferred option.

It is important to note that the SOR will not document these studies as part of this update. The SOR will remain a high-level document that outlines the decision-making process used to identify the preferred option.

Therefore, the data included in the SOR should not be directly compared with, or measured exactly against, the data contained within the routeing and siting documentation.

This SOR Update has considered the revised need case, and the strategic options for meeting this. Changes to the report include identified legislative and policy changes, an update of the need case along with any additional strategic environmental, socio-economic, technical information and updated costs to account for additional scope.

The remainder of this report remains largely unchanged from the March 2024 SOR. National Grid Electricity Transmission's (NGET's) cost base remains 2020/21 for evaluation purposes, the overarching proposed technology for each option remains previous and changes to environmental and socio-economic inputs are minor following review.

The conclusion following the update is that strategic option EDN-2 (Chesterfield to Willington) remains the preferred strategic option for the project. This continues to be the most advantageous of the options when balancing environmental and socio-economic effects, cost, technical performance and constructability.

Update Summary

This table provides a summary of the changes included in this SOR update.

Section	Alterations	Rationale
2.1.5, 3.6.7	Government Policy	Since the previous iteration of the SOR, the government published the ‘Clean Power 2030 Action Plan: A new era of clean electricity’, outlining its strategy to deliver a clean electricity system by 2030.
2.1.2	NIC to NISTA	The National Infrastructure Commission (NIC) has now been replaced by National Infrastructure and Service Transformation Authority (NISTA)
2.2.5, 2.2.6, 2.3.2, 2.4.2, 2.4.5, 2.5.2, 2.5.3, 2.6, 3.4.3, 3,5.3, 3.6.7, 3.6.8, 4.2.9	ESO to NESO	The Electricity System Operator (ESO) became a public corporation in Oct 2024 and is now known as the National Electricity System Operator (NESO). Details of this have been incorporated into the updated SOR.
4.2	Updated project history	Additional detail added regarding the evolution of the project including nomenclature.
4.2.9, 4,2,14, 6.3.2, 11.3.4, 11.5.4, 12.1.6	Changes to EDEU	Information added to capture changes to interacting project EDEU.
1.1.6, 2.6.8, 2.6.9, Appendix H	‘Beyond 2030’ publication	Key points of the ESO ‘Beyond 2030’ publication have been added. The publication presents the findings from the Holistic Network Design Follow-Up Exercise (HND FUE). The document outlines the strategic direction for the UK's electricity transmission network as it transitions towards a decarbonised future.
3, 4.2.3, 4.2.15, 6.3.2, 12.1.6	Need Case Update	Since the previous iteration of the SOR, the need case has been re-visited to bring up to date as of December 2025.
4.2, 6.2	EDN-9 and EDN-10 description update	Update of EDN-9 and EDN-10 option description to reflect scope
5.1.7	Correction of study area definition	Text regarding the study area definition has been updated to correct a previous typo (2 km instead of 20 km). Additional detail has also been added to account for certain instances where the study area is extended to 10 km.
7.2.15, 7.3.5, 7.3.6 8.2.11, 8.3.10 9.2.12, 9.3.7, 9.3.8, 9.3.9 10.2.12, 10.3.8 Table 11.1, 11.2.10 12.1.5	Revision of the environmental and socio-economic appraisals	Reviewed information for environmental and socio-economic appraisals for all strategic options. This further analysis has highlighted additional detail since the previous iteration of the SOR. This includes adding updated information regarding Ratcliffe-on-Soar Power Station and the Local Development Order (LDO) and correcting the names of some railways discussed.

Section	Alterations	Rationale
7.4.2, 7.4,3 8.4.2 9.1.1, 9.4.2, 9.4.4, 9.4.6 10.1.1, 10.4.2, 10.4.5 11.3.2, 11.3.3, 11.3.6, 11.3.7, 11.5.3, 11.5.4, 11.5.5, 11.5.6	Additional detail added to technical appraisals	Reviewed information for technical appraisals for all strategic options. This further analysis has highlighted additional detail since the previous iteration of the SOR.
7.4.7, 9.4.6, 9.4.7, 9.4.8, Table 9.1, 10.4.5, 10.4.6, Table 10.1 11.4.2, Table 11.2, 11.4.5, 11.4.6, 11.5.2, 11.5.4.	Additional cost information added	Updated to incorporate revised Ratcliffe and High Marnham cost information aligned with the updated scope.
Table 11.1, 11.2.10, 11.3.2, 11.3.3, 11.3.6, 11.3.7, 11.4.2, Table 11.2, 11.4.5, 11.4.6, 11.5.2, 11.5.3, 11.5.4, 11.5.5, 11.5.6, 12.1.5, 12.2.1, 12.2.2	SOR Conclusions and Next Steps	Conclusions and next steps updated to reflect revised need case plus updated socio-economic, environmental, technical and cost information following SOR revisions.
Figure 3.1, Figure 3.2, Figure 6.1, Figure 7.1, Figure 8.1, Figure 9.1, Figure 10.1, Figure 11.1 and corresponding figures in executive summary	Figure updates	Re-designed for current National Grid publication standards. Note, no change to route options.

Executive summary

Purpose of This Report

This Strategic Options Report (SOR) is a technical report providing an overview description of the options that National Grid Electricity Transmission plc (National Grid) has identified and subsequently evaluated for reinforcement of the network in the East Midlands region.

The stages of National Grid's process-based approach when transmission system works are identified that would require additional consents and/or permissions are shown in **Image A.**

Image A: National Grid project lifecycle

This report forms part of the initial 'Options identification and selection' stage. The original version of this report (March 2024) supported the non-statutory (Stage 1) consultation. It has now been updated for statutory (Stage 2) consultation, forming part of the 'Defined Proposal and Statutory Consultation' stage of the process shown in **Image A**.

As the project progresses, further studies are naturally undertaken, including preliminary routeing and siting of the preferred option. It is important to note that the SOR will not document these studies as part of this update. The SOR will remain a high-level document that outlines the decision-making process used to identify the preferred option.

This executive summary provides an overview of the contents of this report and highlights key areas relevant to this project and the consultation on it, including:

- reasons why the transmission system in the East Midlands region needs to change;
- a summary description of options for providing additional transmission system capability that we identified as strategic options;
- how National Grid identified and evaluated strategic options; and
- the options that we intend to take forward to the next stage in the process.

National Grid Electricity Transmission

National Grid is the owner of the high voltage transmission system in England and Wales and holds an electricity transmission licence permitting transmission ownership activities. Our transmission licence requires that we develop and maintain an efficient, economic, and co-ordinated transmission system in England and Wales.

National Grid, as the regulated provider of electricity transmission services in England and Wales, is regulated by the Office of Gas and Electricity Markets ('Ofgem').

As of 1 October 2024, the National Energy System Operator (NESO) became a public body owned by the Department for Energy Security and Net Zero. It was formerly part of National Grid plc and called the Electricity System Operator (ESO).

NESO facilitates several roles on behalf of the electricity industry, including making formal offers to applicants requesting connection to the National Electricity Transmission System (NETS).

National Grid is obligated to provide the physical connections to the elements of the NETS that National Grid own.

In accordance with transmission licence requirements, we ensure that the transmission system in England and Wales meets the requirements in respect of transmission system security and quality of service at all times. As part of this requirement, we must ensure that sufficient transmission system capability is provided to meet demand and generator customer requirements and wider transmission system needs that exist and/or are expected.

When planning changes to our transmission system, we must be efficient, co-ordinated and economical and have regard to the desirability of preserving amenity, in line with the duties under sections 9 and 38 of the Electricity Act 1989.

National Energy System Operator's Role in the Development of the Transmission System

NESO is the electricity system operator for Great Britain. NESO ensures electricity is always where it is needed, and the transmission network remains stable and secure in its operation.

NESO has been established to act as the independent organisation responsible for planning Britain's energy system, operating the electricity network and offering expert advice to the sector's decision-makers.

Generators apply to NESO when they wish to connect to the network and NESO leads, working with the Transmission Owners (TOs), to consider how the network may need to evolve to deliver a cleaner, greener future. NESO is currently reforming its connection processes to meet the increasing number of projects wanting to connect to the transmission system.

NESO, in undertaking this role, engages with NGET for England and Wales as well as the two TOs in Scotland: Scottish and Southern Energy Networks (SSEN) and Scottish Power (SP) Energy Networks.

NESO and its predecessor ESO have been or – in the case of NESO – are responsible for multiple roles across the electricity system, including:

- Electricity Market Balancing: NESO ensures that electricity demand and supply is balanced on a second-by-second basis and manages any shortfalls in boundary capacity.
- Future Energy Scenarios (FES): NESO publishes annual scenarios to 2050, consulting industry and considering the Transmission Entry Capacity (TEC) Register, which tracks available capacity for new connections.
- ETYS & NOA: NESO publishes the Electricity Ten Year Statement (ETYS) annually, outlining network performance and needs for the next 10 years based on data from the FES. ESO used ETYS to produce the 2022 Network Options Assessment (NOA), which applied cost-benefit analysis to recommend economically viable transmission reinforcements.

- Network Planning Review: The Pathway to 2030 Holistic Network Design (HND) and NOA marked the shift toward more centralised, strategic planning for affordable, clean, secure power. NESO is transitioning from NOA to a Centralised Strategic Network Plan (CSNP) for holistic NETS development.
- Connections: NESO manages formal offers for transmission system connections; NGET provides physical connections.

The planning activities undertaken by NESO are currently being updated to support the delivery of the government's net-zero commitment. In 2022, ESO published the HND setting out an integrated approach to transmission network design that supports the connection of 23 gigawatts (GW) of offshore wind to Great Britain by 2030.

In 2024, ESO published the findings from the HND Follow-Up Exercise (HND FUE) in a report entitled 'Beyond 2030'[1] which is a pivotal document outlining the strategic direction for the UK's electricity transmission network as it transitions towards a decarbonised future. This report provides an overview of the network design that will act as the pathway to a clean, secure, and affordable energy network, aligning with the Climate Change Committee's Sixth Carbon Budget and Scotland's ScotWind leasing round to 2035. It is closely linked to the Transitional Centralised Strategic Network Plan 2 (tCSNP2)[2], which serves as a framework for the necessary investments and infrastructure developments required to meet the ambitious targets set for 2030 and beyond.

The tCSNP2 provides a comprehensive roadmap for the evolution of the UK's transmission network, ensuring that the infrastructure is not only capable of meeting current demands but also adaptable for future energy needs

The Need Case

NGET must comply with section 9 of the Electricity Act 1989 and Standard Condition D3 (Transmission system security standard and quality of service) of its Transmission Licence. This means that where the boundary capacity of the Main Interconnected Transmission System (MITS) is exceeded against the standards, NGET must resolve the capacity shortfall under the terms of its Transmission Licence. The standards against which NGET assesses these shortfalls are set out in the 'Design of the Main Interconnected Transmission System' section of the National Electricity Transmission System Security and Quality of Supply Standard (NETS SQSS).

NGET assesses the adequacy of its transmission system in accordance with the method defined in the NETS SQSS. We are required to assess power flows between regions of the transmission system (Planned Transfers). The Planned Transfer from the region is calculated by taking the Average Cold Spell (ACS) Peak Demand in the region and the generation operating in the region then modelling the flow expected as set out in the NETS SQSS. The Planned Transfer is therefore the amount of power which will flow in or out of the region at ACS peak. Planned Transfer calculations will always consider the power flows for ACS peak demand conditions, as less generation will be entering the market when demand is lower.

[1] Beyond 2030, National Grid ESO

www.neso.energy/document/304756/download

[2] NESO tCSNP2 Information Page

https://www.neso.energy/publications/transitional-centralised-strategic-network-plan-tcsnp

Any transmission system is susceptible to faults that interfere with the ability of transmission circuits to carry power. Most faults are temporary, many are related to weather conditions such as lightning or severe weather, and many circuits can be restored to operation automatically in minutes after a fault. Other faults may be of longer duration and would require repair or replacement of failed electrical equipment.

Whilst some of these faults may be more likely than others, faults may occur at any time, and it would not be acceptable to have a significant interruption to supplies as a result of specified fault conditions, including combinations of faults. The principle underlying the NETS SQSS is that the NETS should have sufficient spare capability or 'redundancy' such that defined fault conditions do not result in widespread supply interruptions. The level of security of supply has been determined to ensure that the risk of supply interruptions is managed to a level that maintains a minimum standard of transmission system performance. The faults we need to design the system to be compliant with are called 'secured events'.

The NETS SQSS defines the performance required of the NETS in terms of quality and security of supply for secured events such that at all times:

- electricity system frequency should be maintained within statutory limits;
- no part of the NETS should be overloaded beyond its capability;
- voltage performance should be within acceptable statutory limits; and
- the system should remain electrically stable.

Existing Transmission Network

The transmission network in the area of this project was primarily constructed in the 1960s, at the same time as much of the rest of the transmission system. It was designed to connect the in-land large coal fired power stations in the region, with changes occurring in the later parts of the century connecting gas fired power stations in East Midlands and Humber in particular. Since the construction many of the large coal fired power stations in the Midlands have now closed.

The existing transmission system in the region is shown in **Image B**.

Image B: The South Yorkshire and North Midlands transmission system

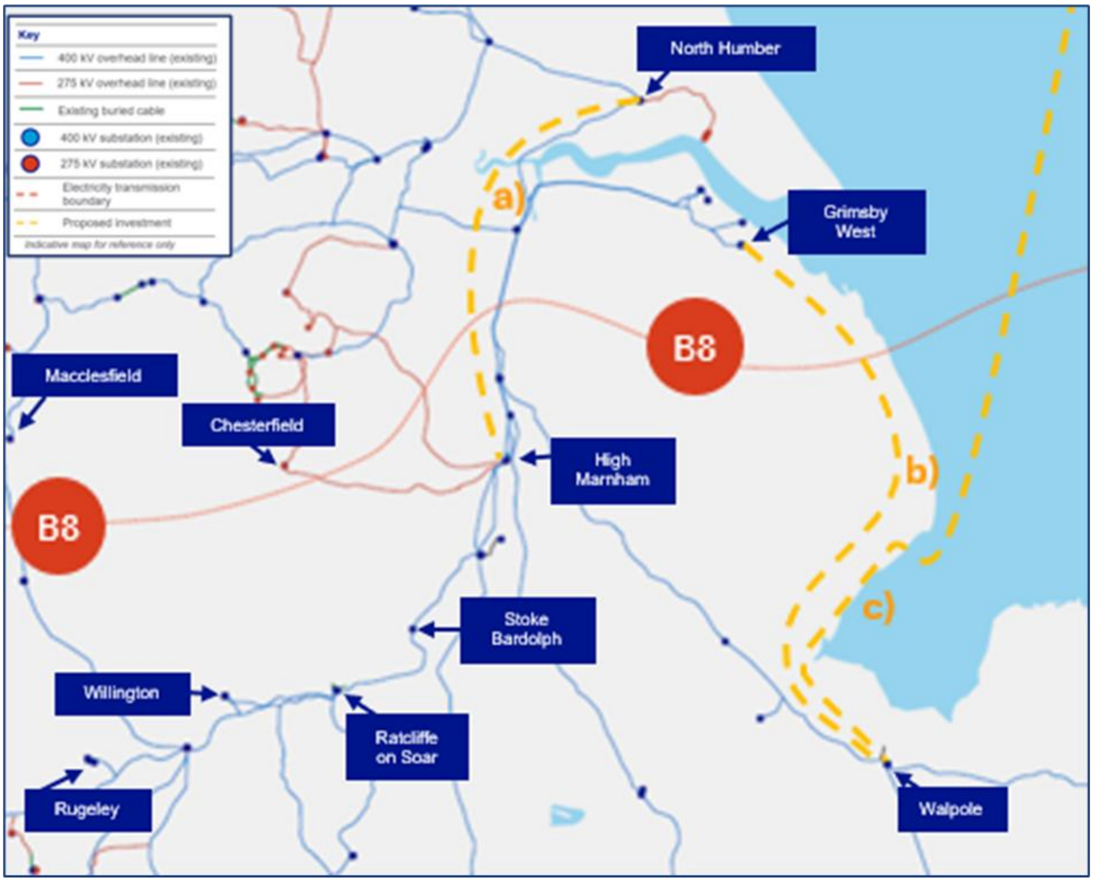


Image B shows the existing transmission system and the B8 boundary. It also shows proposed investments a), b), and c) described below:

- a) Proposed North Humber to High Marnham Circuit;
- b) Proposed Grimsby West to Walpole Circuit; and
- c) EGL3 and EGL4 high voltage direct current (HVDC) connections Scotland to England (New Walpole).

The proposed new circuits a), b), and c) all cross the B8 boundary along with facilitating generation connections. The need case and strategic options for these projects can be found in the North Humber to High Marnham and Grimsby to Walpole Strategic Options Report located on those project websites.

For the purposes of this need case, these projects are considered in the background as they are in the public domain. These projects increase network capacity/capability, which are influential on the need and appraised options set out within this document, and therefore it is important to establish them in the need case background.

Boundaries

A boundary notionally splits the system into two parts, crossing critical circuit paths that carry power between the areas where power flow limitations may be encountered. Boundaries help identify regions where reinforcement is most needed by enabling analysis of power transfers between separated areas. They can be local boundaries, which are small areas of the transmission system with a high concentration of generation, or wider boundaries, which are large areas containing significant amounts of both generation and demand. Boundary definitions have evolved over many years of planning and operating the transmission system.

Image B shows the transmission system and the B8 system boundary.

Future boundary requirements are assessed using the FES 2024, which was used to produce the ETYS 2024, to identify expected future power flows across the boundaries. FES 2025 has now been produced but as of December 2025, has not yet fed into an ETYS update. Power system analysis is conducted by the NESO and NGET to determine the boundary capability, which is the maximum power flow that can be transferred across a boundary while maintaining compliance with technical standards. Limiting factors on transmission capacity include thermal circuit rating, voltage constraints, and dynamic stability.

Summary of the Need Case Conclusions

In summary, NGET is required to ensure that the transmission system is compliant with the requirements of the NGET SQSS. Increasing levels of renewable generation are connecting to the transmission system and the power flows across the network will change as a result. This document sets out the need to add additional capability to the B8 system boundary to ensure future compliance.

Table A: Proposed boundary performance by 2035 including proposed circuits a), b), c)

Generation Group or Boundary Export	Required B8 Boundary Transfers by 2035	Proposed 2035 Post-Fault Capability	Proposed 2035 Post-Fault Gen Impaired Capacity	Capability Deficit (-) / Surplus(+)	Capacity Deficit(-) / Surplus (+)	Secured Event Fault
B8 – 2035 (Boundary)	28,700 megawatts (MW)*	23,400 MW	27,531 MW	**-5,300 MW**	**-1,169 MW**	Proposed North Humber – High Marnham 400 kilovolts (kV) double-circuit

**NESO Future Energy Scenarios 2024, average boundary requirement in 2035*

Table A shows the additional transmission system capability that would need to be provided to facilitate new connections for the B8 transmission system boundary.

As described above, this need case identifies the following requirements:

- provision of 5,300 MW of capability to the B8 boundary;
- provision of 1,169 MW of capacity to the B8 boundary; and
- management of limited fault level increase in the area.

The remainder of this report considers strategic options that resolve the need set out above.

Initial Strategic Options Analysis

Reinforcements in this area were iteratively tested in the ESO's NOA process.

In 2019, the ETYS identified that system boundary B8 between the North and South of England would have insufficient capability by 2035 to remain compliant with the NETS SQSS. Indeed, as set out in the need case – including proposed investments – B8 will have a Capability Deficit of -5,300 MW, insufficient to facilitate future requirements. As a consequence, the 2020 NOA document, produced by the ESO, recommended that network reinforcements to resolve this issue should be developed. The recommendations included the construction of new circuits, as described in this document, and a number of smaller reinforcements such as power flow controllers to maximise the benefits of new and existing circuits. The recommended smaller reinforcements to increase transfer capability included options in Scotland (E2D2, E2DC, E4D3, E4L5, and ECU2). As more generation is built in these areas, the flows to reach the demand in the East Midlands and around London will cross boundary B8. However, driven by the capacity shortfall of -1,169 MW and capability shortfall of -5,300 MW (as set out in the need case), a new circuit is required to accommodate future demand and provide impedance reduction.

The 2021 NOA introduced EDNC (Uprate Brinsworth and Chesterfield double circuits to 400 kV and a new 400 kV double circuit between Ratcliffe and Chesterfield), the set of reinforcements provide network capacity across system boundaries. With further iterative refinement in the January 2022 NOA, these were split out into two distinct projects EDEU and EDN2. This iteration recommended a 'hold' signal for the project, as the earliest in-service date was 2031, two years before its optimal delivery date. A hold signal is given if the optimum delivery date of an option is later than its in-service date. Options that receive a hold signal are still 'optimal', and benefits would still be seen from their delivery.

It should be noted that EDN2 in this context, refers to this historical project name at that point in time, and not the strategic option name, EDN-2, as discussed below and throughout the report. Since the outcome of the optioneering, the project nomenclature has used EDN-2 and EDN2 interchangeably to refer to the project.

We undertook an initial assessment of the strategic options available to meet the need case.

Strategic options are identified at a very high level as being electrical solutions between geographic points. Therefore, the potential circuit lengths are derived by taking a straight line distance between the points and adding 20 per cent to accommodate potential route deviations that might be required if the route proceeds forward to more detailed routeing and siting. Where a clear obstacle exists, such as an estuary, water course or geographical feature, an alternative route length would be derived and explained in the option. Where an offshore alternative is presented, straight lines would be used to a midpoint offshore and 20 per cent added to provide variation in route length.

These initial option lengths do not define route corridors, and environmental appraisal is provided over a wide study area between points of connection. Any routes for circuit technologies to take would be subject to detailed routeing and siting for any strategic option taken forward as a preferred option(s).

Through this options identification process, we identified the following long list of options for new circuits which satisfied the need as it was defined:

- EDN-1 – New Chesterfield Substation to Ratcliffe-on-Soar 400 kV Substation – 48 km;
- EDN-2 – New Chesterfield Substation to Willington 400 kV Substation – 51 km;

- EDN-3 – New High Marnham Substation to Ratcliffe-on-Soar 400 kV Substation – 61 km;
- EDN-4 – New High Marnham Substation to Willington 400 kV Substation – 78 km;
- EDN-5 – New Chesterfield 400 kV Substation to Stoke Bardolph 400 kV Substation – 44.4 km;
- EDN-6 – New Chesterfield 400 kV Substation to Staythorpe 400 kV Substation – 46 km;
- EDN-7 – New Chesterfield 400 kV Substation to Drakelow 400 kV Substation – 63.9 km;
- EDN-8 – New High Marnham 400 kV Substation to Drakelow 400 kV Substation – 91.8 km;
- EDN-9 – New Chesterfield 400 kV Substation to a new substation on the Willington-Drakelow Route – 63 km; and
- EDN-10 – New Chesterfield 400 kV Substation to a point on the Willington-Ratcliffe-on-Soar route – 50.8 km.

The July 2022 NOA Refresh found EDN2 (historical project name) to be ‘HND essential’, with a required in-service date of 2030. This means that reinforcements in this area are essential to delivering the Pathway to 2030.

We were therefore required to assess all of the reinforcement options available for providing the additional capability and capacity required to meet the need as identified in the NOA Refresh.

We evaluated the interactivity between the options considered in this report with other investments identified by the ESO (and later, NESO) to enable the connection of 50 GW of offshore wind by 2030. Most notable is EDEU (Brinsworth to High Marnham). It should be noted that this is now being delivered as two standalone projects, namely Brinsworth to Chesterfield and Chesterfield to High Marnham. The latter interacts directly with options considered in this report due to the new substation builds at Chesterfield and High Marnham which are part of its scope. Together, the EDEU projects (Brinsworth to Chesterfield and Chesterfield to High Marnham) will improve the capability across B8 by providing an additional 3 GW and reduce impedance due to the new circuit.

Following a review of the ETYS end-point assessment, a revised need case was adopted to reflect identified changes, and several of the options were discounted at this stage as they no longer met the need case. In addition, several of the options listed above were excluded from further assessment after application of ‘technical’ and ‘benefits’ filters under Our Approach to Consenting. In summary:

- EDN-5 and EDN-6 were discounted as they do not connect back to the main transmission system and therefore do not meet the need case.
- Options EDN-7, EDN-8, and EDN-9 were discounted as they did not pass the benefits filter on the basis that there would be greater capital costs for no benefit over similar alternative options. EDN-7 and EDN-8 also did not pass the technical filter as they did not offer sufficient technical benefits over options that terminate at Willington.
- EDN-10 was discounted as it did not pass the technical filter as the complexity for system access is increased through this option and temporary diversions of existing overhead lines would put construction timescales at risk.

The remaining options are those considered in this Strategic Options Report. These are:

- EDN-1 – Chesterfield to Ratcliffe-on-Soar 48 km;
- EDN-2 – Chesterfield to Willington 51 km;
- EDN-3 – High Marnham to Ratcliffe-on-Soar 61 km; and
- EDN-4 – High Marnham to Willington 78 km.

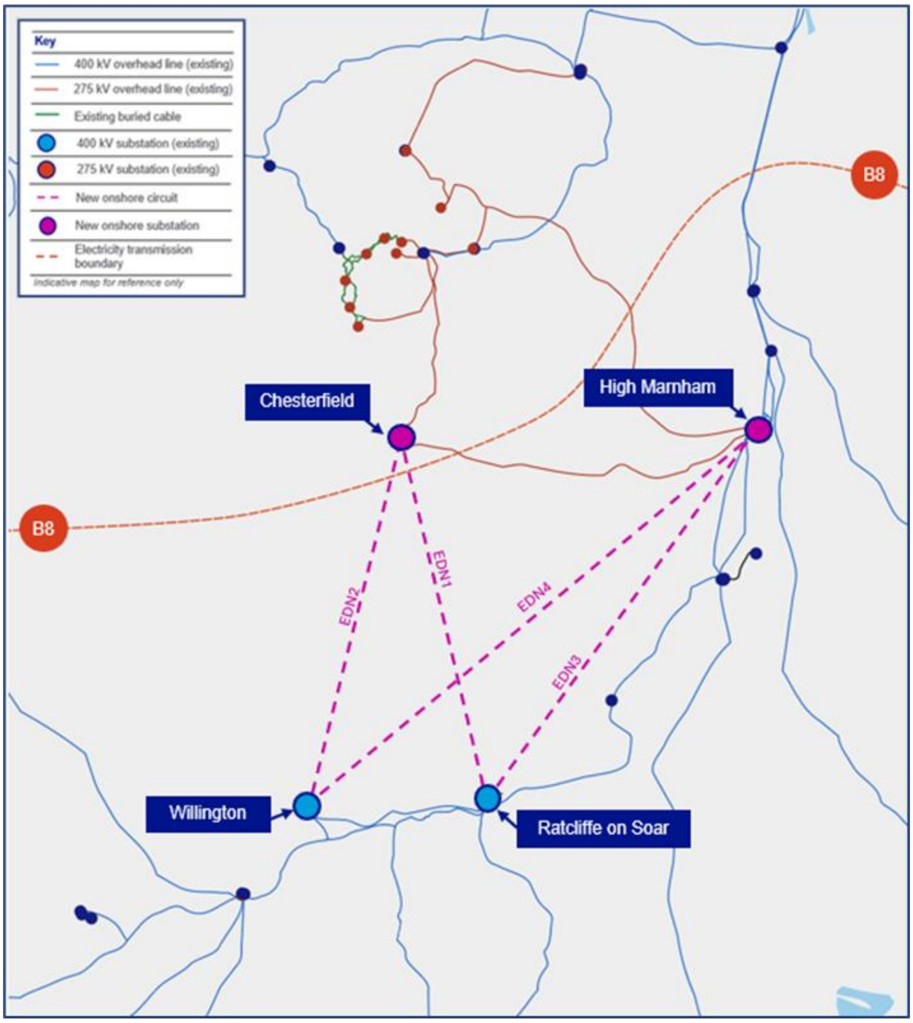
The interaction of the Chesterfield to High Marnham project allows the progression of the these options through the new High Marnham 400 kV Substation or new Chesterfield 400 kV Substation and will improve the capacity across B8 through the additional 400 kV circuit. The 3,000 MW provided by the Brinsworth to Chesterfield and Chesterfield to High Marnham projects will also help to provide a solution to the −5,300 MW Capability Deficit, as set out above, by also providing impedance reduction, and therefore the full -5,300 MW will not need to be met to address the need. Overall, the remaining options would address the NOA 'HND essential' status, providing the required reinforcements across the B8 boundary.

In developing and assessing our options, in addition to the interaction of the Chesterfield to High Marnham project's connection locations, the connection requirements for the East Coast generation and the HND/NOA recommendations for two circuits across B8 have also been considered to determine the overall optimum developments.

The review of the Need Case, as part of the SOR update, generated the revised Capability Deficit of -5,300 MW and revised Capacity Deficit of -1,169 MW, as presented above. These still show a requirement for an uplift of the B8 boundary, as provided by the project. These Need Case updates do not, consequently, alter the identification of the strategic options discussed above, nor the narrowing of the options to those taken forward to the subsequent options appraisal – EDN-1, EDN-2, EDN-3 and EDN-4.

These options are all shown in **Image C**.

Image C: Options considered



Identifying a Preferred Option

In line with Our Approach to Consenting, this Strategic Options Report is designed to test the assumptions and interim conclusions made to date based on the latest information available including those incorporated into March 2026 SOR Update.

This report considers solutions to resolve capacity shortfalls across the B8 boundary – i.e. focusing on the East Midlands area.

The high-level technical, environmental and socio-economic assessment of each option considered a minimum 2 km study area around the strategic option identified, but which was extended to 10 km in certain instances where considered appropriate/necessary in view of particular receptors, for example Special Protection Areas (SPAs) and World Heritage Sites.

For all options, there are ecological designated sites within the study area. The South Pennine and Peak District Moors Important Bird Area (IBA) falls within the study area for both Chesterfield options (EDN-1 and EDN-2), whilst the Sherwood Forest IBA falls within the study area for EDN-1 and EDN-3 and is crossed by EDN-4. For all options, there are also a number SSSIs, several nature reserves, and parcels of ancient woodland. Whilst it is anticipated that all options can avoid these sites, there is potential for direct and indirect effects on breeding, overwintering and passage bird species (collision risk), which will need to be reduced through further routeing and design.

Additionally, there are settlements and urban dwellings located within the study areas. For options EDN-1 and EDN-2, there would likely be some temporary minor adverse effects on local noise receptors during construction and the possibility of operational noise effects. These effects could be resolved through mitigation and appropriate routeing and siting. For options EDN-3 and EDN-4, appropriate routeing and siting for the overhead line, and the appropriate selection of construction compound sites will likely minimise any noise impacts. Whilst appropriate routeing and siting would seek to reduce residual noise impacts, at this stage in the project it is considered that moderate adverse effects may occur during construction. Although there are no environmental and socio-economic factors that distinguish materially between the four options, the longer overhead line route of EDN-4 would be expected to have more environmental and socio-economic effects than EDN-1, EDN-2, or EDN-3.

EDN-1, EDN-2 and EDN-3, propose a significantly shorter overhead line route than EDN-4 with comparable power uplift across the region. This means that EDN-4 would have significantly higher capital and lifetime circuit costs. They would also be expected to have lower environmental and socio-economic effects by virtue of route length. Additionally, EDN-3 has a 10 km longer route length than EDN-2, or 13 km longer route length than EDN-1 without any additional socio-economic or environmental benefit. It is therefore considered that the shortest options (EDN-1 and EDN-2) are preferable in environmental and socio-economic terms.

EDN-1 and EDN-3 propose connections to Ratcliffe 400 kV Substation, which presents major constraints, including land development rights, decommissioning and redevelopment at the Ratcliffe site creating considerable construction risk for connecting there, physical constraints (which would likely require 2km of underground alternating current (AC) cable) and lack of spare bays available for new circuits. Consequently, both options face substantial feasibility challenges, greatly reducing their potential as a viable options.

EDN-3 and EDN-4 require connection at High Marnham. The number of circuits proposed would exceed the capacity of the planned new substation (which is being constructed independently of this project). As such, these options require a second new substation, now included as part of the EDN-3 and EDN-4 scope. Costs have been added to account for this, but it should be noted this would impact timescales, not only for this project but for other projects connecting at High Marnham.

Connections at Chesterfield (EDN-1 and EDN-2) and Willington (EDN-2 and EDN4) are less complex, with sufficient space to accommodate them and limited electrical complexity.

As such, overall EDN-2, with connections to a new Chesterfield 400 kV and Willington 400 kV, has the least electrical and construction complexity and therefore offers a benefit over other options from a technical perspective.

Table B: Cost summary of works required to meet project need

Options	Onshore Options			
	EDN-1*	**EDN-2**	**EDN-3***	**EDN-4**
B8 >6 GW increase				
Economic technology (capacity)	overhead line	overhead line	overhead line	overhead line
	6,980 MW	6,980 MW	6,980 MW	6,980 MW

Options	Onshore Options			
Total capital cost including non-circuit works	£217.5m	£220.6m	£425.3m	£484.0m
Circuit 40 yr lifetime Net Present Value (NPV) cost	£328m	£349m	£417m	£534m

**see below for additional undergrounding costs at Ratcliffe, provided for information*

As outlined above, connecting at Ratcliffe presents significant constraints, the costing of which is outside the SOR methodology, which presents asset level costs, applying 100% technologies across all comparators. However, it has been identified that any connection into Ratcliffe (EDN-1, EDN-3), given the constraints, is likely to require 2 km of underground cable to avoid those potential constraints. Although costing for this is outside the SOR methodology, it is an asset-level cost, and therefore an estimate can be provided for information: £79.8m capital cost and £82m lifetime cost. This is in addition to costs shown in **Table B.** Including this underground section would result in revised estimated costs of:

- EDN-1: £297.3 (capital), £410m (lifetime)
- EDN-3: £505.1m (capital), £499m (lifetime).

Given the significant constraints and challenges identified, these factors form the principal differentiating factor across the assessment due to their impact on overall feasibility. When considered alongside technical, cost, environmental and socio-economic effects, EDN-2 represents the most advantageous overall option, as confirmed through the SOR update.

The progression of EDN-2 is also enabled through the interaction with the Chesterfield to High Marnham project due to the improved capacity across B8 from the additional circuit. The Brinsworth to Chesterfield and Chesterfield to High Marnham projects also provide an additional 3,000 MW, which helps to solve the -5,300 MW Capability Deficit as identified in the need case and also reduces impedance, therefore the full -5,300 MW will not need to be met. Overall, the remaining EDN-2 would address the NOA 'HND essential' status, providing the required reinforcement across the B8 boundary.

At the current stage, following SOR review and update, we therefore propose to take EDN-2 forward. This would consist of a new primarily overhead line connection between Chesterfield Substation and Willington Substation. The high-level assessment of capital cost is £220.6m and the lifetime circuit cost is £349m. This has been assigned the project title of 'Chesterfield to Willington'.

1. Introduction

1.1.1 This Strategic Options Report (SOR) (this report) has been prepared by National Grid Electricity Transmission plc (National Grid) as part of the decision-making process involved in promoting new transmission projects. It records how National Grid has had regard to a range of considerations in developing those projects. This report has been prepared in accordance with National Grid's document 'Our Approach to Consenting'[3].

1.1.2 This report addresses the Chesterfield to Willington project. The project is described in greater detail later in this report. This consideration of strategic options is part of an iterative process in response to interaction of a range of emerging energy projects and customer requirements. This report also considers how the project interacts with other proposals, which would connect power flows from the North and Scotland, with strategic options for the project.

1.1.3 As we continue to develop our plans and as our proposals evolve, we keep strategic options under review, taking account of consultation feedback and any changes that might influence the assessment of technical, environmental, socio-economic, and cost considerations.

1.1.4 As set out in Our Approach to Consenting, there are five stages. This report forms part of the 'Options identification and selection stage' and is at the very start of the process, as shown in **Image 1.1**. The original version of this report (March 2024) supported the non-statutory (Stage 1) consultation. It has now been updated for statutory (Stage 2) consultation, forming part of the 'Defined Proposal and Statutory Consultation' stage of the process shown in **Image 1.1** below.

Image 1.1: The National Grid project lifecycle

1.1.5 The report is structured as follows:

- background to England and Wales electricity transmission system (section 2);
- summary of the need case (section 3);
- identification of strategic options (section 4);
- options assessment process (section 5);
- strategic options overview (section 6);

[3] Our Approach to Consenting, National Grid (April 2022)
https://www.nationalgrid.com/electricity-transmission/document/142336/download

- appraisal of strategic options (sections 7, 8, 9,10);
- strategic options appraisal conclusions (section 11); and
- conclusion and next steps (section 12).

1.1.6 This document is also supported by a detailed set of appendices setting out National Grid's obligations, technology assumptions and cost appraisal methodology. The appendices also present socio-economic study maps and an overview of the ESO Beyond 2030 publication.

2. Background to England and Wales Electricity Transmission System

2.1 Background

2.1.1 In 2019, the Committee on Climate Change published its Net Zero report[4] setting out recommendations to the UK government on long-term emissions targets for the UK. The government subsequently adopted the Climate Change Act 2008 (2050 Target Amendment) Order 2019, which increased its pledge to achieve 100 per cent reduction in emissions by 2050. One of the ways this will be achieved is through decarbonisation, including moving away from fossil fuels providing energy to our homes and businesses. The vision for a transition to clean energy was set out in December 2020 with the publication of the Energy White Paper[5], which added further detail to the Prime Minister's Ten Point Plan for a Green Industrial Revolution. This requires the adoption of alternative sources of energy to power our homes, transport, and businesses.

2.1.2 As a result, electricity production is now moving towards reducing greenhouse gas emissions, by increasing renewable and low-carbon sources, such as offshore and onshore wind, solar energy, and new nuclear generation. In February 2021, the National Infrastructure Commission (NIC) (now replaced by the National Infrastructure and Service Transformation Authority (NISTA)) published a report[6] recommending to the UK government that renewable generation be increased to 65 per cent of supply by 2030 at no adverse cost to consumers, enabling the decarbonisation in part of sectors such as transport and heating via electrification.

2.1.3 Following the publication of the NIC report, the UK government published the British Energy Security Strategy[7] in April 2022, setting out a strategy for secure, clean, and affordable British energy for the long term. This strategy sets out energy ambition across a number of sectors including:

- up to eight reactors of nuclear energy being progressed, reaching up to 24 gigawatts (GW) to be achieved by 2050;
- up to 50 GW of offshore wind connected by 2030, 5 GW of which will be offshore floating wind;

[4] Net Zero the UK's Contribution to stopping global warming, Committee on Climate Change (2019) https://www.theccc.org.uk/wp-content/uploads/2019/05/Net-Zero-The-UKs-contribution-to-stopping-global-warming.pdf

[5] Energy White Paper: Powering our net zero future, HM Government (December 2020) . https://www.gov.uk/government/publications/energy-white-paper-powering-our-net-zero-future

[6] Operability of highly renewable electricity systems, National Infrastructure Commission (2021) https://webarchive.nationalarchives.gov.uk/ukgwa/20250327100139/https://nic.org.uk/studies-reports/operability-highly-renewable-electricity-systems/

[7] Department for Business, Energy & Industrial Strategy. Policy paper: British energy security strategy, HM Government (2022). Available at: https://www.gov.uk/government/publications/british-energy-security-strategy/british-energy-security-strategy

- up to 10 GW of low-carbon hydrogen production capacity by 2030, doubling the previous ambition; and
- 600,000 heat pump installations a year by 2028 and improving housing stock insulation.

2.1.4 The Powering Up Britain paper[8] was published in March 2023 by the UK government. This document provides an update of the strategy for secure, clean and affordable British energy for the long-term future, and closely relates to the points raised in paragraph 3.2.2.

2.1.5 In 2024, the UK government also committed to achieving a clean electricity system by 2030. One of the ways this will be achieved is through decarbonisation. The government has set out how it plans to deliver on this commitment within the Clean Power 2030 Action Plan: A new era of clean electricity[9], published in December 2024.

2.1.6 To facilitate these ambitions, electricity network infrastructure is needed to ensure that energy can be transported from where it is generated to where it is used.

2.1.7 The existing transmission system operates at 400 kilovolts (kV) and 275 kV and transports bulk supplies of electricity from generating stations to demand centres. Distribution systems operate at 132 kV and below in England and Wales and are mainly used to transport electricity from bulk infeed points (interface points with the transmission system) to the majority of end customers; see **Image 2.1**.

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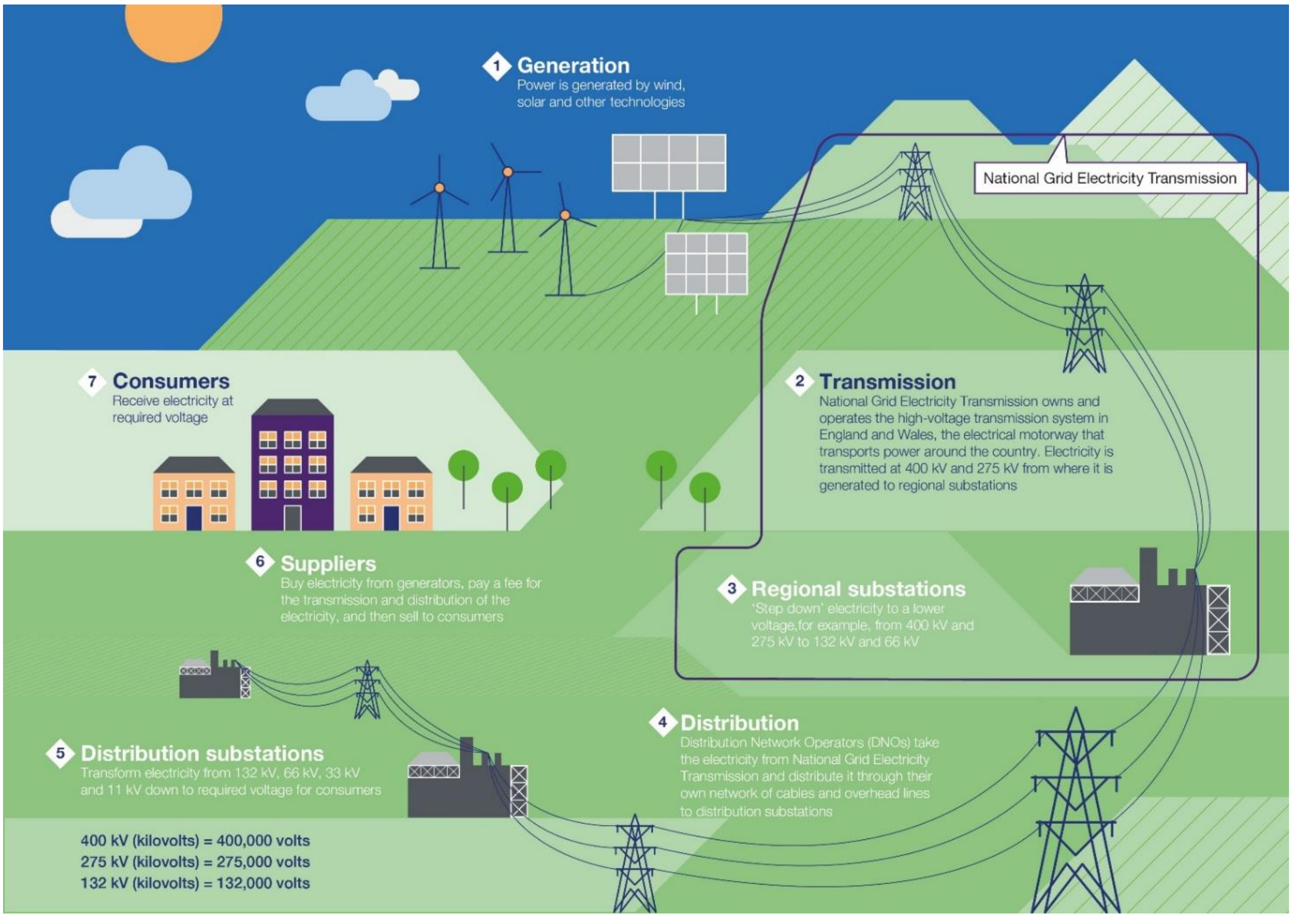
[8] Powering Up Britain: Energy Security Plan

https://assets.publishing.service.gov.uk/media/642708eafbe620000f17daa2/powering-up-britain-energy-security-plan.pdf

[9] Clean Power 2030: Action Plan: A new era of clean electricity

https://assets.publishing.service.gov.uk/media/677bc80399c93b7286a396d6/clean-power-2030-action-plan-main-report.pdf

Image 2.1: The electricity system from generator to consumer



2.1.8 A single electricity market serves the whole of Great Britain. In this competitive wholesale market, generators and suppliers trade electricity on a half-hourly basis. Generators produce electricity from a variety of energy sources, including coal, gas, nuclear and wind, and sell energy produced in the wholesale market. Suppliers purchase electricity in the wholesale market and supply to end customers.

2.1.9 Electricity can also be traded on the single market in Great Britain by generators and suppliers in other European countries. Interconnectors with transmission systems in France, Northern Ireland, Belgium, Denmark and the Netherlands are used to import electricity to and/or export electricity from the transmission system.

2.2 National Grid's Role

2.2.1 National Grid Electricity Transmission plc (National Grid) is the owner of the high-voltage transmission system in England and Wales and is part of the National Grid Group of companies.

2.2.2 Transmission of electricity in Great Britain requires permission by a licence granted under section 6(1)(b) of the Electricity Act 1989[10] (as amended) (the Electricity Act). Providing transmission services in England and Wales, National Grid is regulated by the Office of Gas and Electricity Markets ('Ofgem').

[10] Electricity Act 1989, c. 29., [online]. Available at: https://www.legislation.gov.uk/ukpga/1989/29/contents

2.2.3 National Grid's legal obligations include duties under section 9, section 38 and Schedule 9 of the Electricity Act. In summary, these require National Grid to:

- develop and maintain an efficient, co-ordinated and economical system of electricity transmission;
- when formulating proposals for the installation of electric line or the execution of any other works for or in connection with the transmission or supply of electricity, have regard to the desirability of preserving natural beauty, of conserving flora, fauna and geological or physiographical features of special interest and of protecting sites, buildings and objects of architectural, historic or archaeological interest; and
- when formulating such proposals, do what it reasonably can to mitigate any effect which the proposals would have on the natural beauty of the countryside or on any such flora, fauna, features, sites, buildings or objects.

2.2.4 A fuller consideration of National Grid's legal duties is set out in **Appendix A**.

2.2.5 As of 1 October 2024, the National Energy System Operator (NESO) became a public body owned by the Department for Energy Security and Net Zero. It was formerly part of National Grid plc and called the Electricity System Operator (ESO).

2.2.6 NESO facilitates several roles on behalf of the electricity industry, including making formal offers to applicants requesting connection to the National Electricity Transmission System (NETS).

2.2.7 National Grid is obligated to provide the physical connections to the elements of the NETS that National Grid own.

2.3 National Grid's Existing Transmission System

2.3.1 The electricity transmission system is a means of transmitting electricity around the country from where it is generated to where it is needed. The existing transmission system was developed to transport electricity in bulk from power stations to demand centres. Much of National Grid's transmission system was originally constructed in the 1960s. Incremental changes to the transmission system have subsequently been made to meet increasing customer demand and to connect new power stations and interconnectors with other transmission systems.

2.3.2 National Grid's transmission system consists of over 7,200 km of overhead lines and over 700 km of underground cabling, operating at 400 kV and 275 kV. In general, 400 kV circuits have a higher power-carrying capability than 275 kV circuits. These overhead lines and underground cable circuits connect over 340 substations forming a highly interconnected transmission system. Further details of the transmission system including geographic and schematic representations are published by NESO annually as part of its Electricity Ten Year Statement (ETYS)[11].

2.3.3 National Grid provides a connection between large generation stations and the connection of demand for homes and businesses in England and Wales. The generation directly connected to the electricity transmission system tends to be of two types: low-carbon energy (nuclear, wind farms, solar) and large thermal generation

[11] Electricity Ten Year Statement

https://www.neso.energy/publications/electricity-ten-year-statement-etys (gas-powered generation and older fossil fuel-powered generation). This is also supplemented by new storage technologies such as battery storage and hydro storage.

2.3.4 Circuits are those parts of the system used to connect between substations on the transmission system. The system is mostly composed of double circuits (in the case of overhead lines carried on two sides of a single pylon) and single circuits. Substations provide points of connection to the transmission system for power stations, distribution networks, transmission-connected demand customers (e.g. large industrial customers) and interconnectors.

2.4 How the Transmission System Operates

2.4.1 A generation group consists of a number of existing generating stations and/or proposed generating stations connecting in a particular geographical area of the transmission system.

2.4.2 Proposed generating stations require a connection agreement with NESO to authorise their connection to the transmission system. The relevant transmission owner must then assess the generation group to ensure that the transmission system is sufficient in the area to accommodate the existing and proposed generation. Upon completion of the assessment, NESO will make a formal offer of connection.

2.4.3 The capacity of the transmission system is based on the physical ability of electrical circuits to carry power. Each circuit has a defined capacity, and the total capacity of the circuits in a region or across a boundary is the sum of all of the capacity of all the circuits.

2.4.4 The capability of the transmission system is the natural flow of energy that can occur in the infrastructure comprising the network. Due to the physical properties of the transmission system, this is often not as great as the theoretical capacity of the infrastructure in question.

2.4.5 Where power flows are constrained by the transmission system across a specific number of circuits, this is termed a ‘boundary’ by NESO. Such boundaries are used in the ETYS to identify constraints which may require changes to the transmission system in the next 10 years.

2.4.6 Where capacity and capability of the transmission system are not sufficient, either from a generation group or across a boundary, National Grid will be required to reinforce the network. It does this by either modifying the existing network (if possible) and/or constructing additional transmission infrastructure to resolve the shortfall.

2.5 Requirement for Changes to the Transmission System

2.5.1 Under the terms of the Transmission Licence, National Grid is required to provide an efficient, economic and co-ordinated transmission system in England and Wales. The transmission infrastructure needs to be capable of maintaining a minimum level of security of supply and of transporting electricity from and to customers. National Grid is required to ensure that its transmission system remains capable as customer requirements change.

2.5.2 The transmission system needs to cater for demand, generation and interconnector changes. Customers can apply to the independent NESO for new or modified connections to the transmission system; NESO is then required to respond to each customer application with an offer for a new or modified connection.

2.5.3 In line with the government's 2050 targets, a large volume of applications have been made to NESO for connection at locations that are more remote from the existing transmission system, or which are in the vicinity of parts of the transmission system that do not have sufficient capacity available for the new connection.

2.5.4 National Grid has a key role in providing a transmission system which serves all consumers in England and Wales. As a monopoly, National Grid is regulated by Ofgem on behalf of consumers and is required to operate in accordance with the Transmission Licence. This includes maintaining reliable electricity supplies and offering to connect new energy suppliers. Where the network needs to be developed to do that, National Grid must be efficient, co-ordinated and economical and have regard to the desirability of preserving amenity, in line with the duties under sections 9 and 38 of the Electricity Act.

2.5.5 In developing new network infrastructure proposals, National Grid is therefore guided by the legislative and policy framework set by the UK government. This includes requirements set out in the Planning Act 2008 and associated National Policy Statements as described in detail in **Appendix B**.

2.6 National Energy System Operator's Role in the Development of the Transmission System

2.6.1 NESO is the electricity system operator for Great Britain. NESO ensures electricity is always where it is needed, and the transmission network remains stable and secure in its operation.

2.6.2 NESO has been established to act as the independent organisation responsible for planning Britain's energy system, operating the electricity network and offering expert advice to the sector's decision-makers.

2.6.3 Generators apply to NESO when they wish to connect to the network and NESO leads, working with the Transmission Owners (TOs), to consider how the network may need to evolve to deliver a cleaner, greener future. NESO is currently reforming its connection processes to meet the increasing number of projects wanting to connect to the transmission system.

2.6.4 NESO, in undertaking this role, engages with National Grid Electricity Transmission (NGET) for England and Wales as well as the two TOs in Scotland: Scottish and Scottish and Southern Electricity Network (SSEN) and Scottish Power (SP) Energy Networks.

2.6.5 NESO and its predecessor ESO have been or – in the case of NESO – are responsible for multiple roles across the electricity system, including:

- Electricity market balancing: NESO ensures that electricity demand and supply is balanced on a second-by-second basis and manages any shortfalls in boundary capacity.

What is a boundary?

A boundary notionally splits the system into two parts, crossing critical circuit paths that carry power between the areas where power flow limitations may be encountered.

- Future Energy Scenarios (FES): NESO undertakes an annual process to publish the Future Energy Scenarios[12] which takes energy industry views as part of a consultation process and develops a set of possible energy growth scenarios to 2050. In developing FES, NESO takes into consideration the latest pipeline of connections as detailed within the Transmission Entry Capacity (TEC) Register. The TEC Register is essential for managing the UK's electricity transmission network, providing an overview of the capacity available for new connections. As customers apply to NESO for new or modified connections, the TEC Register helps assess the current and future capacity needs of the network.
- NESO annually publish the ETYS[13] setting out the network performance and requirements for all transmission in Great Britain over the next 10 years based on the data from the FES. ESO used the ETYS to publish annually the Network Options Assessment[14] (NOA), which considered the economic case for options to reinforce the transmission system and makes economic recommendations. The NOA included a Cost Benefit Analysis (CBA) process to determine when would be appropriate to take forward options proposed by TOs to increase network capacity. This considers the capital costs of the proposal, delivery timescales and constraint costs (as explained in section 5) avoided by delivering the proposal. This establishes when a proposed reinforcement becomes the most economical way to deliver value to Great Britain's energy consumers.
- Network Planning Review: The Pathway to 2030 Holistic Network Design (HND)[15] and the recommendations set out in the most recent NOA prepared by ESO were the first steps towards a more centralised, strategic network planning approach that is critical for delivering affordable, clean and secure power, with a view to achieving net zero.
- NESO is currently transitioning from the NOA to a more comprehensive approach, a Centralised Strategic Network Plan[16] (CSNP). The CSNP will aim to foster the holistic development of the NETS, marking a new era in network planning.
- Connections: NESO facilitates several roles on behalf of the electricity industry, including making formal offers to connect applicants to the electricity transmission system. NGET is obligated to provide the physical connections to the elements of the electricity transmission system that NGET owns.

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[12] Future Energy Scenarios 2025: Pathways to Net Zero
https://www.neso.energy/document/364541/download
[13] Electricity Ten Year Statement
https://www.neso.energy/publications/electricity-ten-year-statement-etys
[14] Network Options Assessment 2021/22 Refresh, National Grid ESO, July 2022
https://www.neso.energy/document/262981/download
[15] The Pathway to 2030 Holistic Network Design, National Grid ESO
https://www.neso.energy/document/262681/download

[16] Decision on the initial findings of our Electricity Transmission Network Planning Review, Ofgem
https://www.ofgem.gov.uk/publications/decision-initial-findings-our-electricity-transmission-network-planning-review

2.6.6 The planning activities undertaken by NESO are currently being updated to support the delivery of the government's net-zero commitment. In 2022, ESO published the HND setting out an integrated approach to transmission network design that supports the connection of 23 GW of offshore wind to Great Britain by 2030.

2.6.7 In 2024, ESO published the findings from the HND Follow-Up Exercise (HND FUE) in a report entitled 'Beyond 2030'[17] which is a pivotal document outlining the strategic direction for the UK's electricity transmission network as it transitions towards a decarbonised future. This report provides an overview of the network design that will act as the pathway to a clean, secure, and affordable energy network, aligning with the Climate Change Committee's Sixth Carbon Budget and Scotland's ScotWind leasing round to 2035. It is closely linked to the Transitional Centralised Strategic Network Plan 2 (tCSNP2)[18], which serves as a framework for the necessary investments and infrastructure developments required to meet the ambitious targets set for 2030 and beyond.

2.6.8 The tCSNP2 provides a comprehensive roadmap for the evolution of the UK's transmission network, ensuring that the infrastructure is not only capable of meeting current demands but also adaptable for future energy needs. More detail on the Beyond 2030 report can be found in **Appendix H**.

[17] Beyond 2030, National Grid ESO

www.neso.energy/document/304756/download

[18] NESO tCSNP2 Information Page

https://www.neso.energy/publications/transitional-centralised-strategic-network-plan-tcsnp

3. Need Case

3.1 Background

3.1.1 The electricity industry in Great Britain is undergoing unprecedented change. Closure of fossil fuel burning generation and end of life nuclear power stations means significant additional investment in new sustainable generation and interconnection capacity will be needed to ensure existing minimum standards of security and supply are maintained.

3.1.2 Growth in onshore green technologies, offshore wind generation and interconnectors with Europe has seen a significant number of connections planned in Scotland, England and, significantly, in areas of the East Coast of England.

3.1.3 The Climate Change Act 2008 (as amended) now commits the UK government by law to reducing greenhouse gas emissions by at least 100 per cent from the 1990 baseline by 2050, strengthening the likelihood that increasing numbers of these connections will progress to delivery. This 2050 target is commonly known as ‘Net Zero’.

3.1.4 To achieve Net Zero, there will need to be a substantial shift away from the use of fossil fuel burning generation. This has led to investment in onshore green technologies and offshore wind generation, which will increase further in the future.

3.1.5 Historically, the transmission system was powered by coal-powered generating stations. The increasing importance of low carbon generation has driven the closure of these generating stations, with more expected to close in the future. This generating capacity is being replaced by low carbon generation which is mostly geographically located away from the coal powered generating stations. The transmission system must be updated to reflect the location of the new generation capacity.

3.1.6 Electricity demand is especially concentrated in large urban areas, including urban areas in the M62 corridor, the M18 corridor, the Midlands, the M4 corridor and the South East. The transmission system carries bulk energy from the generators to points on the network where that power is taken onto the distribution networks for onward transmission to homes and businesses across England and Wales. As the country decarbonises, this national demand for energy will increase and new low carbon generation will replace fossil fuel generation.

3.2 National Electricity Transmission System Security and Quality of Supply Standard

3.2.1 NGET must comply with section 9 of the Electricity Act and Standard Condition D3 (Transmission system security standard and quality of service) of its Transmission Licence. This means that where the boundary capacity of the Main Interconnected Transmission System (MITS) is exceeded against the standards, NGET must resolve the capacity shortfall under the terms of its Transmission Licence. The standards against which NGET assesses these shortfalls are set out in the ‘Design of the Main

Interconnected Transmission System' section of the National Electricity Transmission System Security and Quality of Supply Standard (NETS SQSS)[19].

3.2.2 NGET assesses the adequacy of its transmission system in accordance with the method defined in the NETS SQSS. We are required to assess power flows between regions of the transmission system (Planned Transfers). The Planned Transfer from the region is calculated by taking the Average Cold Spell (ACS) Peak Demand in the region and the generation operating in the region then modelling the flow expected as set out in the NETS SQSS. The Planned Transfer is therefore the amount of power which will flow in or out of the region at ACS peak. Planned Transfer calculations will always consider the power flows for ACS peak demand conditions, as less generation will be entering the market when demand is lower.

3.2.3 Any transmission system is susceptible to faults that interfere with the ability of transmission circuits to carry power. Most faults are temporary, many are related to weather conditions such as lightning or severe weather, and many circuits can be restored to operation automatically in minutes after a fault. Other faults may be of longer duration and would require repair or replacement of failed electrical equipment.

3.2.4 Whilst some of these faults may be more likely than others, faults may occur at any time, and it would not be acceptable to have a significant interruption to supplies as a result of specified fault conditions, including combinations of faults. The principle underlying the NETS SQSS is that the NETS should have sufficient spare capability or 'redundancy' such that defined fault conditions do not result in widespread supply interruptions. The level of security of supply has been determined to ensure that the risk of supply interruptions is managed to a level that maintains a minimum standard of transmission system performance. The faults we need to design the system to be compliant with are called 'secured events'.

3.2.5 The NETS SQSS defines the performance required of the NETS in terms of quality and security of supply for secured events such that at all times:

- electricity system frequency should be maintained within statutory limits;
- no part of the NETS should be overloaded beyond its capability;
- voltage performance should be within acceptable statutory limits; and
- the system should remain electrically stable.

3.3 Existing Transmission Network

3.3.1 The transmission network in the North of England and Midlands was primarily constructed in the 1960s, at the same time as much of the rest of the transmission system. It was designed to connect the in-land large coal fired power stations in the region, with changes occurring in the later parts of the century connecting gas fired power stations in East Midlands and Humber in particular. Since the construction many of the large coal fired power stations in the Midlands have now closed.

3.3.2 The existing transmission system in the North of England and the Midlands is shown in **Image 3.1**. The geography under consideration for the project is shown in **Image 3.2**.

[19] NETS Security and Quality of Supply Standards SQSS Code Documents | National Energy System Operator

Image 3.1: The National Electricity Transmission System in the North and Midlands

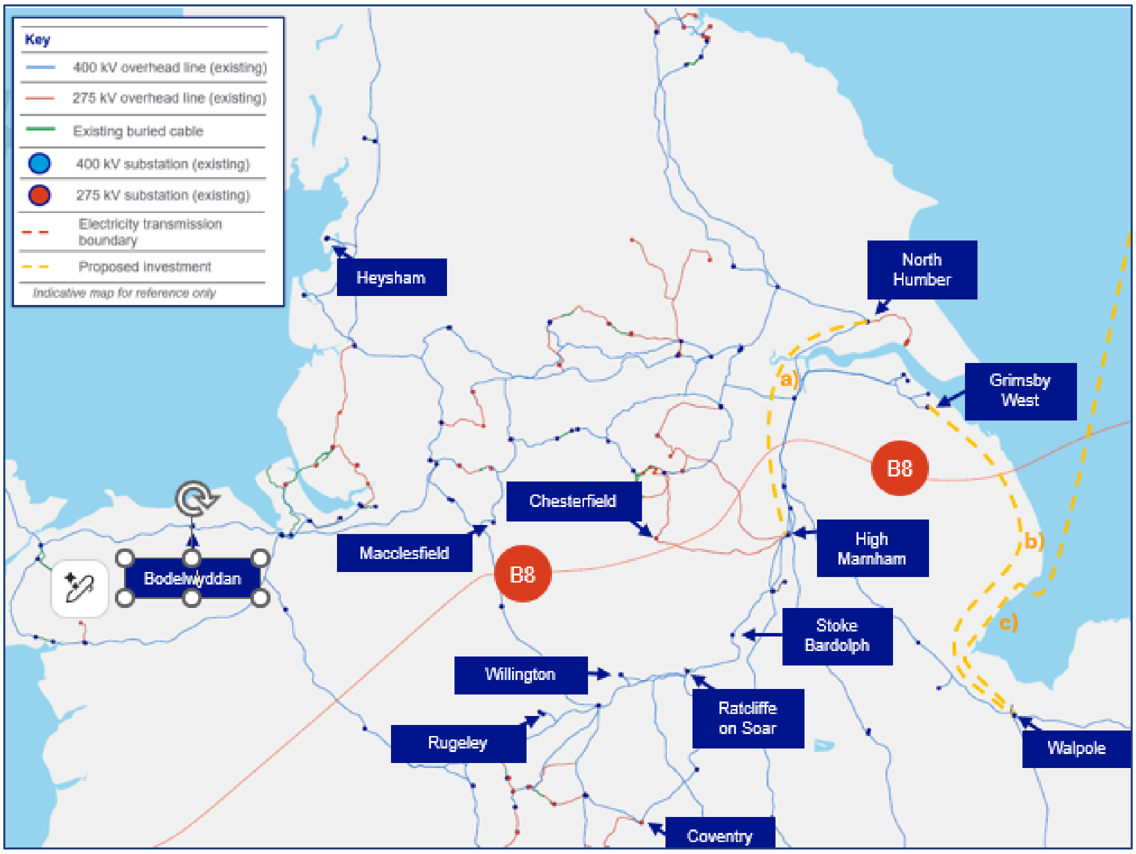
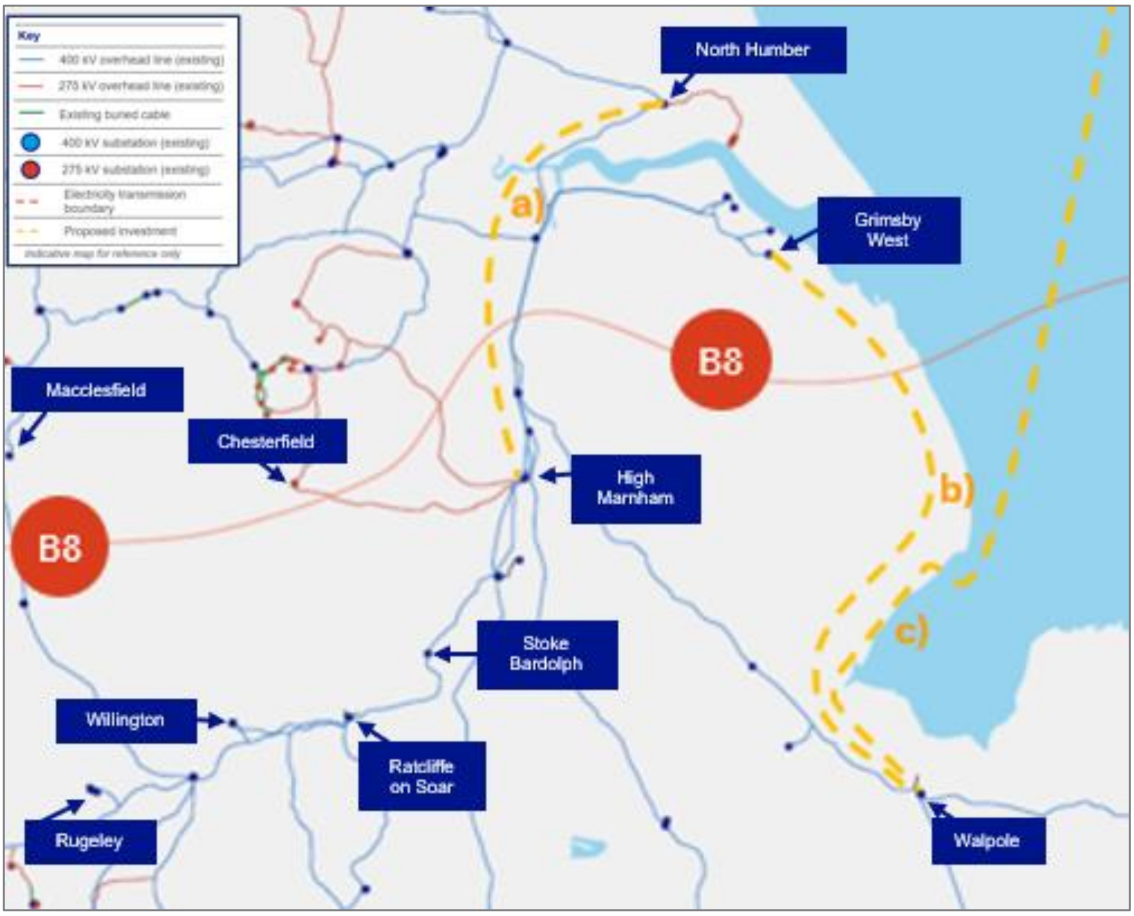


Image 3.2: The South Yorkshire and North Midlands transmission system



3.3.3 **Image 3.1** and **Image 3.2** show the existing transmission system and the B8 boundary. Both **Image 3.1** and **Image 3.2** also show proposed investments a), b), and c) described below:

- a) Proposed North Humber to High Marnham Circuit;
- b) Proposed Grimsby West to Walpole Circuit; and
- c) EGL3 and EGL4 high voltage direct current (HVDC) connections Scotland to England (New Walpole).

3.3.4 The proposed new circuits a), b) and c) all cross the B8 boundary along with facilitating generation connections. The need case and strategic options for these projects can be found in the North Humber to High Marnham[20], Grimsby to Walpole[21] and EGL3 and EGL4[22] SORs, located on the project websites.

3.3.5 For the purposes of this need case, these projects are considered in the background as they are in the public domain. These projects increase network capacity/capability, which are influential on the need and appraised options set out within this document, and therefore it is important to establish them in the need case background.

3.4 Boundaries

3.4.1 As stated above, **Image 3.1** and **Image 3.2** show the transmission system and the B8 system boundary.

3.4.2 A boundary notionally splits the system into two parts, crossing critical circuit paths that carry power between the areas where power flow limitations may be encountered. Boundaries help identify regions where reinforcement is most needed by enabling analysis of power transfers between separated areas. They can be local boundaries, which are small areas of the transmission system with a high concentration of generation, or wider boundaries, which are large areas containing significant amounts of both generation and demand. Boundary definitions have evolved over many years of planning and operating the transmission system.

3.4.3 Future boundary requirements are assessed using the FES 2024[23], which was used to produce the ETYS 2024[24], to identify expected future power flows across the boundaries. FES 2025[25] has now been produced but as of December 2025, has not yet fed into an ETYS update. Power system analysis is conducted by the NESO and NGET to determine the boundary capability, which is the maximum power flow that can be transferred across a boundary while maintaining compliance with technical standards. Limiting factors on transmission capacity include thermal circuit rating, voltage constraints, and dynamic stability.

[20] https://www.nationalgrid.com/the-great-grid-upgrade/north-humber-high-marnham/document-library

[21] https://www.nationalgrid.com/the-great-grid-upgrade/grimsby-to-walpole/document-library

[22] https://www.nationalgrid.com/the-great-grid-upgrade/eastern-green-link-3-and-4/document-library

[23] Future Energy Scenarios 2024: ESO Pathways to Net Zero https://www.neso.energy/document/321041/download

[24] Electricity Ten Year Statement (ETYS) 2024 https://www.neso.energy/document/352001/download

[25] Future Energy Scenarios 2025: Pathways to Net Zero https://www.neso.energy/document/364541/download

3.5 B8 Boundary

3.5.1 Boundary B8 is a wider system boundary containing areas with significant amounts of both generation and demand. Studies have been undertaken jointly by National Grid and NESO to assess the impact of changes in demand and generation on power flows across the boundary and to determine if these impacts require reinforcement to the transmission system.

3.5.2 The B8 boundary as described above has been evaluated using the Economy Planned Transfer assessment, which takes prescribed generation contributions from above and below the boundary, alongside demand in each area to determine the expected flow across the boundary. In this case the Economy Planned Transfer condition represents the most onerous boundary condition which must be secured by NGET to the requirements set out in the NETS SQSS.

3.5.3 Each of the circuits which cross the B8 boundary has a capacity during the winter ACS period. The summation of the capacity for all of these circuits provides the pre-fault capacity. The post-fault capacity is defined by the remaining capacity across a boundary following the worst fault 'secured event' as described above.

3.5.4 Each boundary will then see flows across it based upon the circuit parameters and system conditions, when the natural flow of energy on every circuit will be maximised. This is known as the circuit boundary capability, which is based upon the capability seen following the worst fault 'secured event'. The following capacities and capabilities are applicable to the boundaries by 2035 should no reinforcement occur. Reinforcements across the boundary would seek to deliver enhanced boundary capacity between 2030 and 2035, delivering sufficient capacity to meet the 2035 capacity requirements set out below. If all reinforcements were not delivered ahead of 2035 for each boundary, significant system constraints would be incurred for energy seeking to meet the government 2030 goals and beyond. This means any delays would have a significant impact on government ambitions and consumer need for sustainable and affordable energy.

3.6 NGET's B8 Analysis Results

3.6.1 **Table 3.1** shows the capacities and capabilities applicable to the B8 system boundary in 2035 without reinforcement of the existing transmission system.

Table 3.1: Existing transmission system capacities and capabilities by 2035

System Boundary	Pre-Fault Capacity	Post-Fault Capacity	Post-Fault Capability
	Megawatts (MW)	**MW**	**MW**
B8	23,531	17,426	16,400

3.6.2 **Table 3.2** shows the capacities and capabilities applicable to system boundaries in 2035 with proposed reinforcements a) and b) and c).

Table 3.2: Proposed transmission system capacities and capabilities by 2035 (including Grimsby to Walpole, North Humber to High Marnham projects and EGL3 and EGL4)

System Boundary	Pre-Fault Capacity	Post-Fault Capacity	Post-Fault Generation Impaired Capacity	Post-Fault Capability
	MW	MW	MW	MW
B8	41,391	34,461	27,531	23,400

3.6.3 As described in the Grimsby to Walpole SOR, the East Coast generation connects to new substations on the Grimsby to Walpole route. The Grimsby West to Walpole circuit will have a capacity of 6,930 MW. Whilst this is lower than the total generation capacity contracted to connect into this circuit, it is sufficient to connect the generation when a realistic dispatch is considered.

3.6.4 This effectively limits the amount of additional energy that can flow through the circuit from Grimsby West and limits the capacity of the B8 boundary. At credible dispatch conditions with high renewable output, the circuit will provide no additional capacity to B8.This leads to the boundary having a 'Generation Impaired Capacity' where the Grimsby West to Walpole circuit capacity has been removed from the overall boundary capacity that is shown in **Table 3.2** and **Table 3.3**.

Table 3.3: Proposed boundary performance by 2035 including proposed circuits a), b), c)

Generation Group or Boundary Export	Required B8 Boundary Transfers by 2035	Proposed 2035 Post-Fault Capability	Proposed 2035 Post-Fault Gen Impaired Capacity	Capability Deficit(-) / Surplus(+)	Capacity Deficit(-) / Surplus (+)	Secured Event Fault
B8 – 2035 (Boundary)	28,700 MW*	23,400 MW	27,531 MW	**-5,300 MW**	**-1,169 MW**	Proposed North Humber – High Marnham 400 kV double-circuit

**NESO Future Energy Scenarios 2024, average boundary requirement in 2035*

3.6.5 Taking account of the increases to the B8 system boundary capability and capacity that would be provided by the reinforcement proposals that NGET is progressing and for generation and demand requirements that are highly likely by 2035, **Table 3.3** shows the deficit for the B8 system boundary:

- capacity deficit of -1,169 MW; and
- capability deficit of -5,300 MW.

3.6.6 NGET recognises that both deficits need to be addressed. It is noted that a capability uplift would be expected to facilitate the required boundary transfers.

3.6.7 The boundary assessments completed on the Economy Planned Transfer, as defined in the NETS SQSS, already account for generation contribution. To ensure an appropriate measure of need using current assessments of capacity at the date of this report, we have taken the Holistic Transition, Electric Engagement, Hydrogen Evolution, CP30 – Further Flex and Renewables and CP30 – New Dispatch boundary requirement scenarios from the ETYS 2024 based upon FES 2024 backgrounds, as of February 2025. An average of all five scenarios has been applied, which aligns with NESO's use of three (plus two CP30, (Clean Power 2030)) background scenarios up to 2035, to identify expected future boundary flows.

3.6.8 As described in the 'Communicating our thermal needs' section set out in the NESO ETYS 2024 documentation, the FES boundary graphs for each area display two sets of shaded areas. The 50th percentile of power flows lies in the 25 per cent and 75 per cent range of the graph. The 90th percentile of power flows lies in the 5 per cent to 95 per cent range of the ETYS graphs. It states that where the capability of the boundary is between these two regions, 75 per cent and 95 per cent, over 20 years, then there may be a need for reinforcement.

3.6.9 NGET uses the average of the 95 per cent percentile number across the five scenarios for boundary analysis. This ensures that for all five scenarios, our need case capacity and capability requirement would lie between the 75 per cent and 95 per cent ranges of annual power flows for all five scenarios, demonstrating the need for reinforcement regardless of which scenario occurs. Against this assessment in all five FES 2024 and Clean Power 2030 (CP2030) scenarios there is clearly a shortfall against boundary capability and capacity for the B8 boundary that by 2035 will require reinforcement.

3.6.10 From 2035, further increases in boundary requirements are expected, and this is reflected in NGET's existing contractual commitments. To address this need, additional reinforcements to these boundaries are expected in Central England and Wales, which will supplement these boundaries in the future. This will facilitate connections beyond 2035 when further increases in generation are expected in all regions, which will be subject to their own detailed need case and options assessment. These future requirements would be informed by further SORs and need case assessments. These emerging requirements do not affect the need case set out within this report.

3.6.11 In addition to the significant volume of new energy generators seeking to connect to the transmission system in the Yorkshire and South Midlands area, NGET's analysis needs to consider the impact of existing and/or contracted distribution system generation connections (embedded generators).

3.6.12 Generators that are connected to a system contribute to the fault level of that system. The fault level contribution from an embedded generator is seen from its point of connection with the distribution system and also other connected systems (including the transmission system).

3.6.13 NGET is required to ensure that fault levels are within the capability of our transmission system at all times. In some circumstances, fault level issues can be managed by restricting the configuration of the transmission system. However, it is noted that use of operational restrictions may reduce the capability and capacity limits at transmission system boundaries. NGET seeks opportunities to improve transmission system operational flexibility when developing reinforcement proposals. NGET must comply with section 9 of the Electricity Act and Standard Condition D3

(Transmission system security standard and quality of service) of its Transmission Licence; failing to resolve the need set out above would breach this requirement.

3.6.14 As part of our analysis, we considered additional embedded generator (mainly battery storage and solar) connections that are expected to be made to the distribution system and connected to our transmission system at Chesterfield Substation and High Marnham Substation. We also considered future demand in the area.

3.6.15 Results from our analysis show that these embedded generator connections would:

- have limited impact on B8 system boundary flows; and
- increase fault levels on the NGET transmission system in the South Yorkshire and North Midlands area.

3.6.16 The limited increased fault levels can be managed by the new substations being constructed in the area, having higher fault level ratings and the remaining system being managed with operations response times.

3.7 Need Case Conclusions

3.7.1 As described above, this need case identifies the following requirements:

- provision of 5,300 MW of capability to the B8 boundary;
- provision of 1,169 MW of capacity to the B8 boundary; and
- management of limited fault level increase in the area.

3.7.2 The remainder of this report considers strategic options that resolve the need set out above.

4. Identification of Strategic Options

4.1 Introduction

4.1.1 When a need to reinforce the transmission system is established, we bring together a multi-disciplinary scheme team to evaluate a wide range of options. This team produces a list of strategic options which can be further refined through evaluation processes and which are described within this report. The scheme team keeps the options under review as changes to the drivers emerge. Through this review, options can be modified, or deselected and new options can be added. This section provides the chronological history of the options that are evaluated in this SOR and how the process was used to arrive at this list.

4.2 Initial Electricity System Operator Analysis

4.2.1 Reinforcements in this area were iteratively tested in the ESO's NOA process. As part of the ESO's NOA process, National Grid was required to produce a high-level scope with indicative construction delivery dates and capital costs for each of the options proposed. ESO also required us to explain the impact of each option on boundary capability, which we assessed against the relevant study background at the time of assessment.

4.2.2 In 2019, the ETYS identified that system boundary B8 between the North and South of England would have insufficient capability by 2035 to remain compliant with the NETS SQSS. Indeed, as set out in the need case – including proposed investments – B8 will have a Capability Deficit of -5,300 MW, insufficient to facilitate future requirements. As a consequence, the 2020 NOA document produced by the ESO recommended that network reinforcements to resolve this issue should be developed. The recommendations included the construction of new circuits, as described in this document, and a number of smaller reinforcements such as power flow controllers to maximise the benefits of new and existing circuits. The recommended smaller reinforcements to increase transfer capability included options in Scotland (E2D2, E2DC, E4D3, E4L5, and ECU2). As more generation is built in these areas, the flows to reach the demand in the East Midlands and around London will cross boundary B8. However, driven by the capacity shortfall of -1,169 MW and capability shortfall of -5,300 MW (as set out in the need case), a new circuit is required to accommodate future demand and provide impedance reduction.

4.2.3 The 2021 NOA introduced EDNC (Uprate Brinsworth and Chesterfield double circuits to 400 kV and a new 400 kV double circuit between Ratcliffe and Chesterfield), the set of reinforcements provide network capacity across system boundaries. With further iterative refinement in the January 2022 NOA, these were split out into two distinct projects EDEU and EDN2. This iteration recommended a 'hold' signal for the project, as the earliest in-service date was 2031, two years before its optimal delivery date. A hold signal is given if the optimum delivery date of an option is later than its in-service date. Options that receive a hold signal are still 'optimal', and benefits would still be seen from their delivery.

4.2.4 It should be noted that EDN2 in this context, refers to this historical project name at that point in time, and not the strategic option name, EDN-2, as discussed below and throughout the report. Since the outcome of the optioneering, the project nomenclature has used EDN-2 and EDN2 interchangeably to refer to the project.

4.2.5 Scheme team members were brought together to produce a long list of options, which was subsequently filtered to evaluate the options that met the recommendations of NOA in 2020. Through this options identification process, we identified the following options for new circuits which satisfied the need as it was defined in 2019/20:

- EDN-1 – New Chesterfield Substation to Ratcliffe-on-Soar 400 kV Substation – **48 km**;
- EDN-2 – New Chesterfield Substation to Willington 400 kV Substation – **51 km**;
- EDN-3 – New High Marnham Substation to Ratcliffe-on-Soar 400 kV Substation – **61 km**;
- EDN-4 – New High Marnham Substation to Willington 400 kV Substation – **78 km**;
- EDN-5 – New Chesterfield 400 kV Substation to Stoke Bardolph 400 kV Substation – **44.4 km**;
- EDN-6 – New Chesterfield 400 kV Substation to Staythorpe 400 kV Substation – 46 km;
- EDN-7 – New Chesterfield 400 kV Substation to Drakelow 400 kV Substation – **63.9 km**;
- EDN-8 – New High Marnham 400 kV Substation to Drakelow 400 kV Substation – **91.8 km**;
- EDN-9 – New Chesterfield 400 kV Substation to a new substation on the Willington-Drakelow Route – **63 km**; and
- EDN-10 – New Chesterfield 400 kV Substation to a point on the Willington-Ratcliffe-on-Soar route – **50.8 km**.

4.2.6 As further discussed in paragraph 5.1.14, for this stage of development route lengths are derived by taking a straight line distance between the points and adding 20 per cent to accommodate potential route deviations that might be required if the route proceeds forward to more detailed routeing and siting.

4.2.7 The July 2022 NOA Refresh found EDN2 (historical project name) to be 'HND essential', with a required in-service date of 2030. This means that reinforcements in this area are essential to delivering the Pathway to 2030.

4.2.8 We were therefore required to reassess all of the reinforcement options available for providing the additional capability and capacity required to meet the need as identified in the NOA refresh.

4.2.9 We also evaluated the interactivity between the options considered in this report with other investments identified by the ESO (and later, NESO) to enable the connection of 50 GW of offshore wind by 2030. Most notable is EDEU (Brinsworth to High Marnham). It should be noted that this is now being delivered as two standalone projects, namely Brinsworth to Chesterfield and Chesterfield to High Marnham. The latter interacts directly with options considered in this report due to the new substation builds at Chesterfield and High Marnham which are part of its scope. Together, the EDEU projects (Brinsworth to Chesterfield and Chesterfield to High Marnham) will improve the capability across B8 by providing an additional 3 GW and reduce impedance due to the new circuit.

4.2.10 Following a review of the ETYS, a revised need case was adopted to reflect identified changes. Although this did not impact our initial options analysis, EDN-5 and EDN-6 were discounted at this stage as they no longer met the need case as set out below:

- EDN-5 – Stoke Bardolph Substation would need to be reconfigured significantly to accommodate the connection of the overhead line. Further, there is only one double 400 kV circuit south of Stoke Bardolph, therefore this option would trigger the requirement for a further circuit. The Stoke Bardolph Substation also lies in a flood plain and the overhead line route would present visual impact issues to Sherwood Forest as well as impact on the Nottingham urban area. Overall, EDN-5 was discounted as it does not connect back to the main transmission system and therefore does not meet the need case.
- EDN-6 – Terminating the route at Staythorpe would require a further double-circuit to be created further south of the network. Overall, EDN-6 was discounted as it does not meet the need case without an additional circuit.

4.2.11 Several of the options listed above were also excluded from further assessment after application of the ‘technical filter’ and ‘benefits filter’ (described in section 5).

4.2.12 A summary of the reasons for discounting these options are described below:

- EDN-7 and EDN-8 – Options terminating at Drakelow require a longer overhead line route of approximately 10 km, increasing capital costs for ~300 MW less boundary transfer when compared to terminating the overhead line at Willington. Options EDN-7 and EDN-8 were therefore discounted as they did not pass the benefits filter on the basis that there would be greater capital costs for no benefit over similar alternative options. Additionally, they do not provide sufficient technical benefits over options that terminate at Willington and consequently do not pass the technical filter.
- EDN-9 – Creation of a new substation and turning in multiple circuits would significantly increase the capital project costs and on-going maintenance. A greater volume of work would need to take place in proximity to live conductors, raising avoidable health and safety risk when compared with alternative options. Option EDN-9 was therefore discounted as it did not pass the benefits filter on the basis that there would be greater capital costs for no additional benefits over similar alternative options.
- EDN-10 – This option would trigger an additional double-circuit from Willington and Ratcliffe for the same boundary uplift as EDN-2 Chesterfield to Willington. Overall, option EDN-10 was discounted as it did not pass the technical filter as the complexity for system access is increased through this option and temporary diversions of existing overhead lines would need to be created, putting construction timescales at risk.

4.2.13 The remaining options are those considered in this SOR (EDN-1, EDN-2, EDN-3 and EDN-4).

4.2.14 The interaction of the Chesterfield to High Marnham project allows the progression of these options through the new High Marnham 400 kV Substation or new Chesterfield 400 kV Substation and will improve the capacity across B8 through the additional 400 kV circuit. The 3,000 MW provided by the Brinsworth to Chesterfield and Chesterfield to High Marnham projects will also help to provide a solution to the Capability Deficit by also providing impedance reduction, and therefore the full deficit amount will not need to be met to address the need. Overall, the remaining options would address the NOA 'HND essential' status, providing the required reinforcements across the B8 boundary.

4.2.15 The review of the Need Case, as part of the SOR update, generated the revised Capability Deficit of -5,300 MW and the revised Capacity Deficit of -1,169 MW, as presented above. These still show a requirement for an uplift of the B8 boundary, as provided by the project. These Need Case updates do not, consequently, alter the identification of the strategic options discussed in the sections above, nor the narrowing of the options to those taken forward to the subsequent options appraisal – EDN-1, EDN-2, EDN-3 and EDN-4.

5. Options Assessment Process

5.1.1 National Grid has published 'Our Approach to Consenting', which sets out how we develop our strategic proposal. We apply the following approach to evaluate options we take forward.

5.1.2 Firstly, we identify if our existing network could be modified or enhanced to deliver the required connection or increase in capacity.

5.1.3 If we identify there is a need that is beyond the capability of our existing network, as clearly set out in our project need case, we consider strategic options to provide the required increase in capacity.

5.1.4 We apply a technical filter as part of this assessment to ensure any solution meets the need, either individually or as part of a wider group of reinforcements. There are many ways to achieve increases to our network capability. To allow us to focus on those that best meet our obligations to the environment and consumers, we apply a 'benefits filter', which ensures any option we present has a comparable benefit over an alternative. The criteria for an option to be considered are any of the following:

- environmental benefit;
- technical system benefit; or
- capital and lifetime circuit cost benefit.

5.1.5 Where options are very closely aligned across benefits, then options will be included for appraisal to ensure we capture possible solutions that are of very similar capability.

5.1.6 All options taken forward for appraisal are evaluated in respect of environmental constraints, socio-economic effects, technology alternatives, and capital and lifetime circuit costs. Undertaking this appraisal ensures stakeholders can see how we have made our judgments and balanced the relevant factors in accordance with our legal duties.

5.1.7 The high-level technical, environmental and socio-economic assessment of each option considered a minimum 2 km study area around the strategic option identified, but which was extended to 10 km in certain instances where considered appropriate/necessary in view of particular receptors, for example Special Protection Areas (SPAs) and World Heritage Sites.

5.1.8 The assessment process considers the following areas:

- Environmental assessment topics which consider whether there are environmental constraints or issues of sufficient importance to influence decision making at a strategic level, having particular regard for internationally or nationally important receptors.
- Socio-economic topics which consider whether there are socio-economic constraints or issues of sufficient importance to influence decision making at a strategic level, having particular regard for internationally or nationally important receptors.

- Consideration of technical benefits includes whether the option is providing the required capacity to meet the need case; whether the option has particular system benefits over alternatives; and whether the option introduces any system complexity that would cause system operability issues.
- Capital and lifetime circuit costs consider a range of factors, which are listed below:
  - capital cost of the substation and wider works;
  - capital cost of the circuit costs for each technology appraised; and
  - lifetime circuit costs, including circuit capital cost, cost of losses over 40 years and cost of operation over 40 years.

5.1.9 When considering each strategic option, National Grid provides circuit cost information for the following technology options for all land-based options:

- 400 kV alternating current (AC) overhead line;
- 400 kV AC underground cable;
- 400 kV AC gas insulated line (GIL); and
- 525 kV HVDC underground cable and converter stations.

5.1.10 When considering each strategic option, where relevant, we provide circuit cost information for the following technology options for all subsea-based options:

- 400 kV AC subsea cable; and
- 525 kV HVDC subsea cable and converter stations.

5.1.11 A full evaluation of technologies and costs used in our assessments can be found in the appendices.

5.1.12 In this appraisal, all options are considered using information appropriate to this stage of their development on the assumption that they are deliverable in a reasonable timescale. Timescales and deliverability would only be considered further in the assessment process should they become differentiating factors in the selection of the option that best meets our environmental and legal obligations. If these issues of delivery timescales and risk do become differentiating factors in selection of an option, the issue would be set out clearly in the options conclusion. If it is not differentiating, the factor will not be considered further for this assessment.

5.1.13 At the initial appraisal stage, we prepare indicative estimates of the capital costs. These indicative estimates are based on the high-level scope of works defined for each strategic option in respect of each technology option that is considered to be feasible. As these estimates are prepared before detailed design work has been carried out, we make equivalent assumptions for each option. Final project costs for any solution taken forward following detailed design, consenting and risk mitigation will be in excess of any high-level appraisal cost. However, all options would incur these increases proportional to the initial estimate in the development of a detailed solution. This methodology ensures that all options for appraisal proposals are compared on a like-for-like basis.

5.1.14 Strategic options are identified at a very high level as being electrical solutions between geographic points. Therefore, the potential circuit lengths are derived by taking a straight line distance between the points and adding 20 per cent to accommodate potential route deviations that might be required if the route proceeds forward to more detailed routeing and siting. Where a clear obstacle exists, such as an estuary, water course or geographical feature, an alternative route length will be derived and explained in the option. Where an offshore alternative is presented, straight lines will be used to a midpoint offshore and 20 per cent added to provide variation in route length.

5.1.15 These initial option lengths do not define route corridors, and environmental appraisal is provided over a wide study area between points of connection. Any routes for circuit technologies to take would be subject to detailed routeing and siting for any strategic option taken forward as a preferred option(s).

5.1.16 The options in the following sections of this report have been taken forward in this document as they meet the need case and have been selected using the methodology set out above.

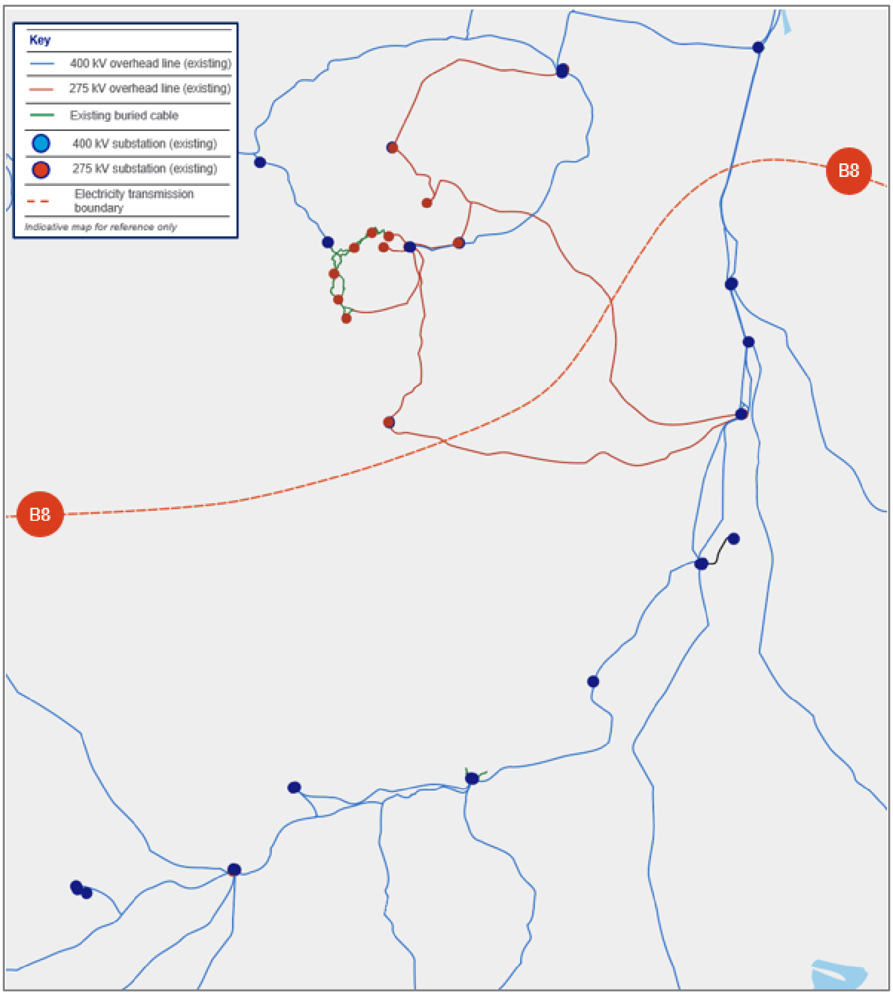
6. Strategic Options Overview

6.1 Introduction

6.1.1 As described in section 3 above, the transmission system needs reinforcement to ensure on-going System Security and Quality of Supply Standard (SQSS) compliance as the volume of generation connecting in the area and demand increases.

6.1.2 **Image 6.1** shows the transmission network in the East Midlands region. This includes existing boundaries, and the B8 boundary, which the options in this report address.

Image 6.1: Considered East Midlands transmission system and boundary B8



6.2 Connection Options Considered for Detailed Appraisal

6.2.1 In line with Our Approach to Consenting, this SOR is designed to test the assumptions and interim conclusions made to date based on the latest information available.

6.2.2 As described in section 3, following a review of the ETYS, a revised need case was adopted to reflect identified changes. Although this did not impact our initial options analysis, several of the options were discounted at this stage because they no longer met the need case.

6.2.3 The reasons for discounting these options are described below:

- EDN-5 – New Chesterfield 400 kV Substation to Stoke Bardolph 400 kV Substation – Stoke Bardolph Substation would need to be reconfigured significantly to accommodate the connection of the overhead line. Further, there is only one double 400 kV circuit south of Stoke Bardolph, therefore this option would trigger the requirement for a further circuit. The Stoke Bardolph Substation also lies in a flood plain and the overhead line route would present visual impact issues to Sherwood Forest as well as impact on the Nottingham urban area. Overall, EDN-5 was discounted as it does not connect back to the main transmission system and therefore does not meet the need case.
- EDN-6 – New Chesterfield 400 kV Substation to Staythorpe 400 kV Substation – Terminating the route at Staythorpe would require a further double-circuit to be created further south of the network. Overall, EDN-6 was discounted as it would require additional infrastructure to meet the project need case.

6.2.4 Several of the long list of options were also excluded from further assessment after application of technical and benefits filters as outlined below:

- EDN-7 – New Chesterfield 400 kV Substation to Drakelow 400 kV Substation – Options terminating at Drakelow require an additional 10 km of overhead line and offer less electrical benefit, when compared to terminating the overhead line at Willington. Option EDN-7 was therefore discounted as it did not pass the benefits filter on the basis that there would be greater capital costs for no benefit over similar alternative options. Additionally, it does not provide sufficient technical benefits over options that terminate at Willington and consequently does not pass the technical filter.
- EDN-8 – New High Marnham 400 kV Substation to Drakelow 400 kV Substation – Options terminating at Drakelow require an additional 10 km of overhead line and offer less electrical benefit, when compared to terminating the overhead line at Willington. Option EDN-8 was therefore discounted as it did not pass the benefits filter on the basis that there would be greater capital costs for no benefit over similar alternative options. Additionally, it does not provide sufficient technical benefits over options that terminate at Willington and consequently does not pass the technical filter.
- EDN-9 – Double-circuit overhead line from the new Chesterfield 400 kV Substation to the new 400 kV Substation between Willington-Drakelow Route – Creation of a new substation and turning in multiple circuits would significantly increase the capital project costs and on-going maintenance. A greater volume of work would need to take place in proximity to live conductors, raising avoidable health and safety risk when compared with alternative options. Option EDN-9 was therefore discounted as it did not pass the benefits filter on the basis that there would be greater capital costs for no additional benefits over similar alternative options.
- EDN-10 – Double Turn In of overhead line from Willington-Ratcliffe-on-Soar at the new Chesterfield 400 kV Substation – This option would trigger an additional double-circuit from Willington and Ratcliffe for the same boundary uplift as EDN-2 Chesterfield to Willington. Overall, option EDN-10 was discounted as it did not pass the technical filter as the complexity for system access is increased through this option and temporary diversions of existing overhead lines would need to be created, putting construction timescales at risk.

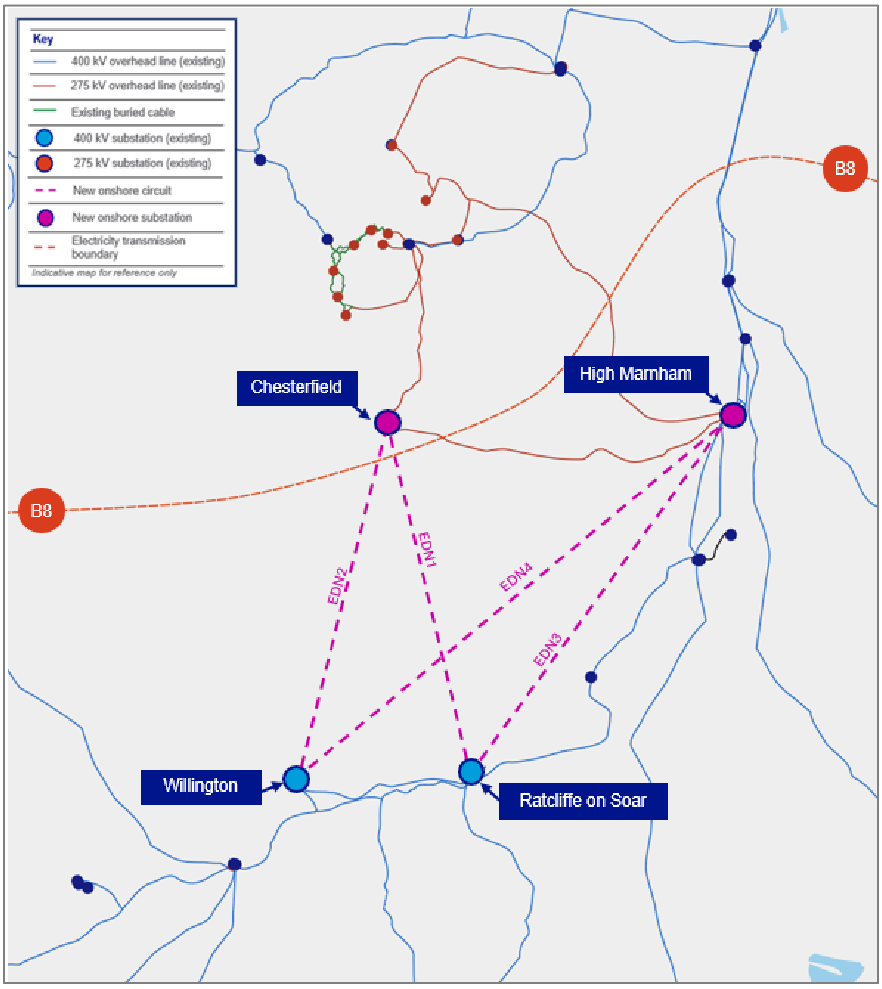
6.3 Options for Strategic Options Assessment

6.3.1 This report considers those options that continue to meet the need case (as updated during the SOR update) outlined in section 3 and have not been discounted based on the technical or benefits filter. These are listed below and are shown on **Image 6.2**.

- EDN-1 – Chesterfield to Ratcliffe-on-Soar (48 km);
- EDN-2 – Chesterfield to Willington (51 km);
- EDN-3 – High Marnham to Ratcliffe-on-Soar (61 km); and
- EDN-4 – High Marnham to Willington (78 km).

6.3.2 The remaining options are enabled through the interaction with the Chesterfield to High Marnham project through the improved capacity across B8. The Brinsworth to Chesterfield and Chesterfield to High Marnham projects also provide an additional 3,000 MW, which helps to provide a solution to the -5,300 MW Capability Deficit as identified in the updated need case and also reduces impedance, therefore the full -5,300 MW will not need to be met. Overall, the remaining options would address the NOA 'HND essential' status, providing the required reinforcements across the B8 boundary.

Image 6.2: Options considered



6.4 Updated Costs

6.4.1 The costs for options included within this report have been updated to account for the latest information and are provided in a 2020/2021 price base. The methodology we have used is set out in **Appendix D.**

6.5 Study Areas / Environmental and Socio-Economic Appraisals

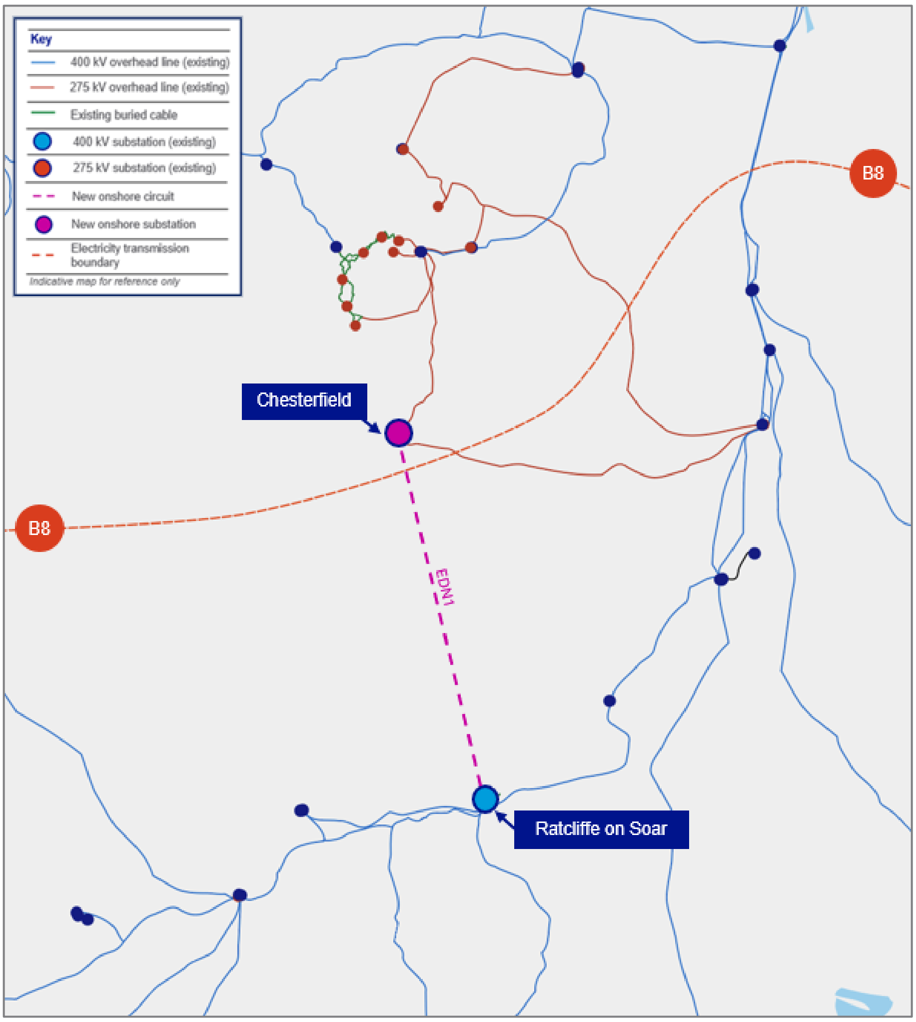
6.5.1 Plans showing the onshore study areas used for the environmental and socio-economic appraisal are included in **Appendix G**.

7. EDN-1 – Chesterfield to Ratcliffe-on-Soar

7.1 Introduction

7.1.1 Strategic option EDN-1 involves the construction of a new transmission circuit connection between a new Chesterfield 400 kV Substation and the existing Ratcliffe 400 kV Substation following a route between Derby and Nottingham. It has a route length of approximately 48 km, as shown in **Image 7.1**.

Image 7.1: Option EDN-1 Chesterfield to Ratcliffe-on-Soar



7.2 Environmental Appraisal

Landscape and Visual

7.2.1 There are a number of built-up areas within the study area for EDN-1.

7.2.2 Developed areas are concentrated around the larger settlements of Derby and Nottingham. There are also a number of smaller towns and villages.

7.2.3 There are no landscape designations or National Trails along EDN-1 or within 2 km of the study area. Option EDN-1 passes through/very close to a number of settlements and villages. The Peak District National Park is located approximately 9 km west of the existing substation at Chesterfield, therefore there is potential for the overhead line to be visible from elevated locations within the National Park. However, there would be opportunities through more detailed routeing and design to reduce the potential for adverse landscape and visual effects.

Historic Environment

7.2.4 There are a number of designated heritage assets within the study area for EDN-1, including one Registered Park and Garden, scheduled monuments and listed buildings.

7.2.5 Grade I and Grade II* listed buildings are in close proximity to option EDN-1, with Kingston Park Pleasure Gardens Registered Park and Garden located approximately 1.74 km to the south of Ratcliffe-on-Soar Substation.

7.2.6 There are also six scheduled monuments present within the study area, with Derwent Valley Mills World Heritage Site located 8.4 km from the centre line of EDN-1.

7.2.7 Whilst these designations should be possible to avoid through the routeing and siting process, there is the potential for adverse effects on the setting of these heritage assets, depending on routeing.

Ecology

7.2.8 Whilst defining a route is outside the scope of this strategic stage, the option would likely be close to the Peak District Moors (South Pennine Moors Phase 1) SPA and South Pennine and Peak District Moors Important Bird Area (IBA), both located approximately 9 km west of the existing substation at Chesterfield, as well as the Sherwood Forest IBA, located north of Nottingham. There is potential for direct effects on breeding, overwintering, and passage bird species (collision risk) that are qualifying / interest features of these designations.

7.2.9 Other ecological designated sites within the study area for the EDN-1 option include Lockington Marshes Site of Special Scientific Interest (SSSI), Duckmanton Railway Cutting SSSI, Attenborough Gravel Pits SSSI, Robbinetts SSSI and Bagthorpe Meadows SSSI, as well as several Local Nature Reserves, and parcels of ancient woodland.

7.2.10 Whilst these designations are avoidable, depending on technical, cost and further routeing considerations, there is the potential for adverse effects on the interest features (both habitats and species) for which a number of these sites are designated. Based on the information available at this stage of the project’s development, it is considered that a route could potentially be identified at the routeing and siting stage that would reduce the level of risk to these designated sites, although this will require further appraisal at the next stage of the process.

Physical Environment

7.2.11 The River Trent runs adjacent to the Ratcliffe-on-Soar Substation from west to east, which would intersect any route from Chesterfield to Ratcliffe-on-Soar. The overhead line would therefore need to cross the river and associated areas of Flood Zones 2 and 3.

7.2.12 The project should be designed to ensure infrastructure is placed within the lowest areas of flood risk possible in accordance with National Policy including the National Planning Policy Framework (NPPF) and National Policy Statements EN-1 and EN-5.

7.2.13 A direct route would intersect the city of Nottingham. To avoid Nottingham, urban areas to the north of Nottingham, and the Sherwood Forest IBA, a route to the east of Nottingham would be preferred.

7.2.14 At this stage of the project's development, it is considered that with appropriate mitigation, potential adverse effects on watercourses and flood risk can be reduced / avoided.

7.2.15 Following SOR review and update, no new or amended information has been identified for the environmental appraisal and the original conclusions therefore remain unchanged.

7.3 Socio-Economic Appraisal

Settlements and Populations

7.3.1 There are a number of settlements and urban dwellings within the study area for EDN-1. These include Pilsley, Tibshelf, Blackwell, South Normanton, Broadmeadows, Westwood, Brinsley, Bailey Grove, Eastwood, New Eastwood, Ilkeston, Larklands, Gallows Inn, Stapleford, and Long Eaton.

7.3.2 There would likely be some temporary minor adverse effects on local noise receptors during construction; however, mitigation would be expected to help to reduce adverse noise impacts. There is the possibility of operational noise effects. However, these effects could be resolved through appropriate routeing and siting.

Tourism and Recreation

7.3.3 There are several tourism and recreation facilities located within the study area including Ilkeston Town Football Club, Archers Field Recreation Ground, and a number of publicly accessible areas of green space.

7.3.4 Adopting appropriate routeing and siting should be able to ensure that impacts are avoided or reduced.

Land Use

7.3.5 The Ratcliffe connection node sits within the East Midlands Freeport (EMF) site and is constrained from all sides by its boundaries. The EMF includes the former Ratcliffe-on-Soar Coal Power Station, owned by Uniper. Coal generation ceased on 30 September 2024. It is understood that decommissioning of the site is expected to last until March 2026, with demolition planned for 2029 – 2030. The coal power station's closure marks the initiation of its redevelopment phase under the UK government's 2022 Freeports Programme initiative.

7.3.6 Rushcliffe Borough Council has prepared a Local Development Order (LDO) for the site, outlining a planning framework and masterplan which was approved in July 2023. The future development emphasis includes energy production, manufacturing, and industry. Retention of existing National Grid assets is specified in the LDO. Within documentation submitted to the Council in September 2025, a phasing plan sets out that redevelopment is expected to take place over a 15-plus year period, commencing 2025. At the time of writing this report, Rushcliffe Borough Council undertook a consultation ending 6 January 2026[26] which according to their website would assess changes to the LDO to include development of data centres in the southern part of the site. Following this a full review of the LDO is planned to take place in summer 2026.

7.3.7 The prevalence of EMF status and the approved LDO provides a potential land use constraint as it means that actions contrary to these plans carry a high risk of socio-economic impacts.

Infrastructure

7.3.8 There are a number of transport networks and facilities located within the study area. This includes one motorway, the M1, and other roads including the A617, A6175, A38, A610, A6096, A609, A52, and the A6005.

7.3.9 Option EDN-1 also crosses multiple railway networks including the Leicester to Nottingham Line, Nottingham to Derby Line, Nottingham to Sheffield Line, and Nottingham to Worksop Line.

7.3.10 Construction works could lead to temporary disruption to these networks due to increased construction traffic. However, it is expected that such impacts could be avoided through appropriate routeing and siting alongside standard construction control measures. It is anticipated that there would be no additional adverse residual impacts on transport networks following the construction phase.

7.4 Technical Scope and Costs

7.4.1 This option has been appraised as it meets the technical appraisal requirements of the need case and is compliant with the NETS SQSS.

7.4.2 Technical analysis of this option has identified the following information, including additional details provided as part of the SOR update.

- EDN-1 will connect to a new Chesterfield 400 kV substation. This new substation is proposed to be built as part of the Chesterfield to High Marnham project. These substation works fall outside the scope of this project (instead forming part of the Chesterfield to High Marnham project) and will proceed regardless of the strategic option taken forward in relation to this project.
- It is currently anticipated that the new Chesterfield substation will be consented and delivered as part of this separate National Grid project, distinct from this Project. However, it is possible that it will be decided to also include the new

[26] 25/02015/LDO | Proposed revisions to Ratcliffe on Soar Local Development Order | Uniper UK Ratcliffe On Soar Power Station Green Street Ratcliffe On Soar Nottinghamshire NG11 0EE

Chesterfield Substation works as part of the development consent order (DCO) application for this Project to provide an alternative consenting mechanism to remove reliance on that separate planning application/consent and so mitigate against the risk of delay to the delivery of the Project.

- The Chesterfield site will be sufficient to accommodate the connection of the circuit set out in this option, requiring only two bays.
- Ratcliffe 400 kV Substation is an indoor substation located at the Ratcliffe Coal Fired Power Station. Operation of the power station ceased in 2024.
- The wider power station is owned by Uniper. NGET's existing land rights are limited to leasehold of the existing 132 kV and 400 kV substation land parcels and the overhead line pylons within the power station.
- An LDO is in place to redevelop the power station site as part of the EMF redevelopment, Further details on the LDO are presented in paragraphs 7.3.5 and 7.3.6. The EMF redevelopment is significant in size and a government initiative to encourage innovation and job creation. Uniper intend to re-purpose the site for sustainable on-site energy generation and storage, convenient commuting links and public transport connections and good freight connectivity via rail, road and air. They also plan to develop large-scale, low carbon hydrogen production. These activities are expected to support an estimated 7,000–8,000 jobs based around advanced manufacturing and energy uses. As a result, NGET's substation is in an area with a great deal of competing development activity (including the decommissioning of the existing power station and the EMF redevelopment). This creates considerable construction risk for connecting the project at Ratcliffe.
- The connection to Ratcliffe 400 kV Substation is complex from a technical perspective due to the high number of physical constraints in the area surrounding the 400 kV substation.
- This means a new 400 kV double circuit to the Ratcliffe Substation would need to be installed underground in the vicinity. This would add civil engineering complexity and would then require the purchase of significant land rights within the wider site – both temporary and permanent easements – alongside extensive underground cabling costs*.* The purchase of these land rights would require agreement with Uniper.
- The indoor 400 kV substation building would require modification to connect new circuits and asbestos is present. The substation already hosts eight transmission circuits on four sets of double-circuit pylons. Ratcliffe also provides demand connections providing supplies to Nottingham and surrounding areas. With the number of circuits already connected to the site, introducing further circuits will impact the electrical complexity and operation of the site.
- To physically connect into Ratcliffe Substation, either the substation would need to be extended on either side or existing bays within the substation would need to be vacated to re-purpose for the circuit. As mentioned above, expansion of the existing substation is not feasible due to physical site constraints and development of the EMF. Uniper are contracted to re-use their power station bays leaving no available bays for this project.
- Consideration has also been given to connecting at a potential new substation in the Ratcliffe area which is independent of this project. This however, would fail to provide sufficient boundary uplift and therefore is not a feasible alternative.

7.4.3 Paragraph 7.4.2 presents additional technical information that identifies major constraints at Ratcliffe. Consequently EDN-1 faces substantial feasibility challenges, greatly reducing its potential as a viable option.

7.4.4 As set out in section 5, we undertake a cost evaluation of the following four technologies for onshore options evaluation:

- 400 kV AC overhead line;
- 400 kV AC underground cable;
- 400 kV AC GIL; and
- 525 kV HVDC underground cable and converter stations.

7.4.5 Option EDN-1 requires the following transmission works to satisfy the requirements of the SQSS.

- **New circuit requirements**
  - AC options use high capacity double-circuits (two 400 kV AC circuits) with a total capacity of up to 6,930 mega volt ampere (MVA).
  - HVDC options use 525 kV 2 GW voltage source links, which would require a convertor station at each end similar in size to a large warehouse. A 6 GW connection would require three convertor stations at each end, to come close to matching the AC high capacity circuits of 6,930 MVA.
- **Substation works**
  - modification of the existing Ratcliffe Substation to make two new circuit connections to new substation bays either side of the site; and
  - two new connection bays at the new Chesterfield 400 kV Substation.

7.4.6 **Table 7.1** sets out the capital costs for option EDN-1 considering substation works and each technology option.

7.4.7 It should be noted that costs to mitigate constraints at Ratcliffe, as discussed in 7.4.2, are not included in **Table 7.1** as this is outside the SOR methodology, where asset-level costs are presented, applying 100% technologies across all comparators. Further information however is presented and discussed in section 11.

Table 7.1: The capital costs for option EDN-1 considering substation works and each technology option*

Item	Need	EDN-1 Capital Cost			
Substation Works	Facilitate generation and connect new circuits	£26.5m			
New Circuits		**AC Overhead Line**	**AC Cable**	**AC GIL**	**HVDC**
New Circuit 48 km	New Circuit across B8	£191.0m	£2,038.0m	£2,076.5m	£2,048.1m
Total Capital Cost		**£217.5m**	**£2,064.5m**	**£2,103.0m**	**£2,074.6m**

** Costs that are included and not included are detailed in 7.4.5 and 7.4.7*

Note: Substation costs are sensitive to varying inflation indices and are therefore indicative costs calculated at a point in time.

7.4.8 **Table 7.2** sets out the lifetime circuit cost for the new circuit technology options. The lifetime circuit costs are different for each circuit technology and are included as a differentiator between technologies. These costs are calculated using the methodology described in **Appendix D**.

Table 7.2: EDN-1 lifetime circuit cost summary

	EDN-1 AC Overhead Line	EDN-1 AC Cable	EDN-1 AC GIL	EDN-1 HVDC
Capital Cost of New Circuits	£191.0m	£2,038.0m	£2,076.5m	£2,048.1m
Net Present Value (NPV) of cost of losses over 40 years	£134.6m	£96.8m	£62.5m	£471.2m
NPV of operation & maintenance costs over 40 years	£2.8m	£8.6m	£2.8m	£171.8m
Lifetime circuit cost of new circuits	**£328m**	**£2,143m**	**£2,142m**	**£2,691m**

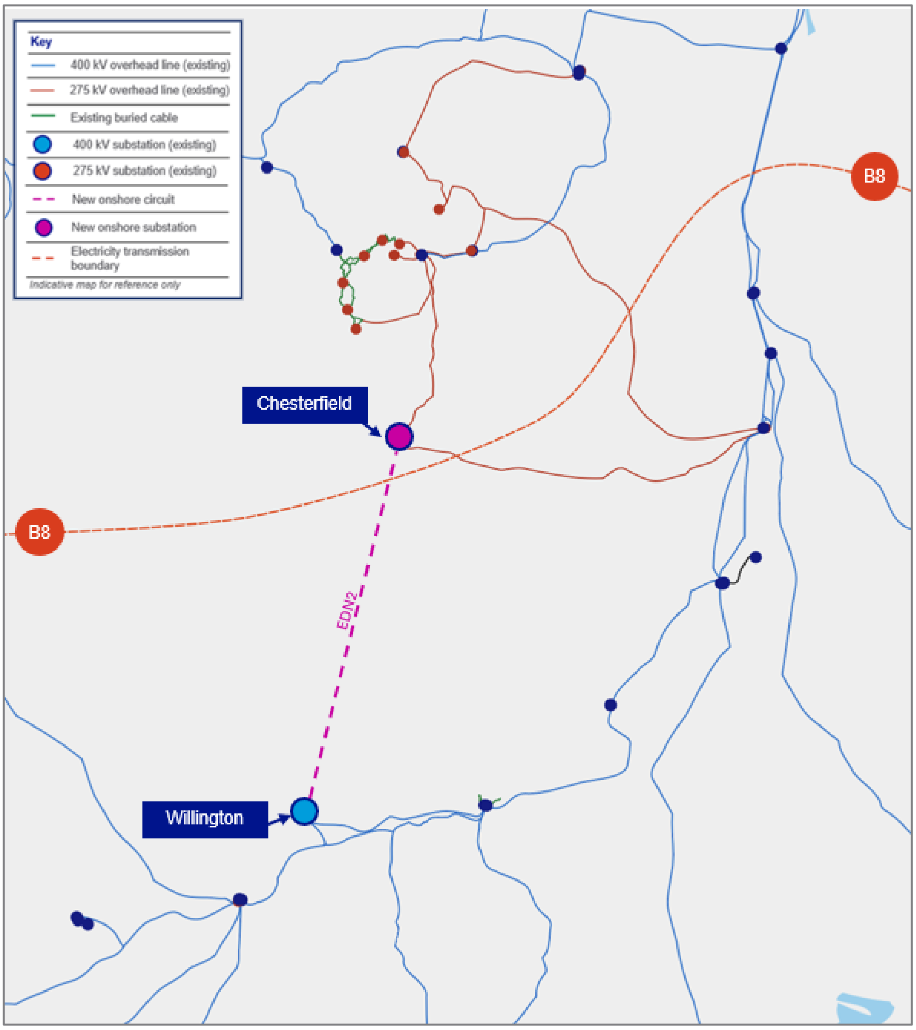
7.4.9 Based on the above environmental, socio-economic and technical appraisal, alongside capital and circuit lifetime circuit costs, the preferred option for EDN-1 is a 48 km AC connection between a new Chesterfield Substation and the existing Ratcliffe Substation. In light of this analysis, our starting presumption for further development of this option, should it be selected, would be for a majority overhead line connection.

8. EDN-2 – Chesterfield to Willington

8.1 Introduction

8.1.1 Option EDN-2 involves the construction of a new 400 kV transmission double-circuit connection between a new Chesterfield 400 kV Substation and the existing Willington 400 kV Substation, with a route length of approximately 51 km as shown in **Image 8.1**.

Image 8.1: Option EDN-2 Chesterfield to Willington



8.2 Environmental Appraisal

Landscape and Visual

8.2.1 There are a number of settlements of various sizes within the study area, with developed areas concentrated around the larger settlements of Derby, Chesterfield and Clay Cross. The Peak District National Park is located approximately 9 km west of the existing substation at Chesterfield, therefore there is potential for the overhead line to be visible from elevated locations within this landscape designation. However, there would be opportunities through more detailed routeing and design to reduce the potential for adverse landscape and visual effects.

8.2.2 To reduce impacts to the Peak District National Park and the Derwent Valley Mills World Heritage Site, a route to the east of Derby would be preferred.

Historic Environment

8.2.3 There are a number of designated heritage assets within the study area for EDN-2 including four Registered Parks and Gardens, and a number of scheduled monuments and listed buildings. Whilst these designations should be possible to avoid through the routeing and siting process, there is the potential for adverse effects on the setting of these heritage assets.

8.2.4 Whilst defining a route is outside the scope of this strategic stage, a direct route between the Chesterfield and Willington Substations would intersect the Derwent Valley Mills World Heritage Site, running from Matlock (west) to Derby (east). There is potential for direct impacts to this designated heritage asset and its setting depending on routeing.

8.2.5 Based on the information available at this strategic stage, it is considered that a route could be identified that runs to the east of Derby, to reduce/avoid adverse impacts to this site and its setting. Further assessment would be undertaken at an appropriate stage, and any further relevant mitigation would be proposed.

Ecology

8.2.6 There are a number of ecological constraints within the study area for EDN-2, including the Peak District Moors (South Pennine Moors Phase 1) SPA, and the South Pennine and the Peak District Moors IBA, 9 km to the west of the existing substation at Chesterfield. There is potential for direct effects on breeding, overwintering and passage bird species (collision risk) that are qualifying/interest features of these designations.

8.2.7 Other designated sites in the study area include Kedleston Park SSSI, Cromford Canal SSSI, Crich Chase SSSI, Ogston Reservoir SSSI, Ambergate and Ridgeway Quarries SSSI and Duckmanton Railway Cutting SSSI, as well as several Local Nature Reserves and parcels of ancient woodland. Whilst these designations are avoidable, there is the potential for adverse effects on the interest features (both habitats and species) for which a number of these sites are designated.

8.2.8 Further consideration will be needed at the routeing stage to reduce potential risks. Based on the information available at this stage of the project’s development, it is considered that a route could potentially be identified at the routeing and siting stage that would reduce the level of risk to these designated sites, although this will require further appraisal at the next stage of the process.

Physical Environment

8.2.9 The River Derwent would intersect any route from Chesterfield to Willington. The overhead line would therefore need to cross the river and associated areas of Flood Zones 2 and 3.

8.2.10 The project should be designed to ensure infrastructure is placed within the lowest areas of flood risk possible in accordance with National Policy, including the NPPF and National Policy Statements EN-1 and EN-5. At this stage of the project's development, it is considered that with appropriate mitigation, potential adverse effects on watercourses and flood risk can be reduced / avoided.

8.2.11 Following SOR review and update, no new or amended information has been identified for the environmental appraisal and the original conclusions therefore remain unchanged.

8.3 Socio-Economic Appraisal

Settlements and Populations

8.3.1 There are a number of built-up areas within the study area for EDN-2.

8.3.2 Developed areas are concentrated around the larger settlements of Derby, Chesterfield and Clay Cross. There are also a number of smaller towns and villages within the study area including Grassmoor, Tupton, Wessington, Ambergate, Belper and Willington.

8.3.3 There would likely be some temporary minor adverse effects on local noise receptors during construction; however, mitigation would be expected to help reduce adverse noise impacts. There is the possibility of operational noise effects; however, these effects could be resolved through appropriate routeing and siting. It is anticipated that a route for this option could be routed to the east of Derby.

Tourism and Recreation

8.3.4 There are a number of community facilities and tourist attractions within the study area. This includes two areas of National Trust land (Duffield Castle and Kedleston Hall), several major visitor attractions (including the Great British Car Journey Museum), and recreation grounds and areas of publicly accessible green space.

8.3.5 Adopting appropriate routeing and siting should be able to ensure that impacts are avoided or reduced.

Land Use

8.3.6 There are two areas of National Trust land within the study area, Duffield Castle and Kedleston Hall.

8.3.7 It should be possible for EDN-2 to route around the National Trust land and therefore to avoid direct impacts. Impacts to the settings of the two areas of National Trust land may continue into operation depending on the routeing of the overhead lines.

Infrastructure

8.3.8 There are a number of transport networks and facilities located within the study area. This includes the A617, A61, A610, A6, A52, A38, and the A50.

8.3.9 Option EDN-2 crosses multiple railway networks including the Tutbury and Hatton to Derby railway line, the Castle Donington freight railway line, Burton upon Trent to Derby railway line, Derby to Chesterfield railway line, Derby to Matlock railway line and Alfreton to Chesterfield railway line. Construction works could lead to temporary disruption to these networks due to increased construction traffic. However, it is expected that such impacts could be avoided through appropriate routeing and siting alongside standard construction control measures. It is anticipated that there would be no additional adverse residual impacts on transport networks following the construction phase.

8.3.10 Following SOR review and update, no new or amended information has been identified for the socio-economic appraisal and the original conclusions therefore remain unchanged.

8.4 Technical Scope and Costs

8.4.1 This option has been appraised as it meets the technical appraisal requirements of the need case and is compliant with the NETS SQSS.

8.4.2 Technical analysis of this option has identified the following information, including additional details provided as part of the SOR update.

- EDN-2 will connect to a new Chesterfield 400 kV substation. This new substation is proposed to be built as part of the Chesterfield to High Marnham project. These substation works fall outside the scope of this project, instead forming part of the Chesterfield to High Marnham project, and will proceed regardless of the strategic option taken forward in relation to this project.
- It is currently anticipated that the new Chesterfield Substation will be consented and delivered as part of this separate National Grid project, distinct from this Project. However, it is possible that it will be decided to also include the new Chesterfield Substation works as part of the DCO application for this Project to provide an alternative consenting mechanism to remove reliance on that separate planning application/consent and so mitigate against the risk of delay to the delivery of the Project.
- The Chesterfield site will be sufficient to accommodate the connection of the circuit set out in this option, requiring only two bays.
- Willington is an existing 400 kV substation located to the south of Derby. Physical constraints at the Willington site are low due to the availability of space within the existing site for expansion to make the connection.
- Electrically there is an opportunity to rationalise existing circuits linking Chesterfield and Willington and to provide a route for the new 400 kV circuit infrastructure via an existing overhead line corridor in the vicinity of Willington.
- Following the SOR update re-evaluation process, no issues were identified with the bay requirements at Chesterfield or Willington Substations, nor with physical constraints or technical complexities that would alter the strategic technical analysis.

8.4.3 As set out in section 5, we undertake a cost evaluation of the following four technologies for onshore options evaluation.

- 400 kV AC overhead line;
- 400 kV AC underground cable;
- 400 kV AC GIL; and

- 525 kV HVDC underground cable and converter stations.

8.4.4 Option EDN-2 requires the following transmission works to satisfy the requirements of the SQSS.

- **New circuit requirements**
  - AC connections options use high capacity double-circuits (two 400 kV AC circuits) with a total capacity of up to 6,930 MVA.
  - HVDC connection options use 525 kV 2 GW voltage source links, which would require a convertor station at each end similar in size to a large warehouse. A 6 GW connection would require three convertor stations at each end, to come close to matching the AC high-capacity circuits of 6,930 MVA.
- **Substation works**
  - two new connection bays at the new Chesterfield 400 kV Substation; and
  - two-bay extension to the existing Willington 400 kV Substation.

8.4.5 **Table 8.1** sets out the capital costs for option EDN-2 considering substation works and each technology option.

Table 8.1: The capital costs for option EDN-2 considering substation works and each technology option*

Item	Need	EDN-2 Capital Cost			
Substation works	Facilitate generation and connect new circuits	£17.6m			
New Circuits		**AC Overhead Line**	**AC Cable**	**AC GIL**	**HVDC**
New circuit 51 km	New circuit across B8	£203.0m	£2,176.2m	£2,206.3m	£2,075.9m
Total capital cost		**£220.6m**	**£2,193.8m**	**£2,223.9m**	**£2,093.5m**

** Costs that are included are presented in 8.4.4*

Note: Substation costs are sensitive to varying inflation indices and are therefore indicative costs calculated at a point in time.

8.4.6 **Table 8.2** sets out the lifetime circuit cost for the new circuit options. The lifetime circuit costs are different for each circuit technology and are included as a differentiator between technologies. These costs are calculated using the methodology described in **Appendix D**.

Table 8.2: EDN-2 lifetime circuit cost summary

	EDN-2 AC Overhead Line	EDN-2 AC Cable	EDN-2 AC GIL	EDN-2 HVDC
Capital cost of new circuits	£203.0m	£2,176.2m	£2,206.3m	£2,075.9m
NPV of cost of losses over 40 years	£143.1m	£99.4m	£66.4m	£471.2m
NPV of operation & maintenance costs over 40 years	£3.0m	£9.8m	£3.0m	£171.8m
Lifetime circuit cost of new circuits	**£349m**	**£2,285m**	**£2,276m**	**£2,719m**

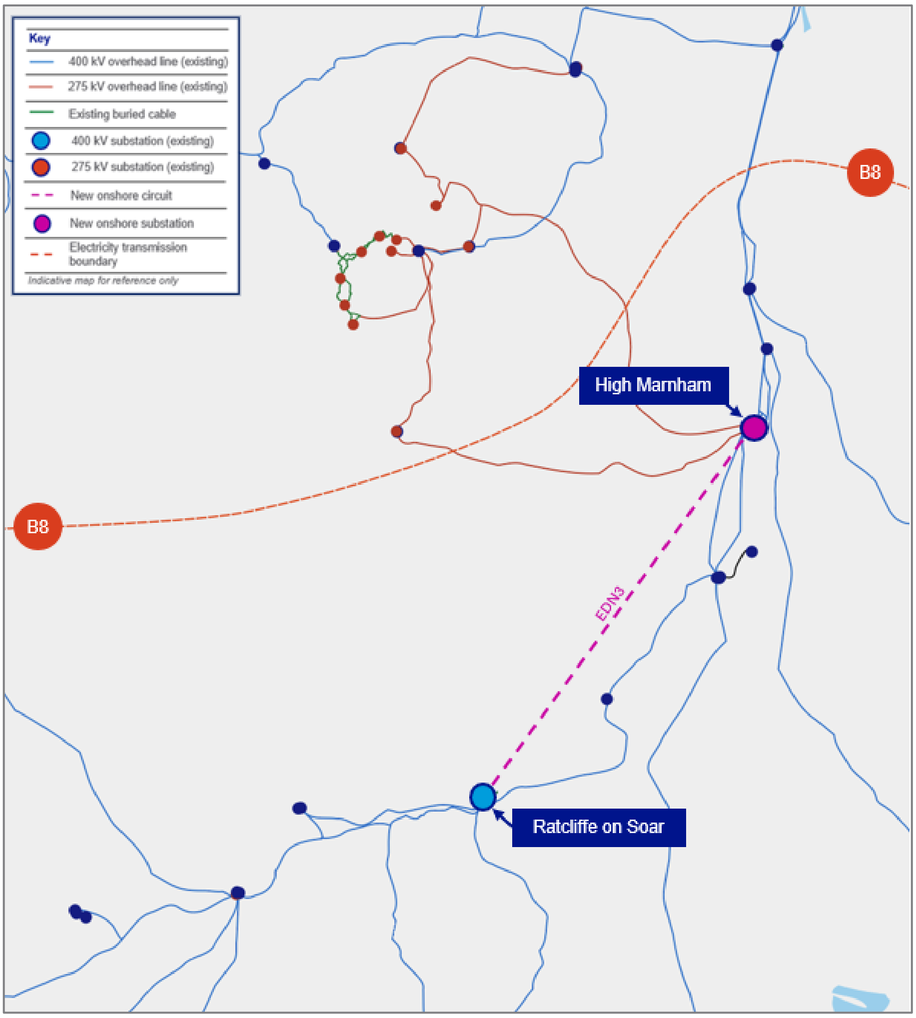
8.4.7 Based on the above environmental, socio-economic and technical appraisal, alongside capital and circuit lifetime circuit costs, the preferred option for EDN-2 is a 51 km connection between a new Chesterfield Substation and the existing Willington Substation and would be an AC circuit. In light of this analysis, our starting presumption for further development of this option, should it be selected, would be for a majority overhead line connection.

9. EDN-3 – High Marnham to Ratcliffe-on-Soar

9.1 Introduction

9.1.1 Option EDN-3 involves a new High Marnham 400 kV substation and the connection of new transmission circuit connections between this new High Marnham 400 kV Substation and the existing Ratcliffe 400 kV Substation, with a route length of approximately 61 km as shown in **Image 9.1**.

Image 9.1: Option EDN-3 High Marnham to Ratcliffe-on-Soar



9.2 Environmental Appraisal

Landscape and Visual

9.2.1 There are a number of settlements of various sizes within the study area, with developed areas concentrated around the city of Nottingham. There are also a number of smaller towns and villages.

9.2.2 There are no landscape designations or National Trails along EDN-3 or within the study area. The Peak District National Park is located approximately 35 km to the north west of Ratcliffe Substation, and due to the distance to the strategic option being over 10 km, no landscape or visual impacts are predicted. Option EDN-3 passes through/very close to a number of settlements and villages, therefore there is potential for this strategic option to impact local sensitive visual receptors within the 2 km study area. However, there would be opportunities through more detailed routeing and design to reduce the potential for adverse landscape and visual effects.

Historic Environment

9.2.3 There are a number of designated heritage assets within the study area for EDN-3 including nine Registered Parks and Gardens, a number of scheduled monuments and a number of Grade I and II* listed buildings.

9.2.4 Whilst these designations should be possible to avoid through the routeing and siting process, there is the potential for adverse effects on the setting of these heritage assets, depending on routeing.

Ecology

9.2.5 There are a number of ecological constraints within the study area for EDN-3.

9.2.6 Whilst defining a route is outside the scope of this strategic stage, a direct route between the substations would run close to the Sherwood Forest IBA, located approximately 13 km from High Marnham, comprising 28 km of fragmented habitat from north to south. Depending on routeing, there is potential for direct effects on breeding, overwintering and passage bird species (collision risk) that are qualifying/interest features of this designation. There would, however, be opportunities through more detailed routeing and design to prevent and/or reduce the potential for adverse effects.

9.2.7 In addition to this, there are a number of designated sites and ecological features present in the study area including Holme Pit SSSI, Roe Wood SSSI, Mather Wood SSSI, Attenborough Gravel Pits SSSI, Lockington Marshes SSSI, Gotham Hill Pasture SSSI, Newhall Reservoir Meadow SSSI and Wilwell Cutting SSSI, as well as several parcels of ancient woodland and Local Nature Reserves. Whilst it is likely to be possible to avoid the SSSIs, areas of ancient woodland and Local Nature Reserves, there is potential for indirect adverse effects on the interest features (both habitats and species) for which a number of these sites are designated, depending on routeing.

9.2.8 Based on the information available at this stage of the project’s development, it is considered that a route could be identified at the routeing and siting stage that would reduce the level of risk to these designated sites, although this will require further appraisal at the next stage of the process.

Physical Environment

9.2.9 A direct route would intersect the city of Nottingham. To avoid Nottingham, urban areas to the north of Nottingham, and the Sherwood Forest IBA, a route to the east of Nottingham would be preferred.

9.2.10 The River Trent runs adjacent to the Ratcliffe-on-Soar Substation from west to east, which would intersect any route from High Marnham to Ratcliffe-on-Soar. The overhead line would therefore need to cross the river and areas of Flood Zones 2 and 3. The project should be designed to ensure infrastructure is placed within the lowest areas of flood risk possible in accordance with National Policy including the NPPF and National Policy Statements EN-1 and EN-5.

9.2.11 At this stage of the project's development, it is considered that with appropriate mitigation, potential adverse effects on watercourses and flood risk can be avoided/reduced.

9.2.12 Following SOR review and update, no new or amended information has been identified for the environmental appraisal and the original conclusions therefore remain unchanged.

9.3 Socio-Economic Appraisal

Settlements and Populations

9.3.1 There are 12 settlements within the study area for EDN-3 including Nottingham, Ossington, Normanton-on-Trent, Weston, Woodborough, Barton-in-Fabis, Wilford, West Bridgford, Southwell, Hockerton, Caunton and Maplebeck.

9.3.2 There would likely be some temporary minor adverse effects on local noise receptors during construction; however, mitigation would be expected to help reduce adverse noise impacts. There is the possibility of operational noise effects, although it is anticipated these effects could be resolved through appropriate routeing and siting. It is anticipated that a route for this option could be run to the east of Nottingham.

Tourism and Recreation

9.3.3 There are several tourism and recreation facilities located within the study area including Gedling Country Park, four golf courses, and a number of publicly accessible areas of green space.

9.3.4 Adopting appropriate routeing and siting should be able to ensure that impacts are avoided or reduced.

9.3.5 It should be possible for EDN-3 to route around the National Trust land and therefore to avoid direct impacts.

Land Use

9.3.6 It should be possible for EDN-3 to route around the National Trust Land and therefore to avoid direct impacts.

9.3.7 The Ratcliffe connection node sits within the EMF site and is constrained from all sides by its boundaries. The EMF includes the former Ratcliffe-on-Soar Coal Power Station, owned by Uniper. Coal generation ceased on 30 September 2024. It is understood that decommissioning of the site is expected to last until March 2026, with demolition planned for 2029–2030. The coal power station's closure marks the initiation of its redevelopment phase under the UK government's 2022 Freeports Programme initiative.

9.3.8 Rushcliffe Borough Council has prepared a LDO for the site, outlining a planning framework and masterplan which was approved in July 2023. The future development emphasis includes energy production, manufacturing, and industry. Retention of existing National Grid assets is specified in the LDO. Within documentation submitted to the Council in September 2025, a phasing plan sets out that redevelopment is expected to take place over a 15-plus year period, commencing 2025. At the time of writing this report, Rushcliffe Borough Council undertook a consultation ending 6 January 2026[27] which according to their website would assess changes to the LDO to include development of data centres in the southern part of the site. Following this a full review of the LDO is planned to take place in summer 2026.

9.3.9 The prevalence of EMF status and the approved LDO provides a potential land use constraint as it means that actions contrary to these plans carry a high risk of socio-economic impacts.

Infrastructure

9.3.10 There are a number of transport networks and facilities located within the study area. This includes the A1, A52, A453, A612, A616, A617, A6011, A6097 and A6211.

9.3.11 Option EDN-3 also crosses multiple railway networks including the Spondon to Loughborough railway line, East Midlands Parkway to Long Eaton railway line, East Midlands Parkway to Langley Mill railway line, and multiple railway networks running through Nottingham.

9.3.12 Construction works could lead to temporary disruption to these networks due to increased construction traffic. However, it is expected that such impacts could be avoided through appropriate routeing and siting alongside standard construction control measures. It is anticipated that there would be no additional adverse residual impacts on transport networks following the construction phase.

9.4 Technical Scope and Costs

9.4.1 This option has been appraised as it meets the technical appraisal requirements of the need case and is compliant with the NETS SQSS.

9.4.2 Technical analysis of this option has identified the following information, including additional details provided as part of the SOR update.

- A new High Marnham 400 kV Substation is proposed to be built as part of the Chesterfield to High Marnham substation works to uprate existing 275 kV infrastructure to 400 kV.
- If EDN-3 were to connect to this High Marnham Substation, a total of 11 feeders would connect to High Marnham in addition to the existing circuits. Further

[27] 25/02015/LDO | Proposed revisions to Ratcliffe on Soar Local Development Order | Uniper UK Ratcliffe On Soar Power Station Green Street Ratcliffe On Soar Nottinghamshire NG11 0EE

analysis has shown that adding 11 feeders at High Marnham would exceed the substation's capacity, making this connection unfeasible.

- Therefore, a second new substation would need to be constructed at High Marnham and would be included in the scope of work for EDN-3. It should be noted that this would require further land acquisition, add significant additional cost and would also impact timescales, not only for this project but for other projects connecting there (Chesterfield to High Marnham works and the North Humber to High Marnham project). Costings for this additional substation are presented below in **Table 9.1**, with associated scope presented in paragraph 9.4.6.
- Ratcliffe 400 kV Substation is an indoor substation located at the Ratcliffe Coal Fired Power Station. Operation of the power station ceased in 2024.
- The wider power station is owned by Uniper. NGET's existing land rights are limited to leasehold of the existing 132 kV and 400 kV substation land parcels and the overhead line pylons within the power station.
- A LDO is in place to redevelop the power station site as part of the EMF redevelopment, Further details on the LDO are presented in paragraphs 9.3.7 and 9.3.8. The EMF redevelopment is significant in size and a government initiative to encourage innovation and job creation. Uniper intend to re-purpose the site for sustainable on-site energy generation and storage, convenient commuting links and public transport connections and good freight connectivity via rail, road and air. They also plan to develop large-scale, low carbon hydrogen production. These activities are expected to support an estimated 7,000–8,000 jobs based around advanced manufacturing and energy uses. As a result, NGET's substation is in an area with a great deal of competing development activity (including the decommissioning of the existing power station and the EMF redevelopment). This creates considerable construction risk for connecting the project at Ratcliffe.
- The connection to Ratcliffe 400 kV Substation is complex from a technical perspective due to the high number of physical constraints in the area surrounding the 400 kV substation.
- This means a new 400 kV double circuit to the Ratcliffe Substation would need to be installed underground in the vicinity. This would add civil engineering complexity and would then require the purchase of significant land rights within the wider site – both temporary and permanent easements – alongside extensive underground cabling costs. The purchase of these land rights would require agreement with Uniper.
- The indoor 400 kV substation building would require modification to connect new circuits and asbestos is present. The substation already hosts eight transmission circuits on four sets of double-circuit pylons. Ratcliffe also provides demand connections providing supplies to Nottingham and surrounding areas. With the number of circuits already connected to the site, introducing further circuits will impact the electrical complexity and operation of the site.
- To physically connect into Ratcliffe Substation, either the substation would need to be extended on either side or existing bays within the substation would need to be vacated to re-purpose for the circuit. As mentioned above, expansion of the existing substation is not feasible due to physical site constraints and development of the EMF. Uniper are contracted to re-use their power station bays leaving no available bays for this project.

- Consideration has also been given to connecting at a potential new substation in the Ratcliffe area which is independent of this project. This, however, would fail to provide sufficient boundary uplift and therefore is not a feasible alternative.

9.4.3 To connect the two substations would require the installation of two interconnecting cables that allow both the main and reserve bars at each substation to be linked, as they would be in a conventional large substation.

9.4.4 Paragraph 9.4.2 presents additional technical information that identifies major constraints at Ratcliffe. Consequently, EDN-3 faces substantial feasibility challenges, greatly reducing its potential as a viable option.

9.4.5 As set out in section 5, we undertake a cost evaluation of the following four technologies for onshore options evaluation:

- 400 kV AC overhead line;
- 400 kV AC underground cable;
- 400 kV AC GIL; and
- 525 kV HVDC underground cable and converter stations.

9.4.6 Option EDN-3 requires the following transmission works to satisfy the requirements of the SQSS.

- **New circuit requirements**
  - AC connections options use high-capacity double-circuits (two 400 kV AC circuits) with a total capacity of up to 6,930 MVA.
  - HVDC connection options use 525 kV 2 GW voltage source links, which would require a convertor station at each end similar in size to a large warehouse. A 6 GW connection would require three convertor stations at each end, to come close to matching the AC high-capacity circuits of 6,930 MVA.
- **Substation works**
  - modification of existing Ratcliffe Substation to make two new circuit connections to new substation bays either side of the site; and
  - A new 400 kV substation at High Marnham
  - two additional new bays at the Chesterfield to High Marnham project's new High Marnham substation to connect with the High Marnham substation associated with EDN-3.

9.4.7 **Table 9.1** sets out the capital costs for option EDN-3 considering substation works and each technology option. This includes costings for the additional High Marnham substation discussed in 9.4.2.

9.4.8 It should be noted that costs to mitigate constraints at Ratcliffe, as discussed in 9.4.2, are not included in **Table 9.1** as this is outside of the SOR methodology, where asset-level costs are presented, applying 100% technologies across all comparators. Additional information however is presented and discussed in section 11.

Table 9.1: The capital costs for option EDN-3 considering substation works and each technology option*

Item	Need	EDN-3 Capital Cost			
Substation works	Facilitate generation and connect new circuits	£182.5m			
New circuits		**AC Overhead Line**	**AC Cable**	**AC GIL**	**HVDC**
New circuit 61 km	New circuit across B8	£242.8m	£2,610.0m	£2,638.9m	£2,168.6m
Total capital cost		**£425.3m**	**£2,792.5m**	**£2,821.4m**	**£2,351.1m**

** Costs that are included and not included are detailed in 9.4.6 – 9.4.8*

Note: Substation costs are sensitive to varying inflation indices and are therefore indicative costs calculated at a point in time.

9.4.9 **Table 9.2** sets out the lifetime circuit cost for the new circuit options. The lifetime circuit costs are different for each circuit technology and are included as a differentiator between technologies. These costs are calculated using the methodology described in **Appendix D**.

Table 9.2: EDN-3 lifetime circuit cost summary

	EDN-3 AC Overhead Line	EDN-3 AC Cable	EDN-3 AC GIL	EDN-3 HVDC
Capital cost of new circuits	£242.8m	£2,610.0m	£2,638.9m	£2,168.6m
NPV of cost of losses over 40 years	£171.1m	£126.5m	£79.4m	£471.2m
NPV of operation & maintenance costs over 40 years	£3.6m	£11.7m	£3.6m	£171.9m
Lifetime circuit cost of new circuits	**£417m**	**£2,748m**	**£2,722m**	**£2,812m**

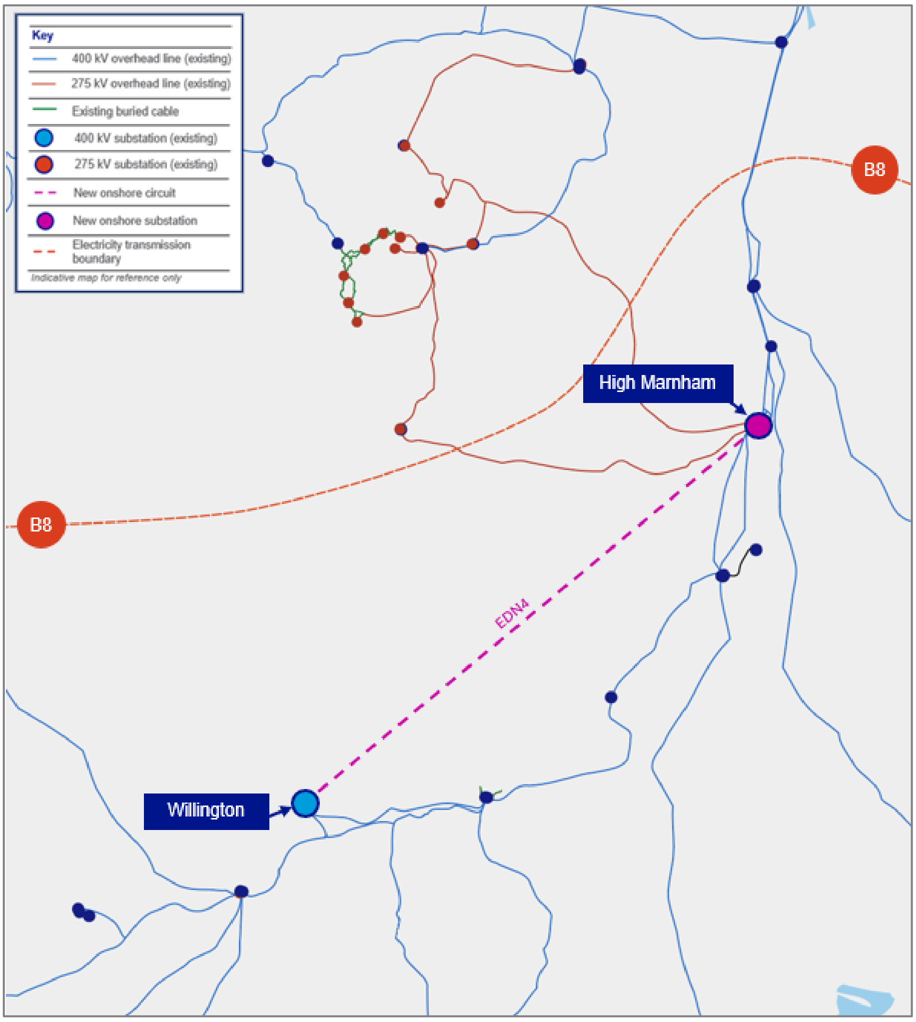
9.4.10 Based on the above environmental, socio-economic and technical appraisal, alongside capital and circuit lifetime circuit costs, the preferred option for EDN-3 is a 61 km connection between a new High Marnham Substation and the existing Ratcliffe-on-Soar substation and would be an AC circuit. In light of this analysis, our starting presumption for further development of this option, should it be selected, would be for a majority overhead line connection.

10. EDN-4 – High Marnham to Willington

10.1 Introduction

10.1.1 Option EDN-4 involves a new High Marnham 400 kV substation and the connection of new transmission circuit connections between this new High Marnham 400 kV Substation and the existing Willington 400 kV Substation with a route length of approximately 78 km as shown in **Image 10.1**.

Image 10.1: Option EDN-4 High Marnham to Willington



10.2 Environmental Appraisal

Landscape and Visual

10.2.1 There are a number of settlements within the study area including the cities of Derby and Nottingham. There are also a number of smaller towns and villages.

10.2.2 Option EDN-4 is constrained in relation to landscape and visual considerations. There is potential for adverse impacts to landscape and visual receptors in the study area. The Peak District National Park is located approximately 28 km to the north west of Willington Substation. There would, however, be opportunities through more detailed routeing and design to reduce the potential for adverse landscape and visual effects.

Historic Environment

10.2.3 Option EDN-4 is constrained in relation to cultural heritage considerations.

10.2.4 The Derwent Valley Mills World Heritage Site is within the study area for this option, located approximately 9 km north east of Willington Substation, running from Matlock (west) to Derby (east). There is potential for direct impacts on this designated heritage asset and its setting depending on routeing. Based on the information available at this stage, it is considered that a route could be identified to the east of Derby, that would reduce or potentially avoid adverse impacts on this designated site. A route east of Derby would run between the cities of Derby and Nottingham, but suitable clearance from both cities should be achievable to minimise impacts.

10.2.5 There are also a number of other designated heritage assets within the study area for EDN-4 including five Registered Parks and Gardens, a number of scheduled monuments and listed buildings. Whilst it should be possible to avoid these sites, there is the potential for adverse effects on the setting of these heritage assets, depending on routeing.

Ecology

10.2.6 Option EDN-4 is constrained in relation to ecological considerations.

10.2.7 A direct route between High Marnham and Willington Substations would cross the Sherwood Forest IBA, with potential for direct effects on breeding, overwintering and passage bird species (collision risk) that are qualifying / interest features of this designation.

10.2.8 In addition to this, there are a number of designated sites and ecological features present in the study area including Redgate Woods and Mansey Common SSSI, Eakring and Maplebeck Meadows SSSI, Laxton Sykes SSSI, Bulwell Wood SSSI, Seller's Wood SSSI, Sledder Wood Meadows SSSI, Robbinetts SSSI, Roe Wood SSSI, as well as a number of parcels of ancient woodland and Local Nature Reserves. Whilst it is likely to be possible to avoid the SSSIs, areas of ancient woodland and Local Nature Reserves, there is potential for indirect adverse effects on the interest features (both habitats and species) for which a number of these sites are designated, depending on routeing.

10.2.9 Based on the information available at this stage of the project's development, it is considered that a route could be identified at the routeing and siting stage that would reduce the level of risk to these designated sites, although this will require further appraisal at the next stage of the process.

Physical Environment

10.2.10 The route would intersect major tributaries of the River Trent including the River Derwent and River Erewash. The overhead line would therefore need to cross the rivers and associated areas of Flood Zones 2 and 3.

10.2.11 The project should be designed to ensure infrastructure is placed within the lowest areas of flood risk possible in accordance with National Policy, including the NPPF and National Policy Statements EN-1 and EN-5. At this stage of the project's development, it is considered that with appropriate mitigation, potential adverse effects on watercourses and flood risk can be reduced or potentially avoided.

10.2.12 Following SOR review and update, no new or amended information has been identified for the environmental appraisal and the original conclusions therefore remain unchanged.

10.3 Socio-Economic Appraisal

Settlements and Populations

10.3.1 There are 11 settlements within the study area for EDN-4 including Farnsfield, Hucknall, Kimberley, Ilkeston, Derby, Nottingham, Weston, Maplebeck, Bestwood Village, Awsworth and Kneesall.

10.3.2 There would likely be some temporary minor adverse effects on local noise receptors during construction; however, mitigation would be expected to help reduce adverse noise impacts. There is the possibility of operational noise effects; however, it is anticipated these effects could be resolved through appropriate routeing and siting. This option would intersect Derby and would therefore need to be routed to the south east of Derby to avoid the city.

Tourism and Recreation

10.3.3 There are five visitor attractions located within the study area for EDN-4, including the Sinfin Golf Course, Pewit Golf Course, City Golf Course, Oakmere Park Golf Course and Shipley Country Park.

10.3.4 Adopting appropriate routeing and siting should be able to ensure that impacts are avoided or reduced.

Land Use

10.3.5 The Willington Power Station is located within the 2 km study area of the strategic option.

10.3.6 Adopting appropriate routeing of the overhead line, and the appropriate selection of sites for construction compounds and working areas, will likely minimise any impacts to the power station.

Infrastructure

10.3.7 There are a number of transport networks and facilities located within the study area. This includes the A1, A6, A50, A52, A609, A610, A614, A616, A617, A5111, A5132, A6097 and M1.

10.3.8 Option EDN-4 also crosses two railway networks, which are the Sutton Bridge to Moor Bridge railway line, Maun Valley line and Matlock to Derby railway line.

10.3.9 Construction works could lead to temporary disruption to these networks due to increased construction traffic. However, it is expected that such impacts could be avoided through appropriate routeing and siting alongside standard construction control measures. It is anticipated that there would be no additional adverse residual impacts on transport networks following the construction phase.

10.4 Technical Scope and Costs

10.4.1 This option has been appraised as it meets the technical appraisal requirements of the need case and is compliant with the NETS SQSS.

10.4.2 Technical analysis of this option has identified the following information, including additional details provided as part of the SOR update.

- A new High Marnham 400 kV Substation is proposed to be built as part of the Chesterfield to High Marnham substation works to uprate existing 275 kV infrastructure to 400 kV.
- If EDN-4 were to connect to this High Marnham Substation, a total of 11 feeders would connect to High Marnham in addition to the existing circuits. Further analysis has shown that adding 11 feeders at High Marnham would exceed the substation's capacity, making this connection unfeasible.
- Therefore, a second new substation would need to be constructed at High Marnham and would be included in the scope of work for EDN-4. It should be noted that this would require further land acquisition, add significant additional cost and would also impact timescales, not only for this project but for other projects connecting there (Chesterfield to High Marnham works and the North Humber to High Marnham project). Costings for this additional substation are presented below in **Table 10.1**, with associated scope presented in paragraph 10.4.5.
- Willington is an existing 400 kV substation located to the south of Derby. Physical constraints at the Willington site are low due to the availability of space within the existing site for expansion to make the connection.

10.4.3 Electrically there is an opportunity to create new circuits linking the existing 400 kV substation at Willington and the new High Marnham 400 kV Substation. However, due to the length of the overhead line for this option, the construction duration would be increased.

10.4.4 As set out in section 5, we undertake a cost evaluation of the following four technologies for onshore options evaluation.

- 400 kV AC overhead line;
- 400 kV AC underground cable;
- 400 kV AC GIL; and
- 525 kV HVDC underground cable and converter stations.

10.4.5 Option EDN-4 requires the following transmission works to satisfy the requirements of the SQSS.

- **New circuit requirements**
  - AC connection options use high capacity double-circuits (two 400 kV AC circuits) with a total capacity of up to 6,930 MVA.

- HVDC connections use 525 kV 2 GW voltage source links, which would require a converter station at each end, similar in size to a large warehouse. In this case, a 6 GW three-ended connection would require three convertor stations at each substation (nine in total as there are three connection locations), to come close to matching the AC high-capacity circuits of 6,930 MVA.

- **Substation works**
  - A new 400 kV substation at High Marnham
  - two additional new bays at the Chesterfield to High Marnham project's new High Marnham substation to connect with the High Marnham substation associated with EDN-4; and
  - two-bay extension to the existing Willington 400 kV Substation

10.4.6 **Table 10.1** sets out the capital costs for option EDN-4 considering substation works and each technology option. This includes costings for the additional High Marnham substation discussed in 10.4.2.

Table 10.1: The capital costs for option EDN-4 considering substation works and each technology option*

Item	Need	EDN-4 Capital Cost			
Substation works	Facilitate generation and connect new circuits	£173.6m			
New circuits		**AC Overhead Line**	**AC Cable**	**AC GIL**	**HVDC**
New circuit 78 km	New circuit across B8	£310.4m	£3,341.5m	£3,374.3m	£2,326.2m
Total capital cost		**£484.0m**	**£3,515.1m**	**£3,547.9m**	**£2,499.83 m**

** Costs that are included are detailed in 10.4.6*

Note: Substation costs are sensitive to varying inflation indices and are therefore indicative costs calculated at a point in time.

10.4.7 **Table 10.2** sets out the lifetime circuit cost for the new circuit options. The lifetime circuit costs are different for each circuit technology and are included as a differentiator between technologies. These costs are calculated using the methodology described in **Appendix D**.

Table 10.2: EDN-4 lifetime circuit cost for each technology option

	EDN-4 AC Overhead Line	EDN-4 AC Cable	EDN-4 AC GIL	EDN-4 HVDC
Capital cost of new circuits	£310.4m	£3,341.5m	£3,374.3m	£2,326.2m
NPV of cost of losses over 40 years	£218.8m	£159.6m	£101.6m	£471.2m
NPV of operation & maintenance costs over 40 years	£4.6m	£15.2m	£4.6m	£172.1m
Lifetime circuit cost of new circuits	**£534m**	**£3,516m**	**£3,480m**	**£2,969m**

10.4.8 Based on the above environmental, socio-economic and technical appraisal, alongside capital and circuit lifetime circuit costs, the preferred option for EDN-4 is a 78 km connection between a new High Marnham 400 kV Substation and the existing Willington 400 kV and would be for an AC circuit. In light of this analysis, our starting presumption for further development of this option, should it be selected, would be for a majority overhead line connection.

11. Strategic Options Appraisal Conclusions

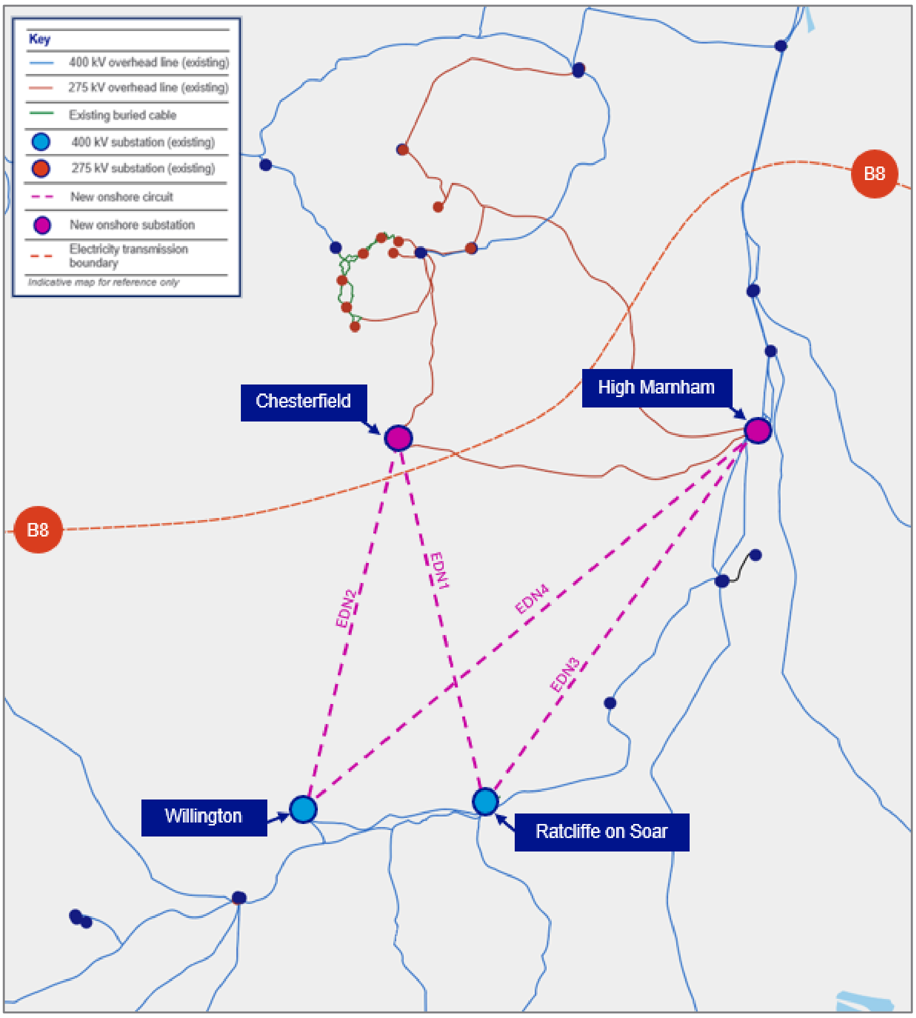
11.1 Introduction

11.1.1 This SOR has considered the following options:

- EDN-1 – Chesterfield to Ratcliffe-on-Soar (48 km);
- EDN-2 – Chesterfield to Willington (51 km);
- EDN-3 – High Marnham to Ratcliffe-on-Soar (61 km); and
- EDN-4 – High Marnham to Willington (78 km).

11.1.2 These are shown in **Image 11.1**.

Image 11.1: Strategic options considered



11.1.3 As outlined in further detail in the previous sections, this strategic options assessment considers for each option:

- environmental and socio-economic constraints;
- technology options available and the associated technical considerations; and
- the capital and lifetime circuit costs of each technology option.

11.1.4 The remainder of this section summarises these considerations across the available options.

11.2 Environmental and Socio-Economic Considerations

11.2.1 The environmental and socio-economic appraisals for each option are fully documented in **Appendix G**. A comparative analysis is provided in **Table 11.1**. One of the key differentiators between options relates to overall route length, which generally would be expected to impact the extent of environmental and socio-economic effects.

Table 11.1: Options Appraisal Summary Table (OAST) for the appraised strategic options

Topic		EDN-1	EDN-2	EDN-3	EDN-4
Environmental	Ecological	The option would likely be close to the Peak District Moors (South Pennine Moors Phase 1) SPA, and South Pennine and Peak District Moors IBA, both located approximately 9 km west of the existing substation at Chesterfield, as well as the Sherwood Forest IBA, located north of Nottingham. There are also a number of ecological designated sites including SSSIs, several nature reserves, and parcels of ancient woodland. Whilst it should be possible to avoid designated sites during the routeing and siting stage, there is still potential for direct and indirect adverse effects on the interest features (both habitats and species) for which a number of these sites are designated, depending on routeing.	The study area comprises the Peak District Moors (South Pennine Moors Phase 1) SPA, and South Pennine and Peak District Moors IBA, both located approximately 9 km west of the existing substation at Chesterfield, as well as other ecological designated sites (including SSSIs, areas of ancient woodland and Local Nature Reserves). Whilst it should be possible to avoid designated sites during the routeing and siting stage, there is still potential for direct and indirect adverse effects on the interest features (both habitats and species) for which a number of these sites are designated, depending on routeing.	The study area comprises of ecological designated sites (including seven SSSIs, areas of ancient woodland and Local Nature Reserves). Whilst it should be possible to avoid designated sites during the routeing and siting stage, there is still potential for direct and indirect adverse effects on the interest features (both habitats and species) for which a number of these sites are designated, depending on routeing.	This option crosses Sherwood Forest IBA. There is potential for direct effects on breeding, overwintering and passage bird species (collision risk) that are qualifying / interest features of these designations. The study area also comprises ecological designated sites (including SSSIs, areas of ancient woodland and Local Nature Reserves). Whilst it should be possible to avoid designated sites during the routeing and siting stage, there is still potential for direct and indirect adverse effects on the interest features (both habitats and species) for which a number of these sites are designated, depending on routeing.

Topic		EDN-1	EDN-2	EDN-3	EDN-4
	Landscape and Visual	There are a number of settlements within the study area including the cities of Derby and Nottingham. The Peak District National Park is located approximately 9 km west of the existing substation at Chesterfield, therefore there is potential for the overhead line to be visible from elevated locations within the National Park. There would however be opportunities through more detailed routeing and design to reduce the potential for adverse landscape and visual effects.	There are a number of settlements within the study area including the city of Derby, and the larger settlements of Chesterfield and Clay Cross. The Peak District National Park is located approximately 9 km from the existing substation at Chesterfield. There is potential for adverse impacts to the landscape and the sensitive visual receptors at the identified settlements in the study area. There would however be opportunities through more detailed routeing and design to reduce the potential for adverse landscape and visual effects.	There are a number of settlements within the study area including the city of Nottingham and nearby towns and villages. The Peak District National Park is located approximately 35 km to the north west of Ratcliffe Substation. There are no landscape or visual impacts predicted on the National Park; however there is potential for adverse impacts to the sensitive visual receptors at the identified settlements in the study area. There would however be opportunities through more detailed routeing and design to reduce the potential for adverse landscape and visual effects.	There are a number of settlements within the study area including the cities of Derby and Nottingham. The Peak District National Park is located approximately 28 km to the north west of Willington Substation. There is potential for adverse impacts to the landscape and sensitive visual receptors at the identified settlements in the study area. There would however be opportunities through more detailed routeing and design to reduce the potential for adverse landscape and visual effects.
	Historic Environment	There is one Registered Park and Garden present within the study area. In addition to this, there are also a number of scheduled monuments	This option intersects the Derwent Valley Mills World Heritage Site. There is potential for direct impacts to this designated heritage asset	There are nine Registered Parks and Gardens present within the study area. In addition to this, there are also a number of	There are several designated heritage assets within the study area for this option, including five Registered Parks and

Topic	EDN-1	EDN-2	EDN-3	EDN-4
	and listed buildings. Whilst it should be possible to avoid these sites, there is the potential for adverse effects on the setting of these heritage assets, depending on routeing.	and its setting depending on routeing. Based on the information available at this stage, it is considered that a route could be identified that runs to the east of Derby, to reduce/avoid adverse impacts to this site and its setting. In addition to this, there are several other designated heritage assets within the study area including four Registered Parks and Gardens and a number of scheduled monuments and listed buildings. Whilst it should be possible to avoid these sites, there is the potential for adverse effects on the setting of these heritage assets, depending on routeing.	scheduled monuments and listed buildings. Whilst it should be possible to avoid these sites, there is the potential for adverse effects on the setting of these heritage assets, depending on routeing.	Gardens and a number of scheduled monuments and listed buildings and Derwent Valley Mills World Heritage Site. There is potential for direct impacts to this World Heritage Asset and its setting depending on routeing. Based on the information available at this stage, it is considered that a route could be identified that runs to the east of Derby, to reduce/avoid adverse impacts to this site and its setting. Whilst it should be possible to avoid these sites, there is the potential for adverse effects on the setting of these heritage assets, depending on routeing.
Physical	The route would intersect the River Trent. The overhead line would therefore need to cross the river and associated areas of Flood Zones 2 and 3. The project should	The route would intersect the River Derwent. The overhead line would therefore need to cross the river and associated areas of Flood Zones 2 and 3. The project should	The route would intersect the River Trent. The overhead line would therefore need to cross the river and associated areas of Flood Zones 2 and 3. The project	The route would intersect major tributaries of the River Trent including the River Derwent and River Erewash. The overhead line would

Topic		EDN-1	EDN-2	EDN-3	EDN-4
		be designed to ensure infrastructure is placed within the lowest areas of flood risk possible (in accordance with National Policy including the NPPF and National Policy Statements EN-1 and EN-5). A direct route would intersect the city of Nottingham. To avoid Nottingham, urban areas to the north of Nottingham, and the Sherwood Forest IBA, a route to the east of Nottingham may be preferred. At this stage of the project's development, it is considered that with appropriate mitigation, potential adverse effects on watercourses can be reduced/avoided.	be designed to ensure infrastructure is placed within the lowest areas of flood risk possible (in accordance with National Policy including the NPPF and National Policy Statements EN-1 and EN-5). At this stage of the project's development, it is considered that with appropriate mitigation, potential adverse effects on watercourses can be reduced/avoided.	should be designed to ensure infrastructure is placed within the lowest areas of flood risk possible (in accordance with National Policy including the NPPF and National Policy Statements EN-1 and EN-5). A direct route would intersect the city of Nottingham. To avoid Nottingham, urban areas to the north of Nottingham, and the Sherwood Forest IBA, a route to the east of Nottingham may be preferred At this stage of the project's development, it is considered that with appropriate mitigation, potential adverse effects on watercourses can be reduced/avoided.	therefore need to cross the rivers and associated areas of Flood Zones 2 and 3. The project should be designed to ensure infrastructure is placed within the lowest areas of flood risk possible (in accordance with National Policy including the NPPF and National Policy Statements EN-1 and EN-5). At this stage of the project's development, it is considered that with appropriate mitigation, potential adverse effects on watercourses can be reduced/avoided.
Socio-economic	Settlements and Population	There are a number of settlements and urban dwellings within the study area for this option that a route would need to avoid.	There are a number of settlements and urban dwellings within the study area for this option that a route would need to avoid, notably Derby. It is anticipated that a route for	There are a number of settlements and urban dwellings within the study area for this option which a route would need to avoid, notably Nottingham. It is	There are a number of settlements and urban dwellings within the study area for this option which a route would need to avoid. This option would

Topic		EDN-1	EDN-2	EDN-3	EDN-4
			this option could be routed around Derby.	anticipated that a route for this option could be routed around Nottingham.	intersect Derby and would therefore need to be routed around Derby to avoid the city.
	Tourism and Recreation	There are a number of tourism and recreation facilities within the study area including a football club, recreation grounds and areas of publicly accessible green space. The option would need to avoid these areas during the routeing and siting stage.	There are a number of community facilities and tourist attractions within the study area including two areas of National Trust land, the Great British Car Journey Museum, recreation grounds and areas of publicly accessible green space. The option would need to avoid these areas during the routeing and siting stage.	There are a number of community facilities and tourist attractions within the study area including Geldling Country Park, four golf courses and areas of publicly accessible green space. The option would need to avoid these areas during the routeing and siting stage.	There are a number of community facilities and tourist attractions within the study area including Shipley Country Park and several golf clubs. The option would need to avoid these areas during the routeing and siting stage.
	Land Use	The Ratcliffe connection node is located within the EMF, which includes the former Ratcliffe-on-Soar Coal Power station, the demolition of which is planned for 2029-2030. The area also falls under Rushcliffe Borough Council's approved LDO for the site prioritising future development in energy, manufacturing, and industry. Within	There are two areas of National Trust land within the study area, Duffield Castle and Kedleston Hall. It should be possible for EDN-2 to route around the National Trust land and therefore to avoid direct impacts. Impacts to the settings may continue into operation, depending on appropriate routeing of overhead lines.	There are two areas of National Trust land within the study area. However, it should be possible for EDN-3 to route around this land and therefore to avoid direct impacts. The Ratcliffe connection node is located within the EMF, , which includes the former Ratcliffe-on-Soar Coal Power station, the	The Willington Power Station is located within the 2 km study area of the strategic option. Adopting appropriate routeing of the overhead line, and the appropriate selection of sites for construction compounds and working areas will likely minimise any impacts to the power station.

Topic	EDN-1	EDN-2	EDN-3	EDN-4
	documentation submitted to the Council in September 2025, a phasing plan sets out that redevelopment is expected to take place over a 15-plus year period, commencing 2025. The Council undertook a consultation in January 2026, which would assess the inclusion of data centres in the development. The LDO's retention of existing National Grid assets, coupled with the prevalence of EMF status, poses a potential land use constraint due to the risk of socio-political impacts if actions deviate from these plans.		demolition of which is planned for 2029-2030. The area also falls under Rushcliffe Borough Council's approved LDO for the site prioritising future development in energy, manufacturing and industry. Within documentation submitted to the Council in September 2025, a phasing plan sets out that redevelopment is expected to take place over a 15-plus year period, commencing 2025. The Council undertook a consultation in January 2026, which would assess the inclusion of data centres in the development. The LDO's retention of existing National Grid assets, coupled with the prevalence of EMF status, poses a potential land use constraint due to the risk of socio-political impacts if actions deviate from these plans.	

Topic	EDN-1	EDN-2	EDN-3	EDN-4
Infrastructure	There are several rail and road networks located within the study area for this option. Construction works could lead to temporary disruption to these networks due to increased construction traffic. However, it is expected that such impacts could be avoided through appropriate routeing and siting alongside standard construction control measures. It is anticipated that there would be no additional adverse residual impacts on transport networks following the construction phase.	There are several rail and road crossings within the study area for this option. Construction works could lead to temporary disruption to these networks due to increased construction traffic. However, it is expected that such impacts could be avoided through appropriate routeing and siting alongside standard construction control measures. It is anticipated that there would be no additional adverse residual impacts on transport networks following the construction phase.	There are several rail and road crossings within the study area for this option. Construction works could lead to temporary disruption to these networks due to increased construction traffic. However, it is expected that such impacts could be avoided through appropriate routeing and siting alongside standard construction control measures. It is anticipated that there would be no additional adverse residual impacts on transport networks following the construction phase.	There are several rail and road crossings within the study area for this option. Construction works could lead to temporary disruption to these networks due to increased construction traffic. However, it is expected that such impacts could be avoided through appropriate routeing and siting alongside standard construction control measures. It is anticipated that there would be no additional adverse residual impacts on transport networks following the construction phase.

Landscape and Visual

11.2.2 Options originating from Chesterfield (EDN-1 and EDN-2) are closer to the Peak District National Park than options originating from High Marnham (EDN-3 and EDN-4) and therefore have more potential to be visible from elevated locations within the National Park. This would need to be considered further at the next stage of the process, although it is anticipated that there would be opportunities through more detailed routeing and design to reduce the potential for adverse landscape and visual effects, which may include routeing the overhead line further east, away from the Peak District National Park and taking into account the current pattern of the landscape and topography.

Ecological

11.2.3 For all options, there are a number of ecological designated sites within the study area. The South Pennine and Peak District Moors IBA falls within the study area for both Chesterfield options (EDN-1 and EDN-2), whilst the Sherwood Forest IBA falls within the study area for EDN-1 and EDN-3, and is crossed by EDN-4. Whilst it is anticipated that all options can avoid these sites, there is potential for direct effects on breeding, overwintering and passage bird species (collision risk), which will need to be reduced through further routeing and design. There are a number of designated ecological sites within the study areas for all options, including SSSIs, Local Nature Reserves and ancient woodland. Whilst it is likely to be possible to avoid the IBAs, SSSIs, areas of ancient woodland and Local Nature Reserves, there is potential for indirect adverse effects on the interest features (both habitats and species) for which a number of these sites are designated, depending on routeing.

Historic Environment

11.2.4 There are a number of designated heritage assets within the study areas for all options, including Registered Parks and Gardens, listed buildings, and scheduled monuments. Whilst it should be possible to avoid these sites, there is the potential for adverse effects on the setting of these heritage assets, depending on routeing. Options connecting to Willington Substation (EDN-2 and EDN-4) will need to run close to the Derwent Valley Mills World Heritage Site, which is located approximately 9 km north east of the Willington Substation. At the next stage of the process, there may be opportunity to consider development of the options such that EDN-2 and EDN-4 could be routed to the east of Derby, which would help to reduce impacts of the overhead line on the setting of the heritage site. Further assessment would be undertaken at an appropriate stage to identify any potential impacts to the setting of the World Heritage Site and any further relevant mitigation would be proposed.

Physical

11.2.5 All options (EDN-1, EDN-2, EDN-3, and EDN-4) will need to cross rivers and their associated floodplains, including areas of Flood Zones 2 and 3. Although it is not considered to be a differentiating factor at this stage, EDN-4 is the only route which would intersect major tributaries.

11.2.6 The project should be designed to ensure infrastructure is placed within the lowest areas of flood risk possible (in accordance with National Policy including the NPPF and National Policy Statements EN-1 and EN-5). At this stage of the project's development, it is considered that with appropriate mitigation, potential adverse effects on watercourses can be reduced/avoided.

Socio-Economic

11.2.7 There are a number of settlements and urban dwellings located within the study areas that all options would need to avoid. Temporary adverse impacts could arise during construction if a route is located close to settlements due to impacts of noise and construction traffic. Mitigation would be expected to help reduce adverse noise and traffic impacts. There is the possibility of operational noise effects; however, these effects could be resolved through appropriate routeing and siting for all four options. As such, there are not considered to be any socio-economic factors that distinguish materially between the four options; however, EDN-1, EDN-2, and EDN-3 have materially shorter overhead line routes than EDN-4 and so are expected to have potentially fewer environmental and socio-economic effects.

Overall Environmental and Socio-Economic Conclusions

11.2.8 Overall, in all cases it is assumed that potential adverse effects to environmental and socio-economic receptors can be reduced/avoided at the next stage of the optioneering process through appropriate routeing and siting, to avoid the receptors, and reduce effects on their setting or qualifying/interest features. Where there is potential for residual adverse effects, further mitigation may be proposed following further detailed assessment for the specific receptors.

11.2.9 However, the appraisal of the strategic options showed that EDN-1, EDN-2, and EDN-3 options would have a materially shorter overhead line route than that of EDN-4 and would be expected to have potentially fewer environmental and socio-economic effects.

11.2.10 Following SOR review and update the original environmental and socio-economic conclusions remain unchanged.

11.3 Technical Considerations

11.3.1 All of the options considered in this report met the technical appraisal requirements of the need case and were compliant with the NETS SQSS.

11.3.2 Options EDN-1 and EDN-3 propose connections to Ratcliffe 400 kV Substation:

- Ratcliffe 400 kV Substation is located at the Ratcliffe Coal Fired Power Station, which ceased operation in 2024. The wider power station is owned by Uniper. NGET’s existing land rights beyond the substation land parcels and overhead lines are limited to leasehold. The wider site is due to be redeveloped under a LDO. This together with the decommissioning of the power station creates considerable construction risk for connecting the project at Ratcliffe. Given the physical constraints surrounding the substation, a new circuit to the substation would need to be installed underground in the vicinity which would add civil engineering complexity, significant land rights difficulties within the wider Uniper owned site and extensive costs. In addition, the indoor substation building would require modification to connect new circuits and asbestos is present.

- To physically connect into Ratcliffe Substation, either the substation would need to be extended on either side or existing bays within the substation would need to be vacated to re-purpose for the circuit. Expansion of the existing substation is not feasible due to physical site constraints and development of the EMF. To connect the development to the substation, Uniper are contracted to re-use their power station bays leaving no available bays for the project.
- Consideration has also been given to connecting at a potential new substation in the Ratcliffe area which is independent of this project. This, however, would fail to provide sufficient boundary uplift and therefore is not a feasible alternative.

11.3.3 Options EDN-3 and EDN-4 propose connections to the new High Marnham Substation:

- A new High Marnham 400 kV Substation is proposed to be built as part of the Chesterfield to High Marnham substation works to uprate existing 275 kV infrastructure to 400 kV.
- If EDN-3 or EDN-4 were to connect to this High Marnham Substation, a total of 11 feeders would connect to High Marnham in addition to the existing circuits. Further analysis has shown that adding 11 feeders at High Marnham would exceed the substation's capacity, making the EDN-3/EDN-4 connection unfeasible.
- Therefore, a second new substation would need to be constructed at High Marnham and would be included in the scope of work for EDN-3/EDN-4. It should be noted that this would require further land acquisition, add significant additional cost and would also impact timescales, not only for this project but for other projects connecting there (Chesterfield to High Marnham works and the North Humber to High Marnham project).

11.3.4 Options EDN-1 and EDN-2 propose connections to a new Chesterfield 400 kV Substation. A new Chesterfield 400 kV Substation is proposed to be built as part of the Chesterfield to High Marnham project works to uprate existing 275 kV infrastructure to 400 kV. The site will be sufficient to accommodate the connection of the circuit set out in this option.

11.3.5 Options EDN-2 and EDN-4 propose connections to Willington 400 kV Substation. Willington is an existing 400 kV substation located to the south of Derby. Physical constraints at the Willington site are low due to the availability of space within the existing site for expansion to make the connection. Electrically there is an opportunity to rationalise existing circuits linking Chesterfield and Willington and provide a route for the new 400 kV circuit infrastructure via an existing overhead line corridor in the vicinity of Willington.

11.3.6 Given the constraints, overall EDN-2, with connections to a new Chesterfield 400 kV and Willington 400 kV, has the least electrical and construction complexity and therefore offers a benefit over other options from a technical perspective. The substations have sufficient space to accommodate them. Further, given the existing circuits and proposed works required on these sites, electrical complexity is limited. These conclusions remain following the SOR update.

11.3.7 Given the significant constraints and challenges discussed in sections 7.4 and 9.4, and summarised above, these factors form the principal differentiating factor across the assessment due to their impact on overall feasibility.

11.4 Cost Considerations

11.4.1 **Table 11.2** provides a comparison of options based on the most economical technology choice for each option (i.e. AC overhead line in each case).

11.4.2 It should be noted that High Marnham options costings (EDN-3, EDN-4) include the additional High Marnham substation which is now required for the project to connect at High Marnham and to ensure EDN-3 and EDN-4 are feasible options.

Table 11.2: Capital and lifetime circuit cost impact

Options	Onshore Options			
	EDN-1*	**EDN-2**	**EDN-3***	**EDN-4**
B8 >6 GW increase				
Economic technology (capacity)	overhead line	overhead line	overhead line	overhead line
	6,980 MW	6,980 MW	6,980 MW	6,980 MW
Total capital cost including non-circuit works	£217.5m	£220.6m	£425.3m	£484.0m
Circuit 40 yr lifetime NPV cost	£328m	£349m	£417m	£534m

**please also refer to 11.4.6*

11.4.3 The lowest overall cost option is option EDN-1 with a capital cost of £217.5m and a lifetime circuit cost of £328m.

11.4.4 EDN-1 is very closely followed by option EDN-2 with a capital cost of £220.6m and a lifetime circuit cost of £349m.

11.4.5 There is a narrow difference in presented costs for EDN-1 and EDN-2, however as presented, EDN-1 has significant constraints associated with Ratcliffe, as discussed in section 7.4. Mitigating these constraints would add further cost to EDN-1.

11.4.6 As outlined above, connecting at Ratcliffe presents significant constraints, the costing of which is outside the SOR methodology, which presents asset level costs, applying 100% technologies across all comparators. However, it has been identified that any connection into Ratcliffe (EDN-1, EDN-3), given the constraints, is likely to require 2km of underground cable to avoid those potential constraints. Although costing for this is outside the SOR methodology, it is an asset-level cost, and therefore an estimate can be provided for information: £79.8m capital cost and £82m lifetime cost. This is in addition to costs shown in **Table 11.2**. Including this underground section would result in revised estimated costs of:

- EDN-1: £297.3 (capital), £410m (lifetime)
- EDN-3: £505.1m (capital), £499m (lifetime).

11.5 Summary and Conclusion

11.5.1 EDN-1, EDN-2, and EDN-3 options would have a materially shorter overhead line route than that of EDN-4 and therefore have significantly lower capital and lifetime circuit costs. They would also be generally expected to have lower environmental and socio-economic effects by virtue of route length. Additionally, EDN-3 has a 10 km longer route length than EDN-2, or a 13 km longer route length than EDN-1 without any additional socio-economic or environmental benefit. Therefore EDN-1 and EDN-2 are preferable in environmental and socio-economic terms.

11.5.2 The similarity in presented costs between options EDN-1 (capital cost of £217.5m, lifetime circuit cost of £328m) and EDN-2 (capital cost of £220.6m, lifetime circuit cost of £349m) means that cost is not a material difference between those options. In comparison, EDN-3 has a capital cost of £425.3m and a lifetime circuit cost of £417m, and EDN-4 has a capital cost of £484.0m and a lifetime circuit cost of £534m. These costs however, do not account for the additional 2km of AC underground cable which would likely be required for EDN-1 and EDN-3 to connect at Ratcliffe, as discussed in paragraph 11.4.6. Taking these likely required costs into consideration, EDN-2 costs would be the lowest.

11.5.3 Whilst EDN-1 and EDN-3 perform marginally better than EDN-2 in terms of network benefit, they each have technical disadvantages in comparison to EDN-2. Those options are also physically more constrained in terms of routeing due to constraints into Ratcliffe-on-Soar Substation. In addition to physical constraints, limited land rights; extensive, competing development activity at the surrounding power station; and the impact on the electrical complexity and operation of the site makes connecting at Ratcliffe a substantially less viable option than initially considered.

11.5.4 EDN-3 and EDN-4 both connect into High Marnham which presented significant feasibility challenges based on connecting to the planned single new 400 kV substation proposed as part of the Chesterfield to High Marnham project works. An alternative solution of building two new substations has been considered: one substation as part of the Chesterfield to High Marnham project; and an additional substation as part of this project for EDN-3 and EDN-4 options. This would make connecting at High Marnham technically feasible and therefore a new substation has been incorporated into the scope and costings of EDN-3 and EDN-4.

11.5.5 Based on the above information regarding the significant technical complexities of Ratcliffe options (EDN-1 and EDN-3) and additional scope required for High Marnham options (EDN-3 and EDN-4) compared to the lower electrical complexity of EDN-2, this option would be preferred from a technical cost and complexity assessment.

11.5.6 Given the significant constraints and challenges discussed in sections 7.4. and 9.4, and summarised above, these factors form the principal differentiating factor across the assessment due to their impact on overall feasibility. When considered alongside technical, cost, environmental and socio-economic effects, EDN-2 represents the most advantageous overall option, as confirmed through the SOR update.

12. Conclusion and Next Steps

12.1 Conclusions

12.1.1 As explained in section 2, we have a key role in providing a transmission system which benefits all consumers in England and Wales. Where new network infrastructure is needed, we must work within the regulatory, legislative and policy framework that is set by government on behalf of consumers and society in developing proposals. That means considering the various benefits and impacts that our potential works could have, including environmental, socio-economic, technical and cost factors.

12.1.2 This report has considered options to meet the need case set out in section 3. A requirement has been identified for two sets of transmission circuits that contribute to NETS SQSS compliance.

12.1.3 We have considered the information that is available to us at this stage of the process. We have outlined in this report how we have gathered data and how we have evaluated it for each option. In addition to this, we have considered our duties under the Electricity Act 1989 to develop efficient, co-ordinated and economical solutions, our duty to have regard to the environment in Schedule 9 of the 1989 Act, and the policy, advice and guidance provided by government through the adopted National Policy Statements EN-1, EN-3 and EN-5.

12.1.4 Taking all of this into account, we propose at the current stage that the optimum option to meet the need case as set out in section 3 is EDN-2 from Chesterfield to Willington. This option is the most advantageous of the options when balancing cost, technical performance and constructability. Further, this option has fewer environmental and socio-economic effects.

12.1.5 The progression of EDN-2 is also enabled through the interaction with the Chesterfield to High Marnham project due to the improved capacity across B8 from the additional circuit. The Brinsworth to Chesterfield and Chesterfield to High Marnham projects also provide an additional 3,000 MW, which helps to solve the -5,300 MW Capability Deficit as identified in the need case and also reduces impedance, therefore the full -5,300 MW will not need to be met. Overall, the remaining EDN-2 would address the NOA ‘HND essential’ status, providing the required reinforcement across the B8 boundary.

12.2 Next Steps

12.2.1 Chesterfield to Willington has been taken to non-statutory consultation and will now be taken forward to the next stage of development, including a statutory consultation, to seek further feedback from consultees and help shape the further development of the project.

12.2.2 Further information regarding the Project and its development can be located here: **nationalgrid.com/chesterfieldtowillington.**

Appendix A
Summary of National Grid Electricity Transmission Legal Obligations

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Appendix A
Summary of National Grid Electricity Transmission Legal Obligations

A.1 Electricity Transmission Licence

A.1.1 The Electricity Act 1989 (the 'Electricity Act') defines transmission of electricity within Great Britain and its offshore waters as a prohibited activity, which cannot be carried out without permission by a transmission licence granted under section 6(1)(b) of the Electricity Act (a 'Transmission Licence').

A.1.2 National Grid Electricity Transmission ('National Grid') has been granted a Transmission Licence that permits transmission owner activities in respect of the electricity transmission system National Grid owns, develops and maintains in England and Wales.

A.1.3 Each Transmission Licence includes conditions which define the scope of the permission granted to carry out a prohibited activity in terms of duties, obligations, restrictions and rights. The generic conditions that apply to any holder of a Transmission Owner licence type are set out in Sections A, B and D of the Standard Conditions of the Transmission Licence. Conditions that only apply to a specific licensee are set out as Special Conditions of that Transmission Licence.

A.1.4 National Grid is therefore bound by the legal obligations primarily set out in the Electricity Act and its Transmission Licence. The following list provides a summary overview of requirements that are considered when developing proposals to construct new transmission system infrastructure.

1.2 Electricity Act Duties

A.1.5 In accordance with section 9 of the Electricity Act, National Grid is required to develop and maintain an efficient, co-ordinated and economical system of electricity transmission.

A.1.6 Schedule 9 of the Electricity Act requires National Grid, when formulating proposals for new lines and other works, to:

'…have regard to the desirability of preserving natural beauty, of conserving flora, fauna, and geological or physiographical features of special interest and of protecting sites, buildings and objects of architectural, historic or archaeological interest; and to do what [it] reasonably can to mitigate any effect which the proposals would have on the natural beauty of the countryside or on any such flora, fauna, features, sites, buildings or objects'.

A.1.7 National Grid's Stakeholder, Community and Amenity Policy ('the Policy') sets out how the company will meet this Schedule 9 duty. The commitments within the Policy include:

- only seeking to build new lines and substations where the existing transmission infrastructure cannot be upgraded technically or economically to meet transmission security standards;

- where new infrastructure is required, seeking to avoid areas that are nationally or internationally designated for their landscape, wildlife or cultural significance; and
- minimising the effects of new infrastructure on other sites valued for their amenity.

A.1.8 The Policy also refers to the application of best practice methods to assess the environmental impacts of proposals and identify appropriate mitigation and/or offsetting measures. Effective consultation with stakeholders and the public is also promoted by the Policy.

A.2 National Grid's Transmission Licence Requirements

A.2.1 Condition B12: System Operator – Transmission Owner Code

All Transmission Licensees are required to have the System Operator Transmission Owner Code (STC) in place that defines the arrangements within the transmission sector and sets out how the transmission system operator can access and use transmission services provided by transmission owners.

The STC structure aligns with key activities within the transmission sector including:

- planning co-ordination (of transmission system development works and construction);
- provision of transmission services within different operational timescales; and
- payments from transmission system operator to providers of transmission services (after service has been delivered).

A.2.2 Condition B16: Electricity Network Innovation Strategy

All Transmission Licensees are required to have a joined up approach to innovation and develop an Electricity Network Innovation Strategy that is reviewed every two years.

A.2.3 Condition D2: Obligation to provide transmission services

Each transmission owner is required to provide transmission services to the transmission system operator as defined in the STC. Transmission services provided to the transmission system operator include:

- enabling use to be made of existing transmission owner assets; and
- responding to requests for the construction of additional transmission system capacity (including system extension, disconnections and/or reinforcement).

A.2.4 Condition D3: Transmission system security standard and quality of service

Transmission owners are required to at all times plan, develop the transmission system in accordance with the National Electricity Transmission System Security and Quality of Supply Standard (NETS SQSS).

A transmission owner with supporting evidence may ask the Authority to grant derogation from the requirements set out in the NETS SQSS. Any decision in respect of NETS SQSS derogations are subject to the Authority's consideration of all relevant factors.

A.2.5 Condition D17: Whole Electricity System Obligations

Transmission owners are required to co-ordinate and co-operate with Transmission Licensees and electricity distributors in order to build common understanding of where actions taken by one could have cross network impacts. A transmission owner should implement actions or processes that are identified that:

- will not have a negative impact on its network; and
- are in the interest of the efficient and economical operation of the total system.

Appendix B Requirement for Development Consent Order

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Appendix B
Requirement for Development Consent Order

B.1 Electricity Network Infrastructure Developments

B.1.1 Developing the electricity transmission system in England and Wales subject to the type and scale of the project may require one or more statutory consents which may include:

- planning permission under the Town and Country Planning Act 1990;
- a marine licence under the Marine and Coastal Access Act 2009;
- a development consent order (DCO) under the Planning Act 2008; and/or
- a variety of consents under related legislation.

B.1.2 The Planning Act 2008 defines developments of new electricity overhead lines of 132 kV and above as Nationally Significant Infrastructure Projects (NSIPs) requiring a DCO. Such an order may also incorporate consent for other types of work that is associated with new overhead line infrastructure development and may be incorporated as part of a DCO that is granted.

B.1.3 Six National Policy Statements (NPS) for energy infrastructure were designated by the Secretary of State for Energy and Climate Change in July 2011. The relevant NPSs for electricity transmission infrastructure developments are the Overarching National Policy Statement for Energy (EN-1) and the National Policy Statement for Electricity Networks Infrastructure (EN-5), which is read in conjunction with EN-1. In September 2021 and then again in March 2023, the government consulted on proposed updates to the NPS suite including EN-1 and EN-5. Following such consultation, the government then published updated versions of those NPSs in November 2023, which were designated in January 2024[28]. The 2011 NPSs have therefore been superseded by the 2024 revised versions. The updates include clear linkages of EN-1 with policy objectives in respect of net zero[29]. National Grid will continue to monitor the relevant policy position as our work on the development consent order application progresses.

B.1.4 Section 104(3) of the Planning Act 2008 states that the decision maker must determine an application for a DCO in accordance with any relevant NPS, except in certain specified circumstances (such as where the adverse impact of the proposed development would outweigh its benefits). The energy NPSs therefore provide the primary policy basis for decisions on DCO applications for electricity transmission projects. The NPSs may also be a material consideration for decisions on other types of development consent in England and Wales (including offshore wind generation projects) and for planning applications under the Town and Country Planning Act 1990.

[28] National Policy Statements for energy infrastructure https://www.gov.uk/government/collections/national-policy-statements-for-energy-infrastructure

[29] Energy White Paper: Powering our net zero future, December 2020 https://www.gov.uk/government/publications/energy-white-paper-powering-our-net-zero-future

B.2 Demonstrating the Need for a Project and Assessment Principles Applied by Decision Maker

B.2.1 NPSs are produced by government and set out the UK government's objectives for the development of nationally significant infrastructure. The extant NPSs relevant to energy network infrastructure are EN-1 Overarching NPS for Energy, EN-3 NPS for Renewable Energy, and EN-5 NPS for Electricity Networks Infrastructure. The relevant versions were published in November 2023 and came into force in January 2024. The project monitored the draft policy statements throughout 2023, and the associated implications were factored into the options assessment. A detailed commentary can be found within the Corridor Preliminary Routeing and Siting Study[30] published as part of the 2024 non-statutory consultation. The main themes are provided below.

B.2.2 Taken together, they provide the primary basis for decisions on applications for electricity networks infrastructure which are classified as NSIPs. Where relevant (e.g. in the case of the consideration of development in nationally designated landscapes), these are referred to in this SOR.

B.2.3 The Overarching NPS for Energy (NPS EN-1) sets out the government's overarching policy about the development of NSIPs in the energy sector. It sets out the goal of decarbonising the energy network to achieve net zero whilst ensuring security of supply. It sets out how, as the electricity system grows in scale, dispersion, variety, and complexity, work would be needed to protect against the risk of large-scale supply interruptions in the absence of sufficiently robust electricity networks. Whilst existing transmission and distribution networks must adapt and evolve to cope with this reality, development of new transmission lines of 132 kV and above would be necessary to preserve and guarantee the robust and reliable operation of the whole electricity system. EN-1 recognises that to '*produce the energy required for the UK and ensure it can be transported to where it is needed, a significant amount of infrastructure is needed at both local and national scale.*' It refers to how the onshore transmission network would require substantial reinforcement in East Anglia to handle increased power flows from offshore wind generation (paragraph 3.3.68).

B.2.4 NPS EN-1 Section 4.2 sets out the government's commitments to prioritise for low-carbon infrastructure. Paragraph 4.2.1 of the NPS states that '*Government has committed to fully decarbonise the power systems by 2035, subject to security of supply, to underpin its 2050 net zero ambitions.*' Paragraph 4.2.4 states that the '*Government has therefore concluded that there is a critical national priority (CNP) for the provision of nationally significant low-carbon infrastructure.*' Paragraph 4.2.5 lists the types of infrastructure that meet the definition of national significant infrastructure, which includes electricity grid infrastructure in the scope of EN-5, including network reinforcement, upgrade works and associated infrastructure such as substations.

B.2.5 NPS EN-3 for Renewable Energy Infrastructure also includes support for the onshore infrastructure required to deliver new offshore wind developments. Paragraphs 2.8.34 to 2.8.43 (inclusive) reiterate the position set out in EN-1 and EN-5 that a co-ordinated approach to onshore-offshore transmission is required. The NPS also includes references to CNP infrastructure and the application of the assessment principles outlined in Section 4 of EN-1. Applicants must show how any likely

[30] Chesterfield to Willington, Corridor Preliminary Routeing and Siting Study, nationalgrid.com/document/151791/download

significant negative effects would be avoided, reduced, mitigated or compensated for, following the mitigation hierarchy.

B.2.6 NPS EN-5 (National Policy Statement for Electricity Networks Infrastructure) in conjunction with NPS EN-1 sets the policy context and provides the main guidance for the development and assessment of new network infrastructure. It outlines the government’s view that the development of overhead lines is not incompatible in principle with an applicants’ statutory duty under Schedule 9 to the Electricity Act 1989 to have regard to visual and landscape amenity and to reasonably mitigate possible impacts. It sets out the government’s position that overhead lines should be the strong starting presumption for electricity networks developments and that the Holford Rules (guidelines for the routeing of new overhead lines), and the equivalent Horlock Rules for substation infrastructure, should be embodied in the applicants’ proposals. The NPS goes on to recognise that this presumption is reversed (i.e. assuming underground cable) when proposed developments will cross part of a nationally designated landscape (i.e. National Park, The Broads, or Area of Outstanding Natural Beauty).

B.2.7 The NPS also sets out the need to consider the case for undergrounding outside designated areas (2.9.23) and to consider, where there is the potential for significant adverse landscape and visual impacts (2.9.14), the need to have given due consideration to feasible alternatives to the overhead line. This could include, where appropriate, re-routeing, underground or subsea cables, and the feasibility, e.g. in cost, engineering or environmental terms of these but with decision making taking into account the costs and benefits of the alternatives.

B.2.8 **Image C.1** shows a typical pylon used to support two 275 kV or 400 kV overhead line circuits. This type of pylon has six arms (three either side), each carrying a set (or bundle) of conductors.

Appendix C
Technology Overview

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Appendix C
Technology Overview

C.1 Introduction

C.1.1 This section provides an overview of the technologies available when the strategic options described in this report were identified. It provides a high level description of the relevant features of each technology. The costs for each technology are presented in **Appendix D**.

C.1.2 The majority of electricity systems throughout the world are alternating current (AC) systems. Consumers have their electricity supplied at different voltages depending upon the amount of power they consume, e.g. 230 V for domestic customers and 11 kV for large factories and hospitals. The voltage level is relatively easy to change when using AC electricity, which means a more economical electricity network can be developed for customer requirement. This has meant that the electrification of whole countries could be and was delivered quickly and efficiently using AC technology.

C.1.3 Direct current (DC) electricity did not develop as the means of transmitting large amounts of power from generating stations to customers because DC is difficult to transform to a higher voltage and bulk transmission by low voltage DC is only effective for transporting power over short distances. However, DC is appropriate in certain applications such as the extension of an existing AC system or when providing a connection to the transmission system.

C.1.4 In terms of voltage, the transmission system in England and Wales operates at both 275 kV and 400 kV. The majority of National Grid's transmission system is now constructed and operated at 400 kV, which facilitates higher power transfers and lower transmission losses.

C.1.5 There are a number of different technologies that can be used to provide transmission connections. These technologies have different features which affect how, when and where they can be used. The main technology options for electricity transmission are:

- overhead lines;
- underground cables;
- gas insulated lines (GIL); and
- high voltage direct current (HVDC).

C.1.6 This appendix provides generic information about each of these four technologies.

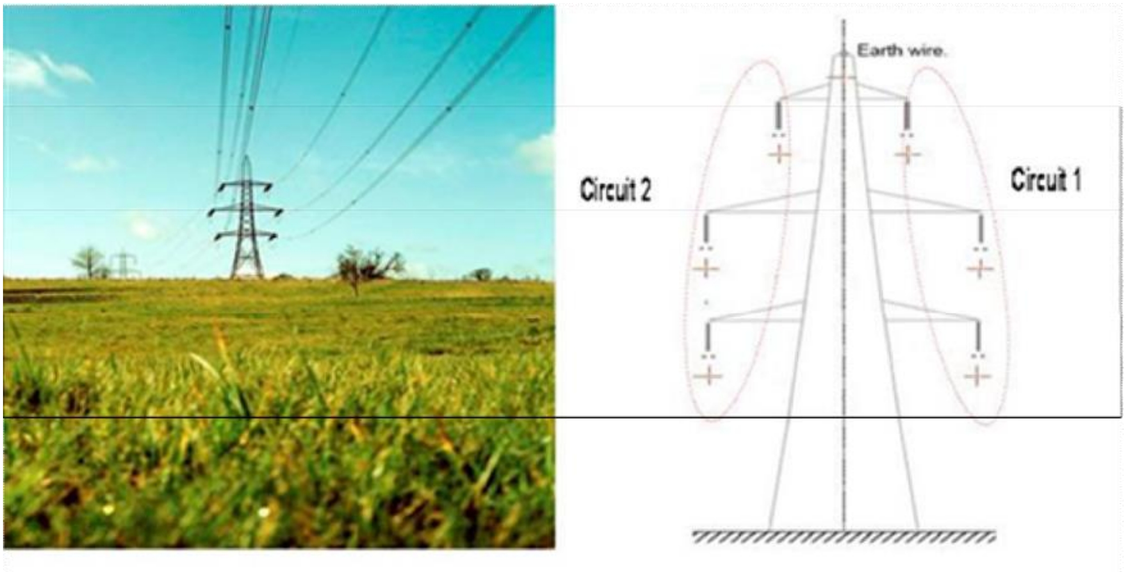
C.2 Overhead Lines

C.2.1 Overhead lines form the majority of the existing transmission system circuits in Great Britain and in transmission systems across the world. As such there is established understanding of their construction and use.

C.2.2 Overhead lines are made up of three main component parts which are: conductors (used to transport the power), pylons (used to support the conductors) and insulators (used to safely connect the conductors to pylons).

C.2.3 **Image C.1** shows a typical pylon used to support two 275 kV or 400 kV overhead line circuits. This type of pylon has six arms (three either side), each carrying a set (or bundle) of conductors.

Image C.1: Example of a 400 kV double circuit pylon



C.2.4 The number of conductors supported by each arm depends on the amount of power to be transmitted and will be either two, three or four conductors per arm. Technology developments have increased the capacity that can be carried by a single conductor and therefore, new overhead lines tend to have two or three conductors per arm.

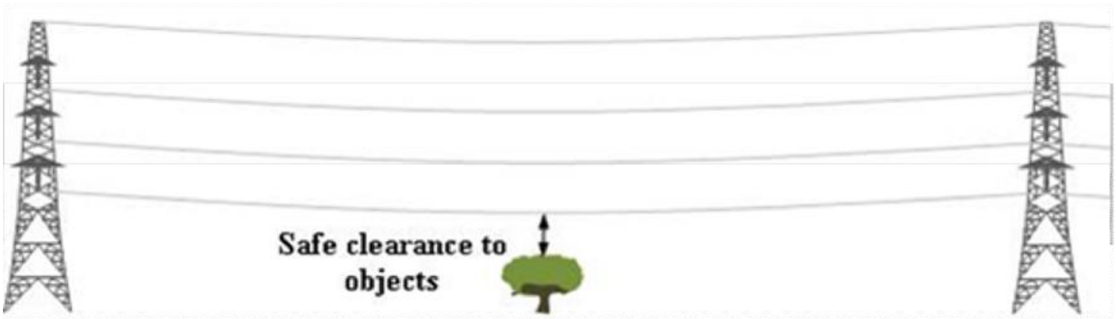
C.2.5 With the conclusion of the Royal Institute of British Architects (RIBA) pylon design competition[31] and other recent work with manufacturers to develop alternative pylon designs, National Grid is now able to consider a broader range of pylon types, including steel lattice and monopole designs. The height and width is different for each pylon type, which may help National Grid to manage the impact on landscape and visual amenity better. **Image C.2** shows an image of the monopole design called the T pylon that was developed by National Grid.

[31] Pylon Design an RIBA competition, https://www.architecture.com/awards-and-competitions-landing-page/competitions-landing-page/pylon

Image C.2: The T pylon

C.2.6 Pylons are designed with sufficient height to ensure that the clearances between each conductor and between the lowest conductor and the ground, buildings or structures are adequate to prevent electricity jumping across. The minimum clearance between the lowest conductor and the ground is normally at the mid-point between pylons. There must be sufficient clearance between objects and the lowest point of the conductor as shown in **Image C.3.**

Image C.3: Safe height between lowest point of conductor and other obstacle ('safe clearance')



C.2.7 The distance between adjacent pylons is termed the 'span length'. The span length is governed by a number of factors, the principal ones being pylon height, number and size of conductors (i.e. weight), ground contours and changes in route direction. A balance must therefore be struck between the size and physical presence of each pylon versus the number of pylons; this is a decision based on both visual and economic aspects. The typical 'standard' span length used by National Grid is approximately 360 m.

C.2.8 Lower voltages need less clearance and therefore the pylons needed to support 132 kV lines are not as high as traditional 400 kV and 275 kV pylons. However, lower voltage circuits are unable to transport the same levels of power as higher voltage circuits.

C.2.9 National Grid has established operational processes and procedures for the design, construction, operation and maintenance of overhead lines. Circuits must be taken out of service from time to time for repair and maintenance. However, shorter emergency restoration times are achievable on overhead lines as compared, for example, to underground cables. This provides additional operational flexibility if circuits need to be rapidly returned to service to maintain a secure supply of electricity when, for example, another transmission circuit is taken out of service unexpectedly.

C.2.10 In addition, emergency pylons can be erected in relatively short timescales to bypass damaged sections and restore supplies. Overhead line maintenance and repair therefore does not significantly reduce security of supply risks to end consumers.

C.2.11 Each of the three main components that make up an overhead line has a different design life, which is:

- between 40 and 50 years for overhead line conductors;
- 80 years for pylons; and
- between 20 and 40 years for insulators.

C.2.12 National Grid expects an initial design life of around 40 years, based on the specified design life of the component parts. However, pylons can be easily refurbished and so substantial pylon replacement works are not normally required at the end of the 40-year design life.

C.3 Underground Cables

C.3.1 Underground cables at 275 kV and 400 kV make up approximately 10 per cent of the existing transmission system in England and Wales, which is typical of the proportion of underground to overhead equipment in transmission systems worldwide. Most of the underground cable is installed in urban areas where achieving an overhead route is not feasible. Examples of other situations where underground cables have been installed, in preference to overhead lines, include crossing rivers, passing close to or through parts of nationally designated landscape areas and preserving important views.

C.3.2 Underground cable systems are made up of two main components – the cable and connectors. Connectors can be cable joints, which connect a cable to another cable, or overhead line connectors in a substation.

C.3.3 Cables consist of an electrical conductor in the centre, which is usually copper or aluminium, surrounded by insulating material and sheaths of protective metal and plastic. The insulating material ensures that although the conductor is operating at a high voltage, the outside of the cable is at zero volts (and therefore safe). **Image C.4** shows a cross section of a transmission cable and a joint that is used to connect two underground cables.

Image C.4: Cable cross section and joint

C.3.4 Underground cables can be connected to above ground electrical equipment at a substation, enclosed within a fenced compound. The connection point is referred to as a Cable Sealing End. **Image C.5** shows two examples of Cable Sealing End Compounds.

Image C.5: Cable Sealing End Compounds

C.3.5 An electrical characteristic of a cable system is capacitance between the conductor and earth. Capacitance causes a continuous 'charging current' to flow, the magnitude of which is dependent on the length of the cable circuit (the longer the cable, the greater the charging current) and the operating voltage (the higher the voltage the greater the current). Charging currents have the effect of reducing the power transfer through the cable.

C.3.6 High cable capacitance also has the effect of increasing the voltage along the length of the circuit, reaching a peak at the remote end of the cable.

C.3.7 National Grid can reduce cable capacitance problems by connecting reactive compensation equipment to the cable, either at the ends of the cable, or, in the case of longer cables, at regular intervals along the route. Specific operational arrangements and switching facilities at points along the cable circuit may also be needed to manage charging currents.

C.3.8 Identifying faults in underground cable circuits often requires multiple excavations to locate the fault and some repairs require removal and installation of new cables, which can take a number of weeks to complete.

C.3.9 High voltage underground cables must be regularly taken out of service for maintenance and inspection and, should any faults be found and depending on whether cable excavation is required, emergency restoration for security of supply reasons typically takes a lot longer than for overhead lines (days rather than hours).

C.3.10 The installation of underground cables requires significant civil engineering works. These make the construction times for cables longer than overhead lines.

C.3.11 The construction swathe required for two AC circuits comprising two cables per phase will be between 35 to 50 m wide.

C.3.12 Each of the two main components that make up an underground cable system has a design life of between 40 and 50 years.

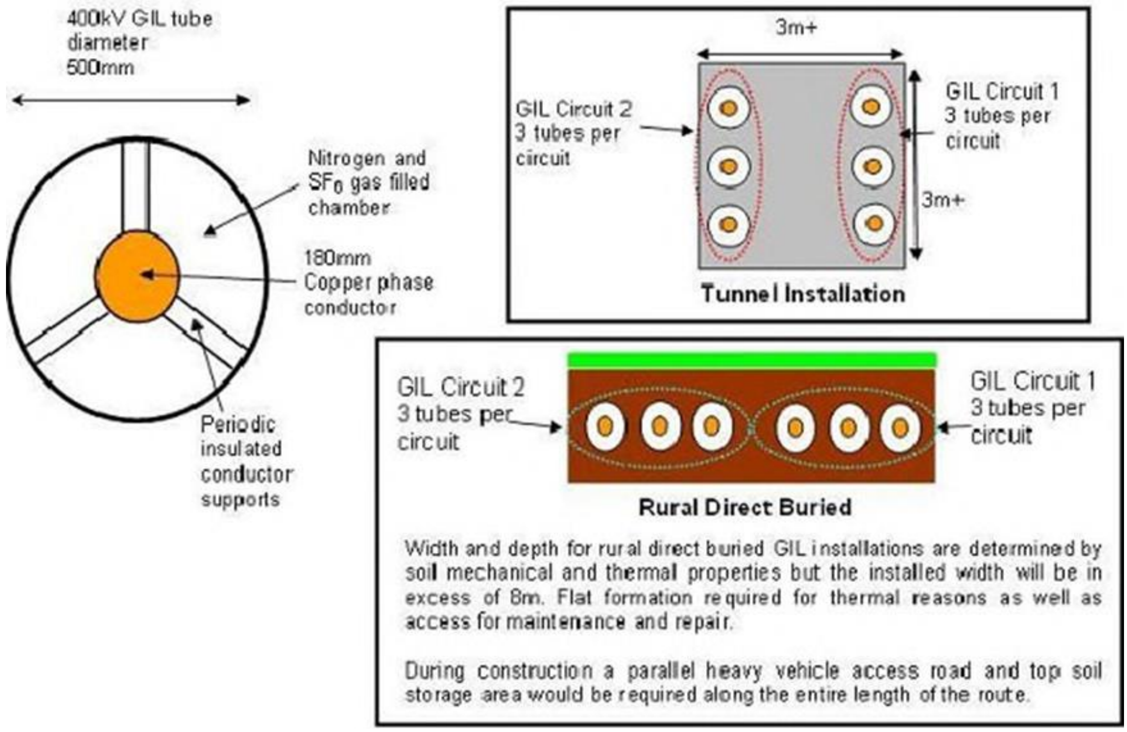
C.3.13 Asset replacement is generally expected at the end of design life. However, National Grid's asset replacement decisions (that are made at the end of design life) will also take account of actual asset condition and may lead to actual life being longer than the design life.

C.4 Gas Insulated Lines (GIL)

C.4.1 GIL is an alternative to underground cable for high voltage transmission. GIL has been developed from the well-established technology of gas insulated switchgear, which has been installed on the transmission system since the 1960s.

C.4.2 GIL uses a mixture of nitrogen and sulphur hexafluoride (SF_6) gas to provide the electrical insulation. GIL is constructed from welded or flanged metal tubes with an aluminium conductor in the centre. Three tubes are required per circuit, one tube for each phase. Six tubes are therefore required for two circuits, as illustrated in **Image C.6.**

Image C.6: Key components of GIL



C.4.3 GIL tubes are brought to site in 10–20 m lengths and they are joined in situ. It is important that no impurities enter the tubes during construction as impurities can cause the gas insulation to fail. GIL installation methods are therefore more onerous than those used in, for example, natural gas pipeline installations.

C.4.4 A major advantage of GIL compared to underground cable is that it does not require reactive compensation.

C.4.5 The installation widths over the land can also be narrower than cable installations, especially where more than one cable per phase is required.

C.4.6 GIL can have a reliability advantage over cable in that it can be re-energised immediately after a fault (similar to overhead lines) whereas a cable requires investigations prior to re-energisation. If the fault was a transient fault it will remain energised and if the fault was permanent the circuit will automatically and safely de-energise again.

C.4.7 There are environmental concerns with GIL as the SF_6[32] gas used in the insulating gas mixture is a potent 'greenhouse gas'. Since SF_6 is an essential part of the gas mixture, GIL installations are designed to ensure that the risk of gas leakage is minimised.

C.4.8 There are a number of ways in which the risk of gas leakage from GIL can be managed, which include:

- use of high integrity welded joints to connect sections of tube;
- designing the GIL tube to withstand an internal fault; and
- splitting each GIL tube into a number of smaller, discrete gas zones that can be independently monitored and controlled.

C.4.9 At decommissioning the SF_6 can be separated out from the gas mixture and either recycled or disposed of without any environmental damage.

C.4.10 GIL is a relatively new technology and therefore has limited historical data, meaning that its operational performance has not been empirically proven. National Grid has two GIL installations on the transmission system which are 545 m and 150 m long[33]. These are both in electricity substations: one is above ground and the other is in a trough. The longest directly buried transmission voltage GIL in the world is approximately one kilometre long and was recently installed on the German transmission system around Frankfurt Airport.

C.4.11 In the absence of proven design life information, and to promote consistency with assessment of other technology options, National Grid assesses GIL over a design life of up to 40 years.

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[32] SF_6 is a greenhouse gas with a global warming potential, according to the Intergovernmental Panel on Climate Change, Working Group 1 (Climate Change 2007, Chapter 2.10.2), of 22,800 times that of CO_2. www.ipcc.ch/publications_and_data/ar4/wg1/en/ch2s2-10-2.html

[33] The distances are based on initial manufacturer estimates of tunnel and buried GIL dimensions which would be subject to full technical appraisal by National Grid and manufacturers to achieve required ratings which may increase the separation required. It should be noted that the diagram does not show the swathe of land required during construction. Any GIL tunnel installations would have to meet the detailed design requirements of National Grid for such installations.

C.5 High Voltage Direct Current (HVDC)

C.5.1 HVDC technology can provide efficient solutions for the bulk transmission of electricity between AC electricity systems (or between points on an electricity system).

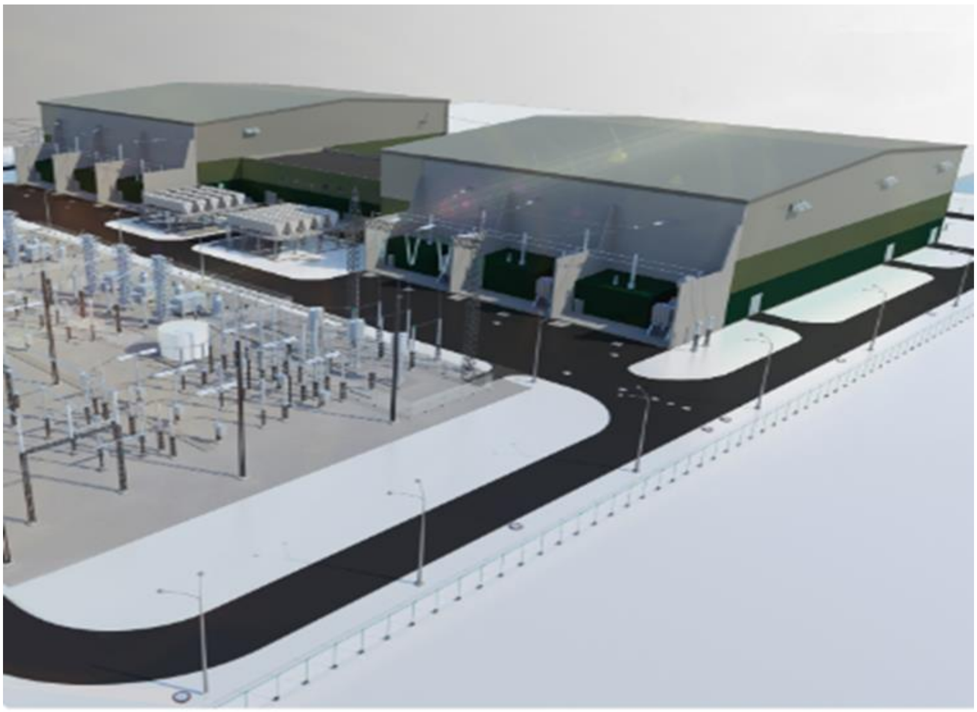
C.5.2 There are circumstances where HVDC has advantages over AC, generally where transmission takes place over very long distances or between different, electrically separate systems, such as between Great Britain and countries in Europe such as France, Belgium, the Netherlands, Ireland, etc.

C.5.3 HVDC links may also be used to connect a generating station that is distant from the rest of the electricity system. For example, very remote hydro-electric schemes in China are connected by HVDC technology with overhead lines.

C.5.4 Proposed offshore wind farms to be located over 60 km from the coast of Great Britain are likely to be connected using HVDC technology as an alternative to an AC subsea cable. This is because AC subsea cables over 60 km long have a number of technical limitations, such as high-charging currents and the need for mid-point compensation equipment.

C.5.5 The connection point between AC and DC electrical systems has equipment that can convert AC to DC (and vice versa), known as a converter. The DC electricity is transmitted at high voltage between converter stations. Convertor stations can use two types of technology. ‘Classic’ or Current Source Convertors (CSC) were the first type of HVDC technology developed and this design was used for National Grid’s Western Link. Voltage Source Convertors (VSC) are a newer design and offer advantages over the previous CSC convertors, as they can better support weaker systems and offer more flexibility in the way they operate, including direction of power flow.

Image C.7: VSC convertor station



C.5.6 HVDC can offer advantages over AC underground cable, such as:

- a minimum of two cables per circuit is required for HVDC whereas a minimum of three cables per circuit is required for AC;
- reactive compensation mid route is not required for HVDC;
- cables with smaller cross-sectional areas can be used (compared to equivalent AC system rating); and
- this allows HVDC cables to be more easily installed for subsea applications than AC cables for a given capacity.

C.5.7 HVDC cables are generally based upon two technology types: Mass Impregnated and Extruded technologies. VSC technology may utilise either technology type, whereas CSC technology tends to be limited to Mass Impregnated cables due to the way poles are reversed for change of power flow direction.

Image C.8: cable laying barge at transition between shore and sea cables

C.5.8 HVDC systems have a design life of about 40 years. This design life period is on the basis that large parts of the converter stations (valves and control systems) would be replaced after 20 years

Appendix D
Economic Appraisal

nationalgrid

Appendix D
Economic Appraisal

D.1.1 As part of the economic appraisal of strategic options, National Grid makes comparative assessments of the lifetime circuit costs associated with each technology option that are considered to be feasible.

D.1.2 This section provides an overview of the methods that National Grid uses to estimate lifetime circuit costs as part of the economic appraisal of a strategic option. It also provides a summary of generic capital cost information for transmission system circuits for each technology option included in **Appendix C** and an overview of the method that National Grid uses to assess the Net Present Value (NPV) of costs that are expected to be incurred during the lifetime of new transmission assets.

D.1.3 The IET, PB/CCI Report[34] presents cost information in size of transmission circuit capacity categories for each circuit design that was considered as part of the independent study. To aid comparison between the cost data presented in the IET PB/CCI Report and that used by National Grid for appraisal of strategic options, this appendix includes cost estimates using National Grid cost data for circuit designs that are equivalent to those considered as part of the independent study. Examples in this appendix are presented using the category size labels of ‘Lo’, ‘Med’ and ‘Hi’ used in the IET PB/CCI Report.

D.2 Lifetime Circuit Costs for Transmission

D.2.1 For each technology option appraised within a strategic option, National Grid estimates total lifetime circuit costs for the new transmission assets. The total lifetime circuit cost estimate consists of the sum of the estimates of the:

- initial capital cost of developing, procuring, installing and commissioning the new transmission assets; and
- NPV of costs that are expected to be incurred during the lifetime of these new transmission assets.

D.3 Lifetime Circuit Costs for Transmission

D.3.1 At the initial appraisal stage, National Grid prepares indicative estimates of the capital costs. These indicative estimates are based on the high level scope of works defined for each strategic option in respect of each technology option that is considered to be feasible. As these estimates are prepared before detailed design work has been carried out, National Grid takes account of equivalent assumptions for each option. Final project costs for any solution taken forward following detailed design and risk mitigation will be in excess of any high level appraisal cost. However, all options would incur these increases in the development of a detailed solution.

[34] Electricity Transmission Costing Study – An Independent Report Endorsed by the Institution of Engineering & Technology by Parsons Brinckerhoff in association with Cable Consulting International. Page 10 refers to Double circuit capacities. https://www.theiet.org/media/9376/electricity-transmission-costing-study.pdf

D.3.2 This section considers the capital costs in two parts: firstly the AC technology costs are discussed, followed by HVDC technologies. Each of these technologies is described in **Appendix C** in more detail.

D.4 AC Technology Capital Cost Estimates

D.4.1 **Table D.1** shows the category sizes that are relevant for AC technology circuit designs.

Table D.1: AC technology circuit designs

Category	Design	Rating
Lo	Two AC circuits of 1,595 MVA	3,190 MVA
Med	Two AC circuits of 3,190 MVA	6,380 MVA
Hi	Two AC circuits of 3,465 MVA	6,930 MVA

Table D.2: AC technology configuration and National Grid capital costs by rating

IET, PB/CCI Report Short-Form Label	Circuit Ratings by Voltage		Technology Configuration			Capital Costs		
	275 kV AC Technologies	400 kV AC Technologies	Overhead Line	AC Underground Cable (AC Cable)	Gas Insulated Line (GIL)	Overhead Line	AC Underground Cable (AC Cable)	Gas Insulated Line (GIL)
	Total rating for two Circuits (2 x rating of each circuit)	Total rating for two Circuits (2 x rating of each circuit)	No. of Conductors Sets 'bundles' on each arm/circuit of a pylon	No. of Cables per phase	No of direct buried GIL tubes per phase	Cost for a 'double' two circuit pylon route (Cost per circuit, of a double circuit pylon route)	Cost for a two circuit AC cable route (Cost per circuit, of a two circuit AC cable route)	Cost for a two circuit GIL route (Cost per circuit, of a two circuit GIL route)
Lo	3,190 MVA (2 x 1,595 MVA) [2,000 MVA 2 x 1,000 MVA for AC Cable only]	3,190 MVA (2 x 1,595 MVA)	2 conductor sets per circuit (6 conductors per circuit)	1 Cable per phase (3 cables per circuit)	1 tube per phase (3 standard GIL tubes per circuit)	£3.31m/km (£1.66m/km)	£16.35m/km (£8.17m/km)	£26.81m/km (£13.411m/km)
Med	N/A [3,190 MVA 2 x 1,595 MVA for AC Cable only]	6,380 MVA (2 x 3,190 MVA)	2 conductor sets per circuit (6 conductors per circuit)	2 Cables per phase (6 cables per circuit)	1 tube per phase (3 'developing' new large GIL tubes per circuit)	£3.64m/km (£1.82m/km)	£28.32m/km (£14.16m/km)	£31.13m/km (£15.56m/km)

IET, PB/CCI Report Short-Form Label	Circuit Ratings by Voltage		Technology Configuration			Capital Costs		
	275 kV AC Technologies	400 kV AC Technologies	Overhead Line	AC Underground Cable (AC Cable)	Gas Insulated Line (GIL)	Overhead Line	AC Underground Cable (AC Cable)	Gas Insulated Line (GIL)
	Total rating for two Circuits (2 x rating of each circuit)	Total rating for two Circuits (2 x rating of each circuit)	No. of Conductors Sets 'bundles' on each arm/circuit of a pylon	No. of Cables per phase	No of direct buried GIL tubes per phase	Cost for a 'double' two circuit pylon route (Cost per circuit, of a double circuit pylon route)	Cost for a two circuit AC cable route (Cost per circuit, of a two circuit AC cable route)	Cost for a two circuit GIL route (Cost per circuit, of a two circuit GIL route)
Hi	N/A	6,930 MVA (2 x 3,465 MVA)	3 conductor sets per circuit (9 conductors per circuit)	3 Cables per phase (9 cables per circuit)	2 tubes per phase (6 standard GIL tubes per circuit)	£3.98m/km (£1.99m/km)	£39.89m/km (£19.95m/km)	£43.25m/km (£21.63m/km)

Notes:

1. *Capital Costs for all technologies are based upon rural/arable land installation with no major obstacles (examples of major obstacles would be roads, rivers, railways, etc.).*
2. *All underground AC cable and GIL technology costs are for direct buried installations only. AC cable and GIL Tunnel installations would have a higher capital installation cost than direct buried rural installations. However, AC cable or GIL replacement costs following the end of conductor life would benefit from re-use of the tunnel infrastructure.*
3. *AC cable installation costs exclude the cost of reactors and mid-point switching stations, which are described later in this appendix.*
4. *275 kV circuits will often require Super-Grid Transformers (SGT) to allow connection into the 400 kV system, SGT capital costs are not included above but described later in this appendix.*
5. *275 kV AC cable installations above 1,000 MVA, as indicated in the table above, would require two cables per phase to be installed to achieve ratings of 1,595 MVA per circuit at 275 kV.*

D.4.2 **Table D.2** provides a summary of the capital costs associated with the key[35] components of transmission circuits for each technology option. Additional equipment is required for technology configurations that include new:

- AC underground cable circuits; and
- connections between 400 kV and 275 kV parts of the National Grid's transmission system.

D.4.3 The following sections provide an overview of the additional requirements associated with each of these technology options and indicative capital costs of additional equipment.

D.5 AC Underground Cable Additional Equipment

D.5.1 **Appendix C** of this report provides a summary of the electrical characteristics of AC underground cable systems and explains that reactive gain occurs on AC underground cables.

D.5.2 **Table D.3** provides a summary of the typical reactive gain within AC underground cable circuits forming part of National Grid's transmission system.

Table D.3: Reactive gain within AC underground cable circuits

Category	Voltage	Design	Reactive Gain Per Circuit
Lo	275 kV	One 2,500 mm^2 cable per phase	5 megavolt ampere reactive (Mvar)/km
Med	275 kV	Two 2,500 mm^2 cable per phase	10 Mvar/km
Lo	400 kV	One 2,500 mm^2 cable per phase	10 Mvar/km
Med	400 kV	Two 2,500 mm^2 cable per phase	20 Mvar/km
Hi	400 kV	Three 2,500 mm^2 cable per phase	30 Mvar/km

D.5.3 National Grid is required to ensure that reactive gain on any circuit that forms part of its transmission system does not exceed 225 Mvar. Above this limit, reactive gain would lead to unacceptable voltages (voltage requirements as defined in the NETS SQSS). In order to manage reactive gain and therefore voltages, reactors are installed on AC underground cable circuits to ensure that reactive gain in total is less than 225 Mvar.

D.5.4 For example, a 50 km 'Med' double circuit would have an overall reactive gain of 1,000 Mvar per circuit (2,000 Mvar in total for two circuits). The standard shunt reactor size installed at 400 kV on the National Grid transmission system is 200 Mvar. Therefore four 200 Mvar reactors (800 Mvar) need to be installed on each

[35] Components that are not required for all technology options are presented separately in this appendix.

circuit or eight 200 Mvar reactors (1,600 Mvar) reactors for the two circuits. Each of these reactors cost £8.7m adding £69.6m to an overall cable cost for the example double circuit above.

D.5.5 Mid-point switching stations may be required as part of a design to meet the reactive compensation requirements for AC underground cable circuit. The need for switching stations is dependent upon cable design, location and requirements which cannot be fully defined without detailed design.

D.5.6 For the purposes of economic appraisal of strategic options, National Grid includes a cost allowance that reflects typical requirements for switching stations. These are shown in **Table D.4**.

Table D.4: Substation to manage reactive gain within AC underground cable circuits

Category	Switching Station Requirement
Lo	Reactive Switching Station every 60 km between substations
Med	Reactive Switching Station every 30 km between substations
Hi	Reactive Switching Station every 20 km between substations

D.5.7 It is noted that more detailed design of AC underground cable systems may require a switching station after a shorter or longer distance than the typical values used by National Grid at the initial appraisal stage.

D.5.8 **Table D.5** shows the capital cost associated with AC underground cable additional equipment.

Table D.5: Additional costs associated with AC underground cables

Category	Cost Per Mid-Point Switching Station	Cost Per 200 Mvar Reactor
Lo	£15.09m	£8.7m per reactor
Med	£18.44m	
Hi	£18.44m	

D.6 Connections Between AC 275 kV and 400 kV Circuits Additional Equipment

D.6.1 Equipment that transforms voltages between 275 kV and 400 kV (a 400/275 kV supergrid transformer or ‘SGT’) is required for any new 275 kV circuit that connects to a 400 kV part of the National Grid’s transmission system (and vice versa). The number of SGTs needed is dependent on the capacity of the new circuit. National Grid can estimate the number of SGTs required as part of an indicative scope of works that is used for the initial appraisal of strategic options.

D.6.2 **Table D.6** shows the capital cost associated with the SGT requirements.

Table D.6: Additional costs associated with 275 kV circuits requiring connection to the 400 kV system

275 kV Equipment	Capital Cost (SGT – Including Civil Engineering Work)
400/275 kV SGT 1,100 MVA (excluding switchgear)	£7.75m per SGT

D.7 High-Voltage Direct Current (HVDC) Capital Cost Estimates

D.7.1 Conventional HVDC technology sizes are not easily translated into the 'Lo', 'Med' and 'Hi' ratings suggested in the IET, PB/CCI report. Whilst National Grid information for HVDC is presented for each of these categories, there are differences in the circuit capacity levels. As part of an initial appraisal, National Grid's assessment is based on a standard 2 GW converter size. Higher ratings are achievable using multiple circuits.

D.7.2 The capital costs of HVDC installations can be much higher than for equivalent AC overhead line transmission routes. Each individual HVDC link, between each converter station, requires its own dedicated set of HVDC cables. HVDC may be more economic than equivalent AC overhead lines where the route length is many hundreds of kilometres.

D.7.3 **Table D.7** provides a summary of technology configuration and capital cost information (in financial year 2020/21 prices) for each of the HVDC technology options that National Grid considers as part of an appraisal of strategic options.

Table D.7: HVDC technology capital costs for 2 GW installations

HVDC Converter Type	2 GW Total HVDC Link Converter Costs (Converter Cost at Each End)	2 GW DC Cable Pair Cost
Current Source Technology or 'Classic' HVDC	£475m HVDC link cost (£237.5m at each end)	£3.09m/km
Voltage Source Technology HVDC	£534.38m HVDC link cost (£267.19m at each end)	£3.09m/km

Notes:

- Sometimes a different HVDC capacity (different from the required AC capacity) can be *utilised for a project due to the different way HVDC technology can control power flow. The capacity requirements for HVDC circuits will be specified in any option considering HVDC. The cost shall be based upon **Table D.7**.*
- *Where a single HVDC Link is proposed as an option, to maintain compliance with the NETS SQSS, there may be a requirement to install an additional 'Earth Return' DC cable. For example, a 2 GW Link must be capable of operating at ½ its capacity, i.e. 1 GW during maintenance or following a cable fault. To allow this operation the additional cable known as an 'Earth Return' must be installed; this increases cable costs by a further 50 per cent to £4.6m/km.*
- *Capital Costs for HVDC cable installations are based upon subsea or rural/arable land installation with no major obstacles (examples of major* obstacles would be subsea pipelines, roads, rivers, railways, etc.).

D.7.4 Costs can be adjusted from this table to achieve equivalent circuit ratings where required. For example, a 'Lo' rating 3,190 MW would require two HVDC links of (1.6 GW capacity each), while 'Med' and 'Hi' rating 6,380 MW 6,930 MW would require three links with technology stretch of (2.1 2.3 GW each).

D.7.5 Converter costs at each end can also be adjusted, by linear scaling, from the cost information in **Table D.7**, to reflect the size of the HVDC link being appraised. HVDC Cable costs are normally left unaltered, as operating at the higher load does not have a large impact on the cable costs per km.

D.7.6 The capacity of HVDC circuits assessed for this report is not always exactly equivalent to the capacity of AC circuits assessed. However, **Table D.8** illustrates how comparisons may be drawn using scaling methodology outlined above.

Table D.8: Illustrative example using scaled 2 GW HVDC costs to match equivalent AC ratings (only required where HVDC requirements match AC technology circuit capacity requirements)

IET, PB/CCI Report Short-Form Label	Converter Requirements (Circuit Rating)	Total Cable Costs/km (Cable Cost Per Link)	CSC 'Classic' HVDC Total Converter Capital Cost (Total Converter Cost Per End)	VSC HVDC Total Converter Capital Cost (Total Converter Cost Per End)
Lo	2 x 1.6 GW HVDC Links (3,190 MW)	£5.82m/km (2 x £2.91m/km)	£704m (4 x £176m [4 converters 2 each end])	(4 x £736m (4 x £184m [4 converters 2 each end])
Med	3 x 2.1* GW HVDC Links (6,380 MW)	£9.27m/km (3 x £3.09m/km)	£1,422m (6 x £237m [6 converters 3 each end])	£1,602m (6 x £267m [6 converters 3 each end])
Hi	3 x 2.3* GW HVDC Links (6,930 MW)	£10.32m/km (3 x £3.44m/km)	£1,818m (6 x £303m [6 converters 3 each end])	£1,890m (6 x £315m [6 converter 3 each end])

Notes:

- *Costs based on 2 GW costs shown in **Table D.7** and **Table D.8** show how HVDC costs are estimated based upon HVDC capacity required for each option.*
- *Scaling can be used to estimate costs for any size of HVDC link required.*
- **Current subsea cable technology for VSC design restricted to 2 GW, so above examples illustrative if technology should become available.*

D.8 Indication of Technology End of Design Life Replacement Impact

D.8.1 It is unusual for a part of National Grid's transmission system to be decommissioned and the site reinstated. In general, assets will be replaced towards the end of the asset's design life. Typically, transmission assets will be decommissioned and removed only as part of an upgrade or replacement by different assets.

D.8.2 National Grid does not take account of replacement costs in the lifetime circuit cost assessment.

D.8.3 National Grid's asset replacement decisions take account of actual asset condition. This may lead to the actual life of any technology being longer or shorter than the design life, depending on the environment it is installed in, lifetime loading, equipment family failures among other factors for example.

D.8.4 The following provides a high-level summary of common replacement requirements applicable to specific technology options:

- Overhead line – Based on the design life of component parts, National Grid assumes an initial design life of around 40 years for overhead line circuits. After the initial 40-year life of an overhead line circuit, substantial pylon replacement works would not normally be required. The cost of pylons is reflected in the initial indicative capital costs, but the cost of replacement at 40 years would not include the pylon cost as pylons have an 80-year life and can be re-used to carry new replacement conductors. The replacement costs for overhead line circuits at the end of their initial design life are assessed by National Grid as being around 50 per cent of the initial capital cost, through the re-use of pylons.
- AC underground cable – At the end of their initial design life, circa 40 years, replacement costs for underground cables are estimated to be equal or potentially slightly greater than the initial capital cost. This is because of works being required to excavate and remove old cables prior to installing new cables in their place in some instances.
- GIL – At the end of the initial design life, circa 40 years, estimated replacement costs for underground GIL would be equal to or potentially greater than the initial capital cost. This is because of works being required to excavate and remove GIL prior to installing new GIL in their place in some instances.
- HVDC – It should be noted at the end of the initial design life, circa 40 years, replacement costs for HVDC are significant. This is due to the large capital costs for the replacement of converter stations and the cost of replacing underground or subsea DC cables when required.

D.9 Net Present Value Cost Estimates

D.9.1 At the initial appraisal stage, National Grid prepares estimates for the costs that are expected to be incurred during the design lifetime of the new assets. National Grid considers costs associated with:

- operation and maintenance; and
- electrical losses.

D.9.2 For both categories, NPV calculations are carried out using annual cost estimates and a generic percentage discount rate over the design life period associated with the technology option being considered.

D.9.3 The design life for all technology equipment is outlined in the technology description in **Appendix C**. The majority of expected design lives are of the order of 40 years, which is used to assess the following NPV cost estimates below[36].

D.9.4 In general, discount rates used in NPV calculations would be expected to reflect the normal rate of return for the investor. National Grid's current rate of return is 6.25 per cent. However, the Treasury Green Book recommends a rate of 3.5 per cent for the reasons set out below.

D.9.5 '*The discount rate is used to convert all costs and benefits to 'present values', so that they can be compared. The recommended discount rate is 3.5 per cent. Calculating the present value of the differences between the streams of costs and benefits provides the net present value (NPV) of an option. The NPV is the primary criterion for deciding whether government action can be justified.'*

D.9.6 National Grid considered the impact of using the lower Rate of Return (used by UK government) on lifetime circuit cost of losses assessments for transmission system investment proposals. Using the rate of 3.5 per cent will discount loss costs, at a lower rate than that of 6.25 per cent. This has the overall effect of increasing the 40 year cost of losses giving a more onerous cost of losses for higher loss technologies.

D.9.7 For the appraisal of strategic options, National Grid recognises the value of closer alignment of its NPV calculations with the approach set out by government for critical infrastructure projects.

D.10 Annual Operations and Maintenance Cost

D.10.1 The maintenance costs associated with each technology vary significantly depending upon type. Some electrical equipment is maintained regularly to ensure system performance is maintained. More complex equipment like HVDC converters have a significantly higher cost associated with them, due to their high maintenance requirements for replacement parts. **Table D.9** shows the cost of maintenance for each technology, which unlike capital and losses is not dependent on capacity.

[36] https://www.gov.uk/government/collections/the-green-book-and-accompanying-guidance-and-documentsParagraph 5.49 on Page 26 recommends a discount rate of 3.5 per cent calculation for NPV is also shown in the footnote of this page.

NPV calculations are carried out using the following equation over the period of consideration.

Dn =1/(1 + r)n

Where Dn = Annual Loss Cost, r = 3.5% and n = 40 years

Table D.9: Annual maintenance costs by technology

	Overhead Line	AC Underground Cable (AC Cable)	GIL	HVDC
Circuit Annual maintenance cost per two circuit km (AC) (Annual cost per circuit km [AC])	£2,660/km (£1,330/km)	£5,644.45/km (£2,822.22/km)	£2,687.83/km (£1,343.92/km)	£134/km Subsea Cables
Associated equipment Annual Maintenance cost per item	N/A	£6,719.58 per reactor £41,661 per switching station	N/A	£1,300,911 per converter station
Additional costs for 275 kV circuits requiring connection to the 400 kV system				
275/400 kV SGT 1,100 MVA Annual maintenance cost per SGT	£6,719.58 per SGT	£6,719.58 per SGT	£6,719.58 per SGT	N/A

D.11 Annual Electrical Losses and Cost

D.11.1 At a system level annual losses on the National Grid electricity system equate to less the 2 per cent of energy transported. This means that over 98 per cent of the energy entering the transmission system from generators/interconnectors reaches the bulk demand substations where the energy transitions to the distribution system. Electricity transmission voltages are used to reduce losses, as more power can be transported with lower currents at transmission level, giving rise to the very efficient loss level achieved of less than 2 per cent. The calculations below are used to show how this translates to a transmission route.

D.11.2 Transmission losses occur in all electrical equipment and are related to the operation and design of the equipment. The main losses within a transmission system come from heating losses associated with the resistance of the electrical circuits, often referred to as I2R losses (the electrical current flowing through the circuit, squared, multiplied by the resistance). As the load (the amount of power each circuit is carrying) increases, the current in the circuit is larger.

D.11.3 The average load of a transmission circuit which is incorporated into the transmission system is estimated to be 34 per cent (known as a circuit average utilisation). This figure is calculated from the analysis of the load on each circuit forming part of National Grid’s transmission system over the course of a year. This takes account of varying generation and demand conditions and is an appropriate assumption for the majority of strategic options.

D.11.4 This level of circuit utilisation is required because if a fault occurs there needs to be an alternative route to carry power to prevent wide scale loss of electricity for homes, business, towns and cities. Such events would represent a very small part of a circuit's 40 year life, but this availability of alternative routes is an essential requirement at all times to provide secure electricity supplies to the nation.

D.11.5 In all AC technologies the power losses are calculated directly from the electrical resistance and impedance properties of each technology and associated equipment. **Table D.10** provides a summary of circuit resistance data for each AC technology and the capacity options considered in this report.

Table D.10: AC circuit technologies and associated resistance per circuit

IET, PB/CCI Report Short-Form Label	AC Overhead Line Conductor Type (Complete Single Circuit Resistance for Conductor Set)	AC Underground Cable Type (Complete Single Circuit Resistance for Conductor Set)	AC GIL Type (Complete Single Circuit Resistance for Conductor Set)
Lo	2 x 570 mm^2 (0.025 Ω/km)	1 x 2,500 mm^2 (0.013 Ω/km*)	Single Tube per phase (0.0086 Ω/km)
Med	2 x 850 mm^2 (0.0184 Ω/km)	2 x 2,500 mm^2 (0.0065 Ω/km*)	Single Tube per phase (0.0086 Ω/km)
Hi	3 x 700 mm^2 (0.014 Ω/km)	3 x 2,500 mm^2 (0.0043 Ω/km*)	Two tubes per phase (0.0065 Ω/km)
Losses per 200 Mvar Reactor required for AC underground cables			
Reactor Losses	N/A	0.4 MW per reactor	N/A
Additional losses for 275 kV circuits requiring connection to the 400 kV system			
275 kV options only 275/400 kV SGT losses	0.2576 Ω (plus 83 kW of iron losses) per SGT	0.2576 Ω (plus 83 kW of iron losses) per SGT	0.2576 Ω (plus 83 kW of iron losses) per SGT

D.11.6 The process of converting AC power to DC is not 100 per cent efficient. Power losses occur in all elements of the converter station: the valves, transformers, reactive compensation/filtering and auxiliary plant. Manufacturers typically represent these losses in the form of an overall percentage. **Table D.11** shows the typical percentage losses encountered in the conversion process, ignoring losses in the DC cable circuits themselves.

Table D.11: HVDC circuit technologies and associated resistance per circuit

HVDC Converter Type	2 GW Converter Station Losses	2 GW DC Cable Pair Losses	2 GW Total Link Loss
Current Source (CSC) Technology or 'Classic' HVDC	0.5% per converter	Ignored	1% per HVDC Link
Voltage Source (VSC) Technology HVDC	1.0% per converter	Ignored	2% per HVDC Link

D.11.7 The example calculation explained in detail below is for 'Med' category circuits and has been selected to demonstrate the principles of the mathematics set out in this section. This example does not describe specific options set out within this report. A detailed example explanation of the calculations used to calculate AC losses is included in **Appendix E**.

D.11.8 The circuit category, for options contained within this report, is set out within each option. The example below demonstrates the mathematics and principles, which is equally applicable to 'Lo', 'Med' and 'Hi' category circuits, over any distance.

D.11.9 The example calculations (using calculation methodology described in **Appendix E**) of instantaneous losses for each technology option for an example circuit of 40 km 'Med' capacity 6,380 MVA (two x 3,190 MVA).

- Overhead Lines = (2 x 3) x 1,565.5 A2 x (40 x 0.0184 Ω/km) = 10.8 MW
- Underground Cable = (2 x 3) x1,565.5 A2 x (40 x 0.0065 Ω/km) + (6 x 0.4 MW) = 6.2 MW
- GIL = (2 x 3) x 1,565.5 A2 x (40 x 0.0086 Ω/km) = 5.1 MW
- CSC HVDC = 34% x 6,380 MW x 1% = 21.7 MW
- VSC HVDC = 34% x 6,380 MW x 2% = 43.4 MW

D.11.10 An annual loss figure can be calculated from the instantaneous loss. National Grid multiplies the instantaneous loss figure by the number of hours in a year and also by the cost of energy. National Grid uses £60/MWhr.

D.11.11 The following is a summary of National Grid's example calculations of Annual Losses and Maintenance costs for each technology option for an example circuit of 40 km 'Med' capacity 6,380 MVA (two x 3,190 MVA).

- Overhead Line annual loss = 10.8 MW x 24 x 365 x £60/MWhr = £5.7m
- Underground Cable annual loss = 6.2 MW x 24 x 365 x £60/MWhr = £3.3m
- GIL annual loss = 5.1 MW x 24 x 365 x £60/MWhr = £2.7m
- CSC HVDC annual loss = 21.7 MW x 24 x 365 x £60/MWhr = £11.4m
- VSC HVDC annual loss = 43.4 MW x 24 x 365 x £60/MWhr = £22.8m

D.12 Example Lifetime Circuit Costs and NPV Cost Estimate

D.12.1 The annual Operation, Maintenance and loss information is assessed against the NPV model at 3.5 per cent over 40 years and added to the capital costs to provide a lifetime circuit cost for each technology.

D.12.2 **Table D.12** shows an example for a 'Med' capacity route 6,380 MVA (2 x 3,190 MVA) 400 kV, 40 km in length over 40 years.

Table D.12: Example lifetime circuit cost table (rounded to the nearest £m)

Example 400 kV 'Med' Capacity Over 40 km	Overhead Line	AC Underground Cable (AC Cable)	GIL	CSC HVDC	VSC HVDC
Capital Cost	£145.6m	£1,167.6m	£1,244.8m	£1,795.8m	£1,973.9m
NPV Loss Cost over 40 years at 3.5% discount rate	£125m	£62.6m	£58.4m	£235.6m	£471.2m
NPV Maintenance Cost over 40 years at 3.5% discount rate	£2.33m	£5.5m	£2.4m	£171.7m	£171.7m
Lifetime Circuit Cost	£273m	£1,236m	£1,306m	£2,203m	£2,617m

Appendix E Mathematical Principles Used for AC Loss Calculation

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Appendix E
Mathematical Principles Used for AC Loss Calculation

E.1.1 This appendix provides a detailed description of the mathematical formulae and principles that National Grid applies when calculating transmission system losses. The calculations use recognised mathematical equations which can be found in power system analysis text books.

E.1.2 The example calculation explained in detail below is for ‘Med’ category circuits and has been selected to demonstrate the principles of the mathematics set out in this section. This example does not describe specific options set out within this report.

E.1.3 The circuit category, for options contained within this report, is set out within each option. The example below demonstrates the mathematics and principles, which are equally applicable to ‘Lo’, ‘Med’ and ‘Hi’ category circuits, over any distance.

E.2 Example Loss Calculation (1) – 40 km 400 kV ‘Med’ Category Circuits

E.2.1 The following is an example loss calculation for a 40 km 400 kV ‘Med’ category (capacity of 6,380 MVA made up of two 3,190 MVA circuits).

E.2.2 Firstly, the current flowing in each of the two circuits is calculated from the three phase power equation of $P= \sqrt{3}VLLILL \cos \theta$. Assuming a unity power factor ($\cos \theta = 1$), the current in each circuit can be calculated using a rearranged form of the three phase power equation of:

(In a star (Y) configuration electrical system $I = I_{LL} = I_{LN}$)

$I = P/\sqrt{3}V_{LL}$

Where, P is the circuit utilisation power, which is 34 per cent of circuit rating as set out in D.10 of **Appendix D**, which for each of the two circuits in the ‘Med’ category example is calculated as:

$P = 34\% \times 3{,}190 \text{ MVA} = 1{,}084.6 \text{ MVA}$

and VLL is the line to line voltage which for this example is 400 kV.

For this example, the average current flowing in each of the two circuits is:

$I = 1{,}084.6 \times 106/(\sqrt{3} \times 400 \times 103) = 1{,}565.5$ amps

E.2.3 The current calculated above will flow in each of the phases of the three phase circuit. Therefore from this value it is possible to calculate the instantaneous loss which occurs at the 34 per cent utilisation loading factor against circuit rating for any AC technology.

E.2.4 For this ‘Med’ category example, the total resistance for each technology option is calculated (from information in **Appendix D**, **Table D.10**) as follows:

Overhead Line = $0.0184\ \Omega/\text{km} \times 40\ \text{km} = 0.736\ \Omega$

Cable Circuit[37] = 0.0065 Ω/km x 40 km = 0.26 Ω

Gas Insulated Line = 0.0086 Ω/km x 40 km = 0.344 Ω

These circuit resistance values are the total resistance seen in each phase of that particular technology taking account the number of conductors needed for each technology option.

E.2.5 The following is a total instantaneous loss calculation for the underground cable technology option for the 'Med' category example:

Losses per phase are calculated using P=I2R

1,565.52 x 0.26 = 0.64 MW

Losses per circuit are calculated using P=3I2R

3 x 1,565.52 x 0.26 = 1.91 MW

Losses for 'Med' category are calculated by multiplying losses per circuit by number of circuits in the category.

2 x 1.91 MW = 3.8 MW

E.2.6 For underground cable circuits, three reactors per circuit are required (six in total for the two circuits in the 'Med' category). Each of these reactors has a loss of 0.4 MW. The total instantaneous losses for this 'Med' category example with the underground cable technology option are assessed as:

3.8 + (6 x 0.4) = 6.2 MW

E.2.7 The same methodology is applied for the other AC technology option types for the 'Med' category example considered in this appendix. The following is a summary of the instantaneous total losses that were assessed for each technology option:

Overhead Lines = (2 x 3) x 1,565.52 x 0.736 = 10.8 MW

Cables = (2 x 3) x 1,565.52 x 0.26 + (6 x 0.4) = 6.2 MW

Gas Insulated Lines = (2 x 3) x 1,565.52 x 0.344 = 5.1 MW

E.3 Example Loss Calculation (2) – 40 km 275 kV 'Lo' Category Circuits Connecting to a 400 kV Part of the National Grid's Transmission System

E.3.1 The following is an example loss calculation for a 40 km 275 kV 'Lo' category (capacity of 3,190 MVA made up of two 1,595 MVA circuits) and includes details of how losses of the supergrid transformer (SGT) connections to 400 kV circuits are assessed. This example assesses the losses associated with the GIL technology option up to a connection point to the 400 kV system.

E.3.2 The circuit utilisation power (P) which for the each of the two circuits in the 'Lo' category example is calculated as:

[37] A 40 km three phase underground cable circuit will also require three reactors to ensure that reactive gain is managed within required limits

P = 34% x 1,595 = 542.3 MVA

For this example, the average current flowing in each of the two circuits is:

$I = 542.3 \times 10^6 / (\sqrt{3} \times 275 \times 10^3) = 1{,}138.5$ amps

E.3.3 For this 'Lo' category example, the total resistance for the GIL technology option is calculated (from information in **Appendix D**, **Table D.10**) as follows:

0.0086 Ω/km x 40 km = 0.344 Ω

E.3.4 The following is a total instantaneous loss calculation for the GIL technology option for this 'Lo' category example:

Losses per circuit are calculated using P=3I2R

3 x 1,138.5 x 0.344 = 1.35 MW

Losses for 'Lo' category 275 kV circuits are calculated by multiplying losses per circuit by number of circuits in the category

2 x 1.35 MW = 2.7 MW

E.3.5 SGT losses also need to be included as part of the assessment for this 'Lo' category example which includes connection to 400 kV circuits. SGT resistance[38] is calculated (from information in **Appendix D**, **Table D.10**) as 0.2576 Ω.

E.3.6 The following is a total instantaneous loss calculation for the SGT connection part of this 'Lo' category example:

The average current flowing in each of the two SGT 400 kV winding are calculated as:

$I_{HV} = 542.3 \times 10^6 / (\sqrt{3} \times 400 \times 10^3) = 782.7$ amps

Losses per SGT are calculated using $P=3I^2R$

SGT Loss = 3 x 782.7 x 0.2576 = 0.475 MW

Iron Losses in each SGT = 84 kW

Total SGT instantaneous loss (one SGT per GIL circuit) = (2 x 0.475) + (2 x 0.084) = 1.1 MW.

E.3.7 For this example, the total 'Lo' category loss is the sum of the calculated GIL and SGT total loss figures:

'Lo' category loss = 2.7 + 1.1 = 3.8 MW

[38] Resistance value referred to the 400 kV side of the transformer.

Appendix F Glossary of Terms and Acronyms

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Appendix F
Glossary of Terms and Acronyms

AC	Alternating current
AC Cable	AC Underground Cable
ACS	Average cold spell
CBA	Cost Benefit Analysis
CNP	Critical national priority
Conductor	Used to transport power
CP30	Clean Power 2030
CP2030	Clean Power 2030
CSC	Current Source Converter
CSNP	Centralised Strategic Network Plan
DC	Direct current
DCO	Development consent order issued under the Planning Act 2008
EGL3	Eastern Green Link 3
EGL4	Eastern Green Link 4
Electricity Act	Electricity Act 1989
EMF	East Midlands Freeport
EN-1	Overarching National Policy Statement for Energy
EN-3	National Policy Statement for Renewable Energy Infrastructure
EN-5	National Policy Statement for Electricity Networks Infrastructure
ETYS	Electricity Ten Year Statement
ESO*	Electricity System Operator
EV	Electric Vehicle
FES	Future Energy Scenarios
FUE	Follow-Up Exercise
GIL	Gas insulated lines
HND	Holistic Network Design
HVDC	High voltage direct current
IBA	Important Bird Area
IET, PB/CCI Report	An independent report endorsed by the Institution of Engineering and Technology by Parsons Brinckerhoff in association with Cable Consulting International
Insulators	Used to safely connect conductors to pylons

LDO	Local Development Order
MITS	Main interconnected transmission system
MVA	Megavolt ampere
Mvar	Megavolt ampere reactive
National Grid	National Grid Electricity Transmission plc
NESO*	National Electricity System Operator
NETS	National Electricity Transmission System
NETS SQSS	National Electricity Transmission System Security and Quality of Supply Standard
NGET	National Grid Electricity Transmission
NIC	National Infrastructure Commission
NISTA	National Infrastructure and Service Transformation Authority
NOA	Network Options Assessment
NPFF	National Planning Policy Framework
NPS	National Policy Statements
NPV	Net Present Value
NSIP	Nationally Significant Infrastructure Project
OAST	Options Appraisal Summary Table
Ofgem	The Office of Gas and Electricity Markets
(the) Policy	National Grid's Stakeholder, Community and Amenity Policy
Pylons	Used to support conductors
RIBA	Royal Institute of British Architects
SF_6	Sulphur hexafluoride (gas used to provide electrical insulation)
SGT	Super-Grid Transformer
SOR	Strategic Options Report
SP Energy Networks	Scottish Power Energy Networks
SPA	Special Protection Area
Span length	Distance between adjacent pylons
SQSS	System Security and Quality of Supply Standard
SSEN	Scottish and Southern Energy Networks
SSSI	Site of Special Scientific Interest
STC	System Operator – Transmission Owner Code
tCSNP2	Transitional Centralised Strategic Network Plan 2
TEC	Transmission Entry Capacity
The Authority	Gas and Electricity Markets Authority, the governing body of Ofgem

TO	Transmission Owner
T-pylon	Monopole pylon design developed by National Grid
Transmission Licence	Licence granted under section 6(1)(b) of the Electricity Act
volt (V)	The electrical unit of potential difference 1 kilovolt (kV) = 1,000 volts
VSC	Voltage Source Convertors
watt (W)	The SI unit of power 1 kilowatt (kW) = 1,000 watts 1 megawatt (MW) = 1,000 kW 1 gigawatt (GW) = 1,000 MW
XLPE	Cross Linked Polyethylene (solid material used to provide electrical insulation)

** NESO replaced ESO on 1 October 2024. Throughout this SOR there are references to ESO documents that were published prior to this change.*

Appendix G Environmental and Socio-Economic Study Maps

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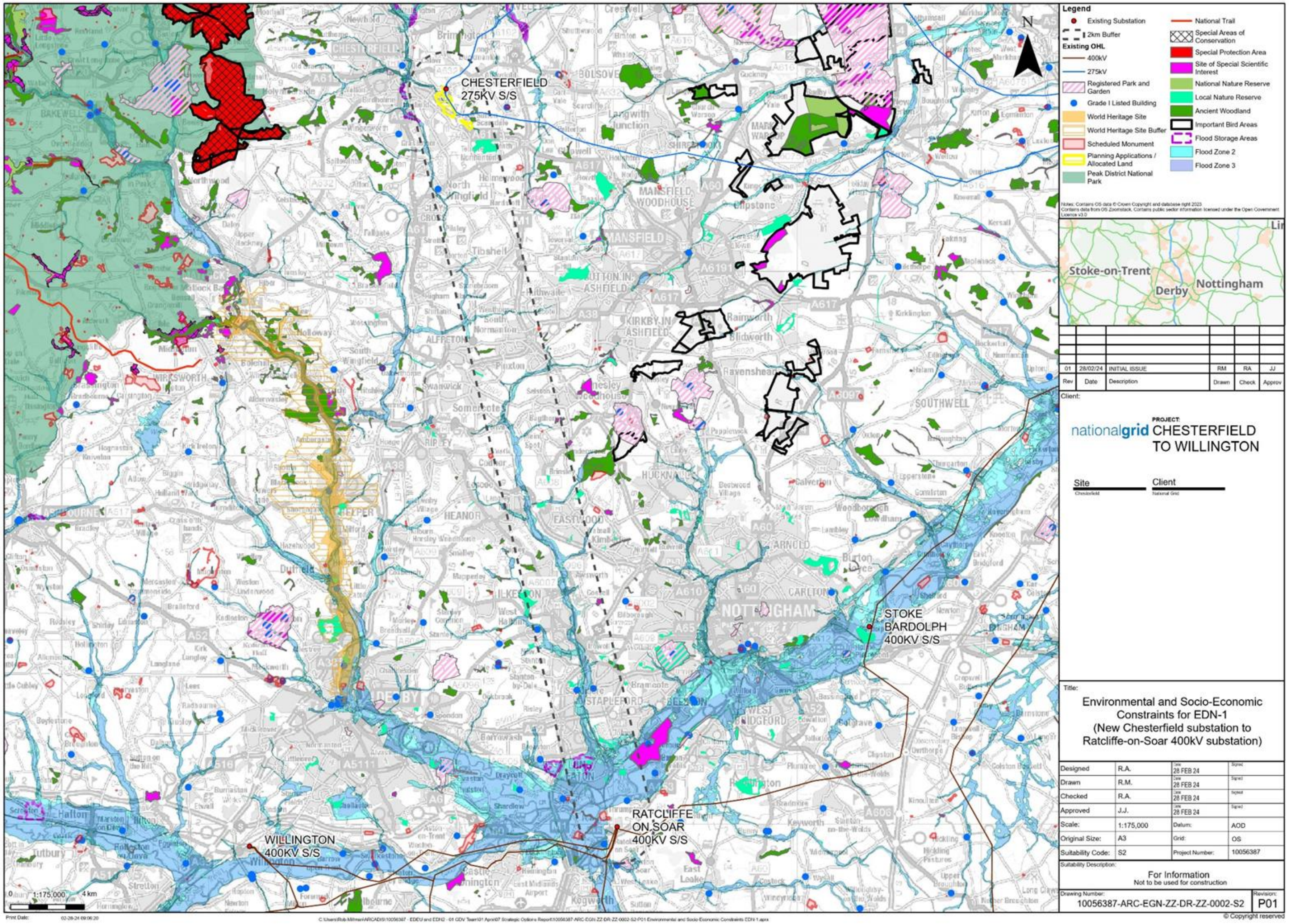
Appendix G
Environmental and Socio-Economic Study Maps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Peak District National Park
National Trail
Special Areas of Conservation
Special Protection Area
Site of Special Scientific Interest
National Nature Reserve
Local Nature Reserve
Ancient Woodland
Important Bird Areas
Flood Storage Areas
Flood Zone 2
Flood Zone 3
Notes: Contains OS data © Crown Copyright and database right 2023
Contains data from OS Zoomstack. Contains public sector information licensed under the Open Government Licence v3.0
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STOKE BARDOLPH 400KV S/S
RATCLIFFE ON SOAR 400KV S/S
WILLINGTON 400KV S/S
Stoke-on-Trent
Derby
Nottingham
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nationalgrid
PROJECT:
CHESTERFIELD TO WILLINGTON
Title:
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Designed R.A. 28 FEB 24
Drawn R.M. 28 FEB 24
Checked R.A. 28 FEB 24
Approved J.J. 28 FEB 24
Scale: 1:175,000 Datum: AOD
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Suitability Code: S2 Project Number: 10056387
Suitability Description:
For Information
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Revision: P01
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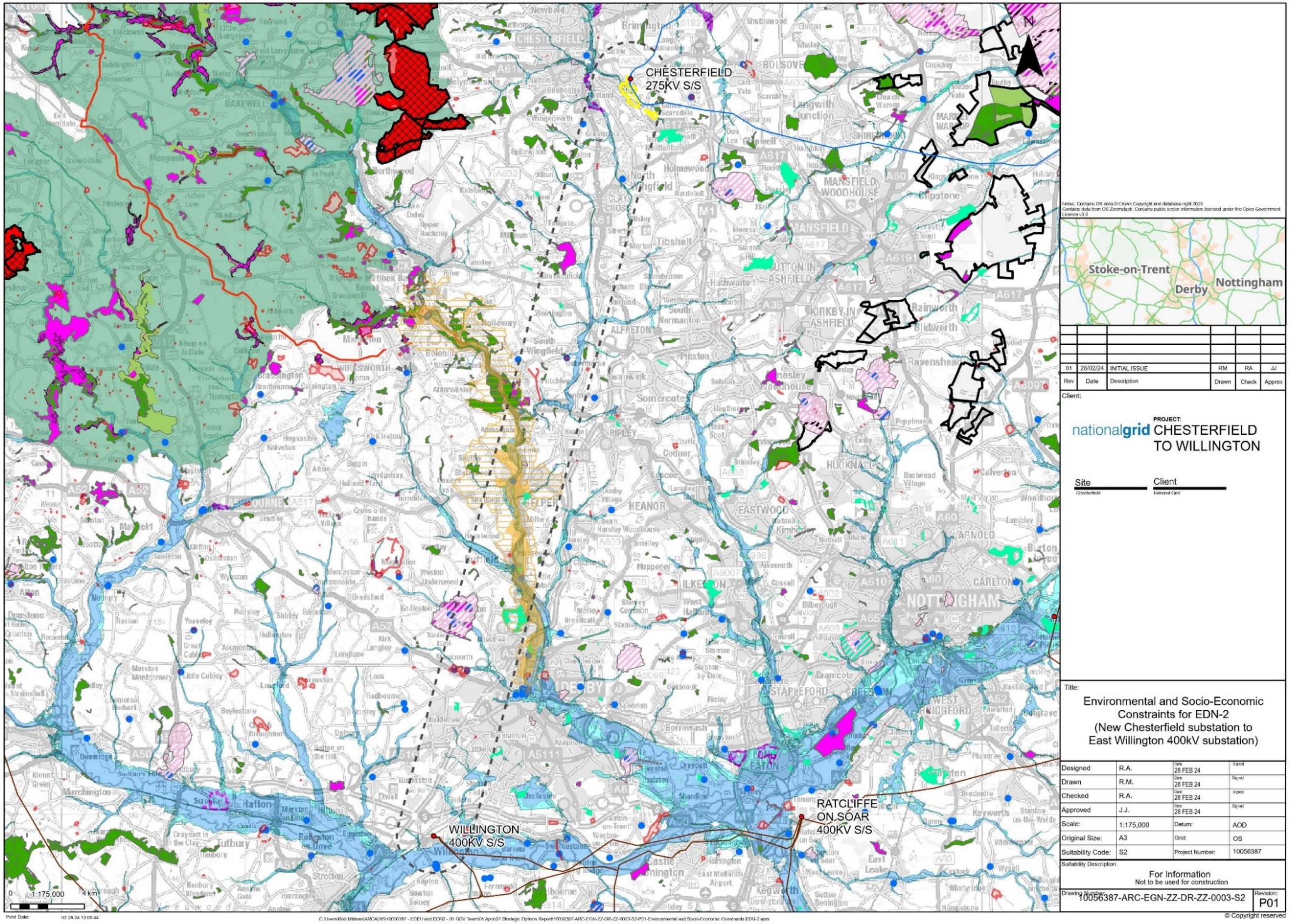
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Client:
nationalgrid
PROJECT:
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Checked R.A. Date 28 FEB 24
Approved J.J. Date 28 FEB 24
Scale: 1:175,000 Datum: AOD
Original Size: A3 Grid: OS
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Suitability Description:
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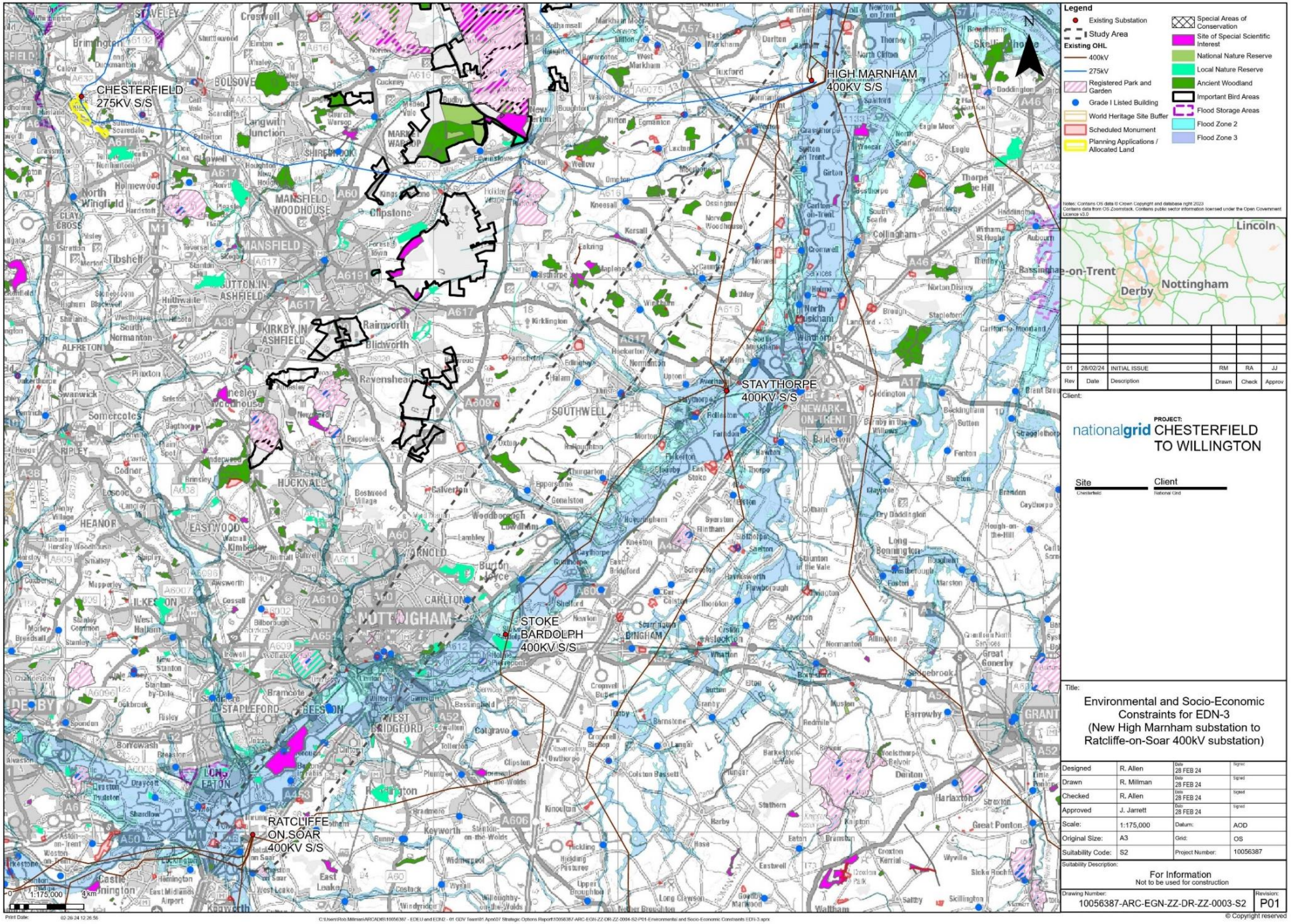
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400kV
275kV
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Grade I Listed Building
World Heritage Site Buffer
Scheduled Monument
Planning Applications / Allocated Land
Special Areas of Conservation
Site of Special Scientific Interest
National Nature Reserve
Local Nature Reserve
Ancient Woodland
Important Bird Areas
Flood Storage Areas
Flood Zone 2
Flood Zone 3
CHESTERFIELD 275KV S/S
HIGH MARNHAM 400KV S/S
STAYTHORPE 400KV S/S
STOKE BARDOLPH 400KV S/S
RATCLIFFE ON SOAR 400KV S/S
Lincoln
Nottingham
Derby
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nationalgrid
PROJECT: CHESTERFIELD TO WILLINGTON
Site
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Title:
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Drawn R. Millman 28 FEB 24
Checked R. Allen 28 FEB 24
Approved J. Jarrett 28 FEB 24
Scale: 1:175,000 Datum: AOD
Original Size: A3 Grid: OS
Suitability Code: S2 Project Number: 10056387
Suitability Description:
For Information
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Drawing Number: 10056387-ARC-EGN-ZZ-DR-ZZ-0003-S2
Revision: P01
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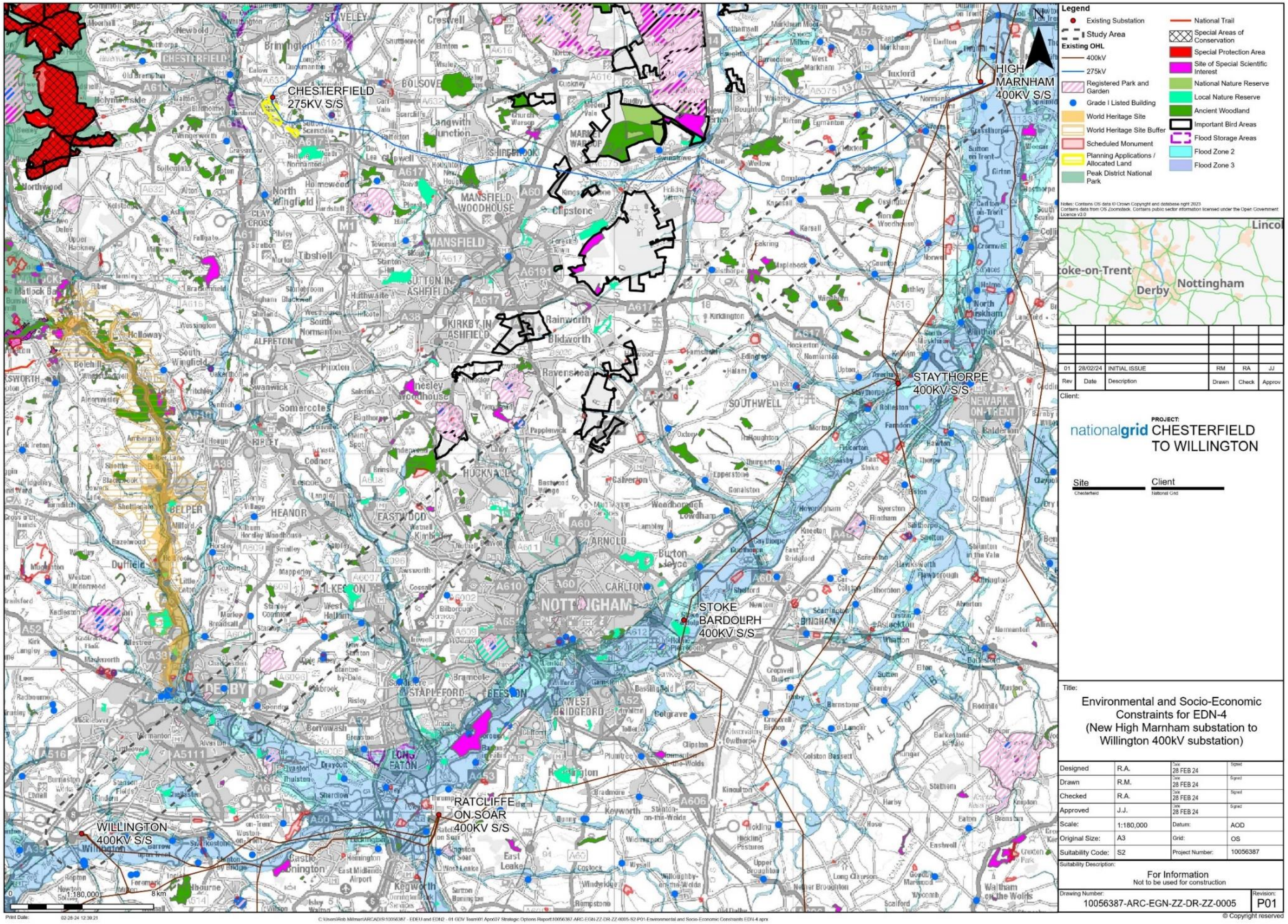

Legend
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Study Area
Existing OHL
400kV
275kV
Registered Park and Garden
Grade I Listed Building
World Heritage Site
World Heritage Site Buffer
Scheduled Monument
Planning Applications / Allocated Land
Peak District National Park
National Trail
Special Areas of Conservation
Special Protection Area
Site of Special Scientific Interest
National Nature Reserve
Local Nature Reserve
Ancient Woodland
Important Bird Areas
Flood Storage Areas
Flood Zone 2
Flood Zone 3
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CHESTERFIELD 275KV S/S
HIGH MARNHAM 400KV S/S
STAYTHORPE 400KV S/S
STOKE BARDOLPH 400KV S/S
RATCLIFFE ON SOAR 400KV S/S
WILLINGTON 400KV S/S
CHESTERFIELD
MANSFIELD
NOTTINGHAM
DERBY
Stoke-on-Trent
Derby
Nottingham
Lincol
01 | 28/02/24 | INITIAL ISSUE | RM | RA | JJ
Rev | Date | Description | Drawn | Check | Approv
Client:
nationalgrid
PROJECT: CHESTERFIELD TO WILLINGTON
Site: Chesterfield
Client: National Grid
Title:
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Designed: R.A. | 28 FEB 24
Drawn: R.M. | 28 FEB 24
Checked: R.A. | 28 FEB 24
Approved: J.J. | 28 FEB 24
Scale: 1:180,000 | Datum: AOD
Original Size: A3 | Grid: OS
Suitability Code: S2 | Project Number: 10056387
Suitability Description: For Information
Not to be used for construction
Drawing Number: 10056387-ARC-EGN-ZZ-DR-ZZ-0005
Revision: P01
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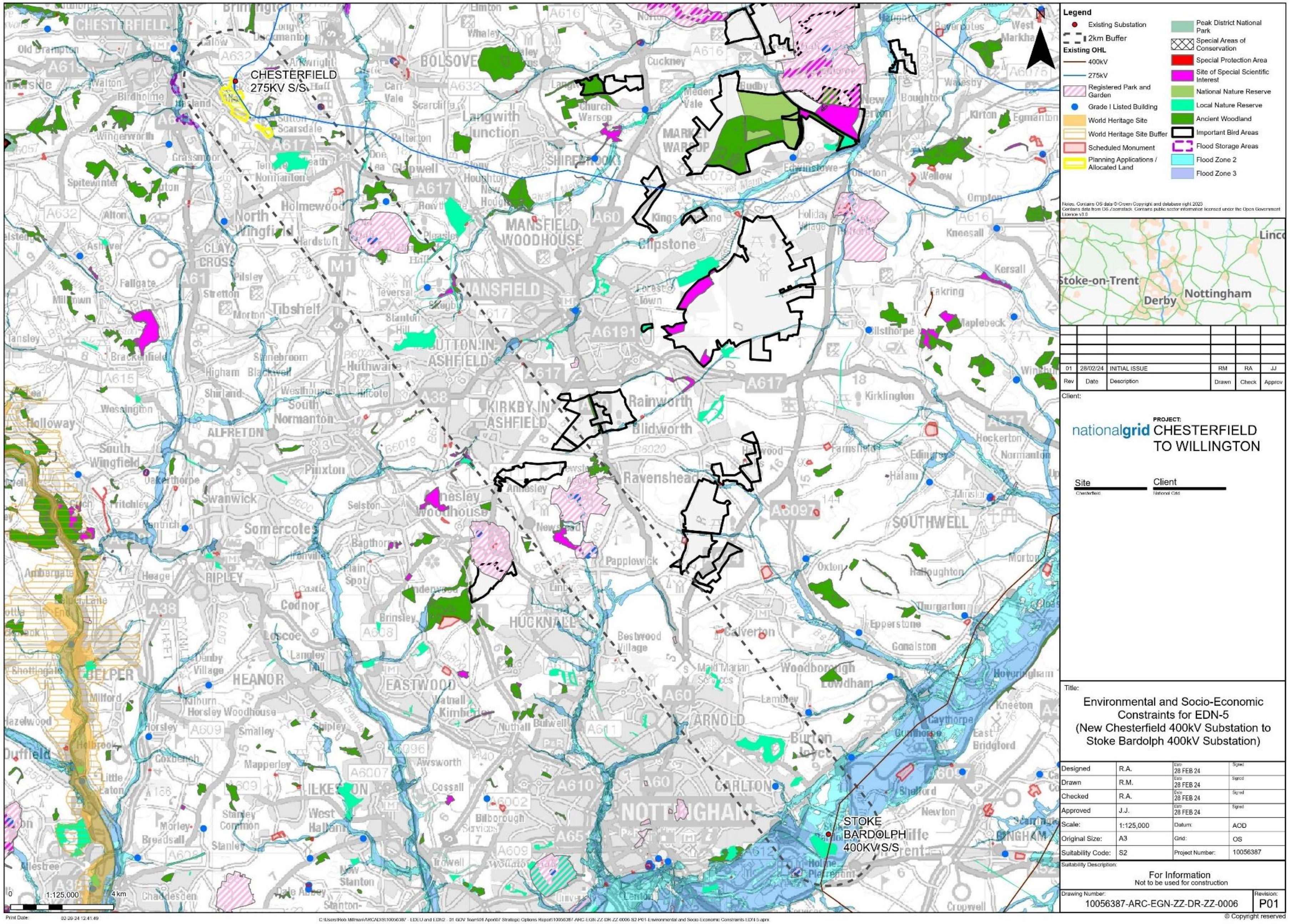
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Existing OHL
400kV
275kV
Registered Park and Garden
Grade I Listed Building
World Heritage Site
World Heritage Site Buffer
Scheduled Monument
Planning Applications / Allocated Land
Peak District National Park
Special Areas of Conservation
Special Protection Area
Site of Special Scientific Interest
National Nature Reserve
Local Nature Reserve
Ancient Woodland
Important Bird Areas
Flood Storage Areas
Flood Zone 2
Flood Zone 3
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Derby
Nottingham
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Rev | Date | Description | Drawn | Check | Approv
Client:
nationalgrid
PROJECT:
CHESTERFIELD TO WILLINGTON
Site
Client
Title:
Environmental and Socio-Economic Constraints for EDN-5 (New Chesterfield 400kV Substation to Stoke Bardolph 400kV Substation)
Designed | R.A. | Date 28 FEB 24 | Signed
Drawn | R.M. | Date 28 FEB 24 | Signed
Checked | R.A. | Date 28 FEB 24 | Signed
Approved | J.J. | Date 28 FEB 24 | Signed
Scale: | 1:125,000 | Datum: | AOD
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Not to be used for construction
Drawing Number:
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Revision:
P01
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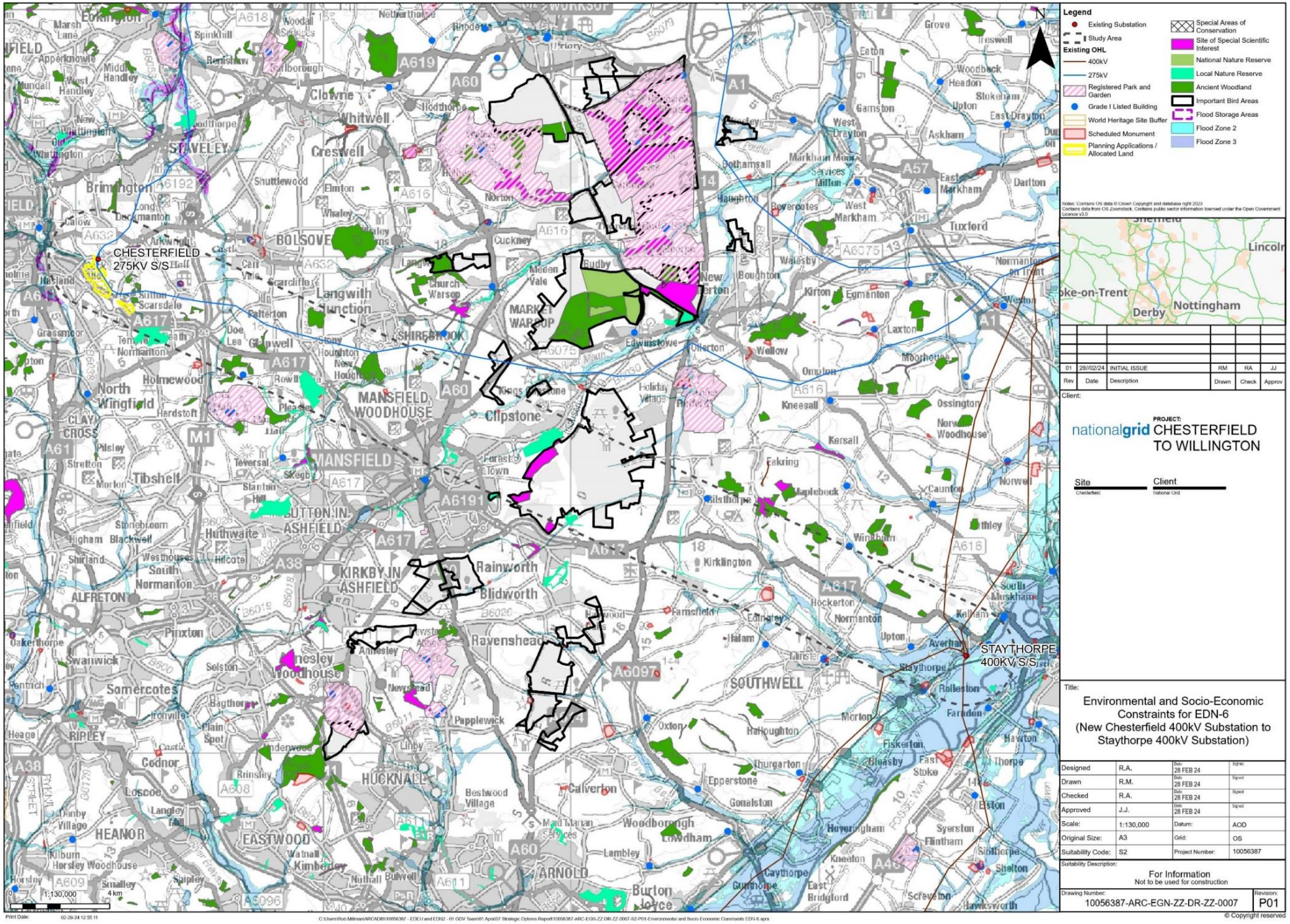
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Scheduled Monument
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Special Areas of Conservation
Site of Special Scientific Interest
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Local Nature Reserve
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Important Bird Areas
Flood Storage Areas
Flood Zone 2
Flood Zone 3
CHESTERFIELD 275KV S/S
STAYTHORPE 400KV S/S
MANSFIELD
SOUTHWELL
01 28/02/24 INITIAL ISSUE RM RA JJ
Rev Date Description Drawn Check Approv
Client:
nationalgrid
PROJECT: CHESTERFIELD TO WILLINGTON
Title:
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Designed R.A. 28 FEB 24
Drawn R.M. 28 FEB 24
Checked R.A. 28 FEB 24
Approved J.J. 28 FEB 24
Scale: 1:130,000 Datum: AOD
Original Size: A3 Grid: OS
Suitability Code: S2 Project Number: 10056387
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Drawing Number: 10056387-ARC-EGN-ZZ-DR-ZZ-0007
Revision: P01
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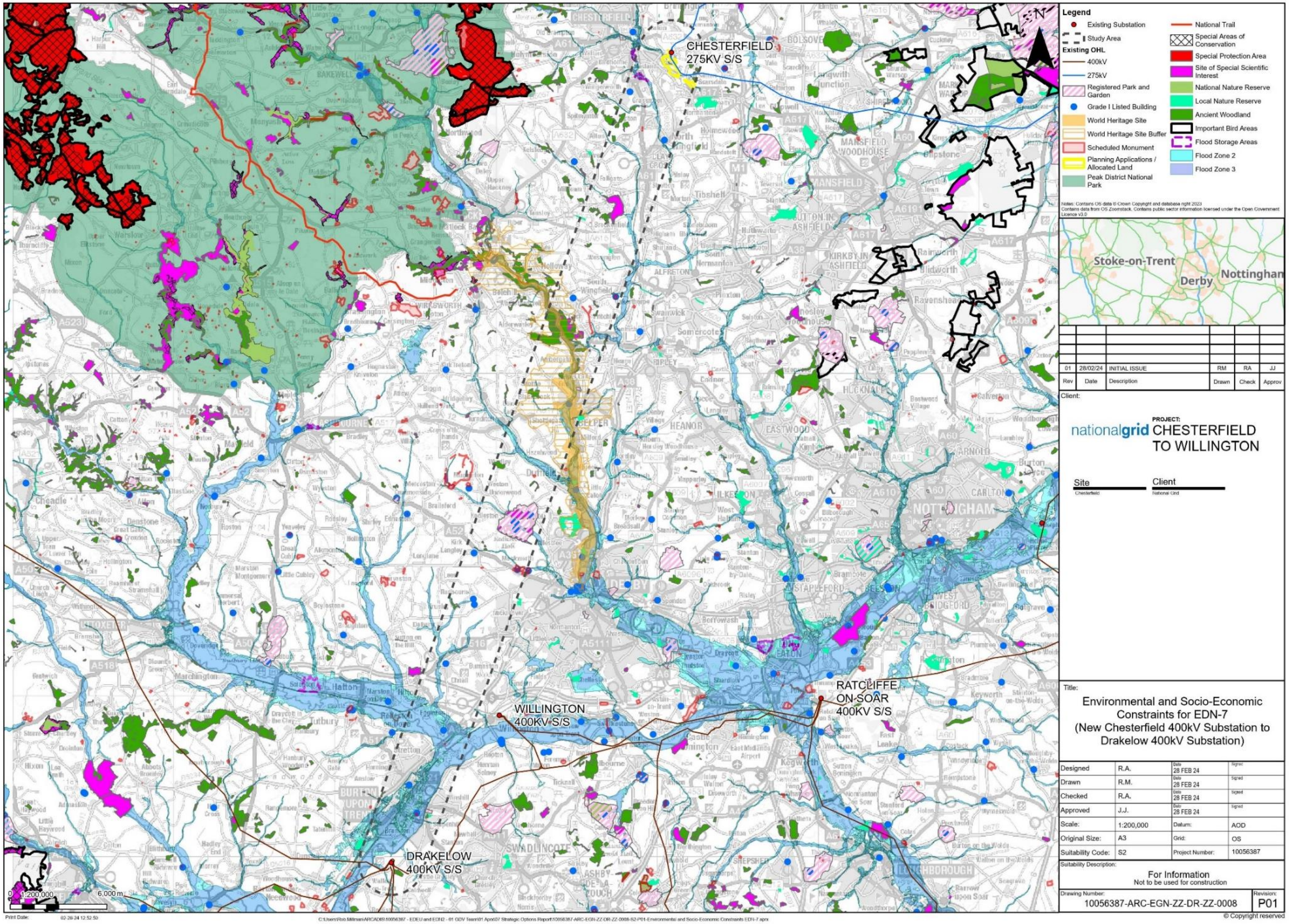

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Peak District National Park
National Trail
Special Areas of Conservation
Special Protection Area
Site of Special Scientific Interest
National Nature Reserve
Local Nature Reserve
Ancient Woodland
Important Bird Areas
Flood Storage Areas
Flood Zone 2
Flood Zone 3
CHESTERFIELD 275KV S/S
WILLINGTON 400KV S/S
RATCLIFFE ON-SOAR 400KV S/S
DRAKELOW 400KV S/S
Stoke-on-Trent
Derby
Nottingham
01 28/02/24 INITIAL ISSUE RM RA JJ
Rev Date Description Drawn Check Approv
Client:
nationalgrid
PROJECT: CHESTERFIELD TO WILLINGTON
Site
Client
Title:
Environmental and Socio-Economic Constraints for EDN-7 (New Chesterfield 400kV Substation to Drakelow 400kV Substation)
Designed R.A. 28 FEB 24
Drawn R.M. 28 FEB 24
Checked R.A. 28 FEB 24
Approved J.J. 28 FEB 24
Scale: 1:200,000 Datum: AOD
Original Size: A3 Grid: OS
Suitability Code: S2 Project Number: 10056387
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Drawing Number: 10056387-ARC-EGN-ZZ-DR-ZZ-0008
Revision: P01
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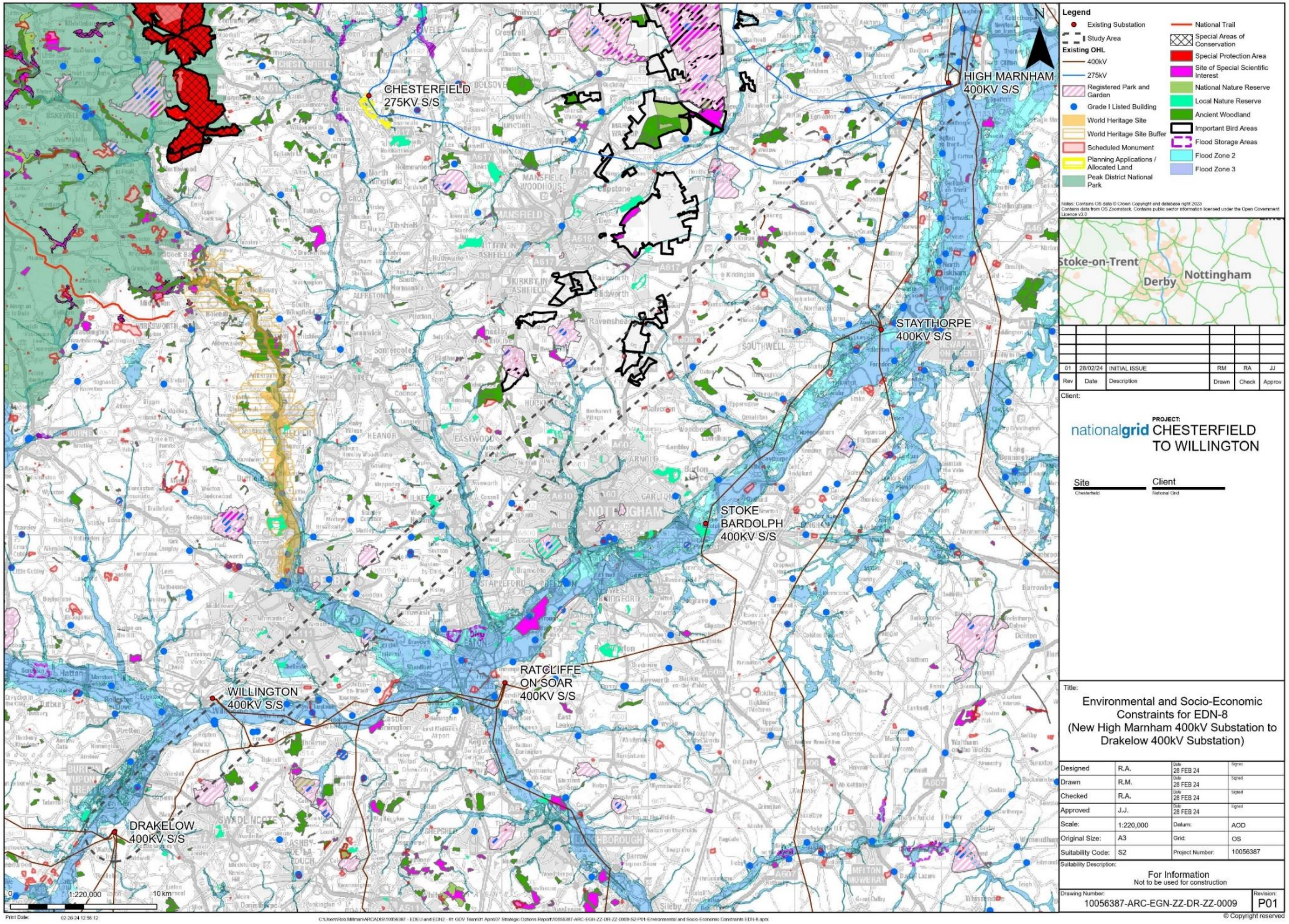
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WILLINGTON 400KV S/S
DRAKELOW 400KV S/S
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Legend
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Study Area
Existing OHL
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275kV
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Planning Applications / Allocated Land
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National Trail
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Ancient Woodland
Important Bird Areas
Flood Storage Areas
Flood Zone 2
Flood Zone 3
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Nottingham
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Client:
nationalgrid
PROJECT: CHESTERFIELD TO WILLINGTON
Site
Client
Title:
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(New High Marnham 400kV Substation to Drakelow 400kV Substation)
Designed | R.A. | Date 28 FEB 24
Drawn | R.M. | Date 28 FEB 24
Checked | R.A. | Date 28 FEB 24
Approved | J.J. | Date 28 FEB 24
Scale: | 1:220,000 | Datum: | AOD
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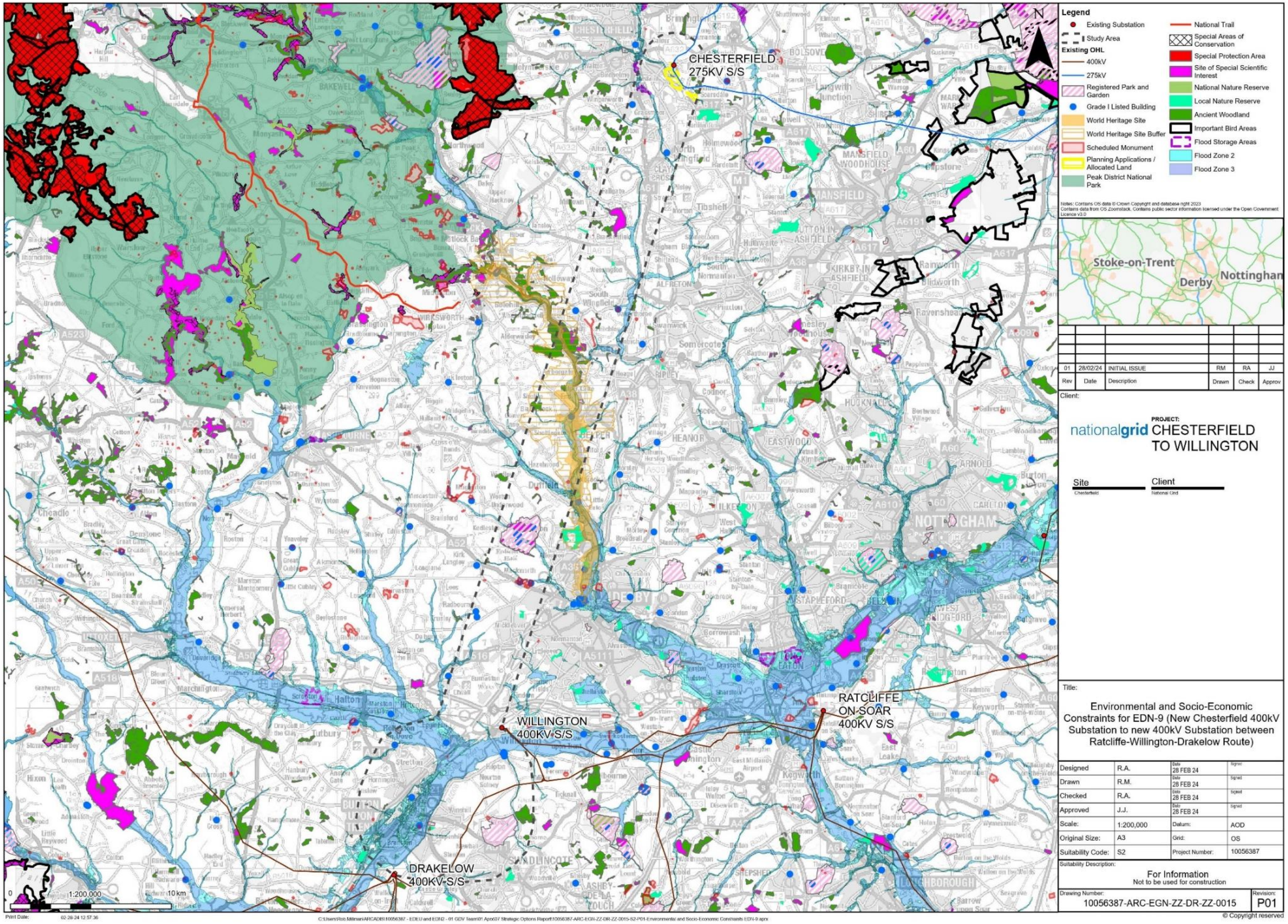
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National Trail
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Site of Special Scientific Interest
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Local Nature Reserve
Ancient Woodland
Important Bird Areas
Flood Storage Areas
Flood Zone 2
Flood Zone 3
CHESTERFIELD 275KV S/S
WILLINGTON 400KV S/S
RATCLIFFE-ON-SOAR 400KV S/S
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Rev | Date | Description | Drawn | Check | Approv
Client:
nationalgrid
PROJECT: CHESTERFIELD TO WILLINGTON
Site
Client
Title:
Environmental and Socio-Economic Constraints for EDN-9 (New Chesterfield 400kV Substation to new 400kV Substation between Ratcliffe-Willington-Drakelow Route)
Designed R.A. 28 FEB 24
Drawn R.M. 28 FEB 24
Checked R.A. 28 FEB 24
Approved J.J. 28 FEB 24
Scale: 1:200,000 Datum: AOD
Original Size: A3 Grid: OS
Suitability Code: S2 Project Number: 10056387
Suitability Description: For Information Not to be used for construction
Drawing Number: 10056387-ARC-EGN-ZZ-DR-ZZ-0015
Revision: P01
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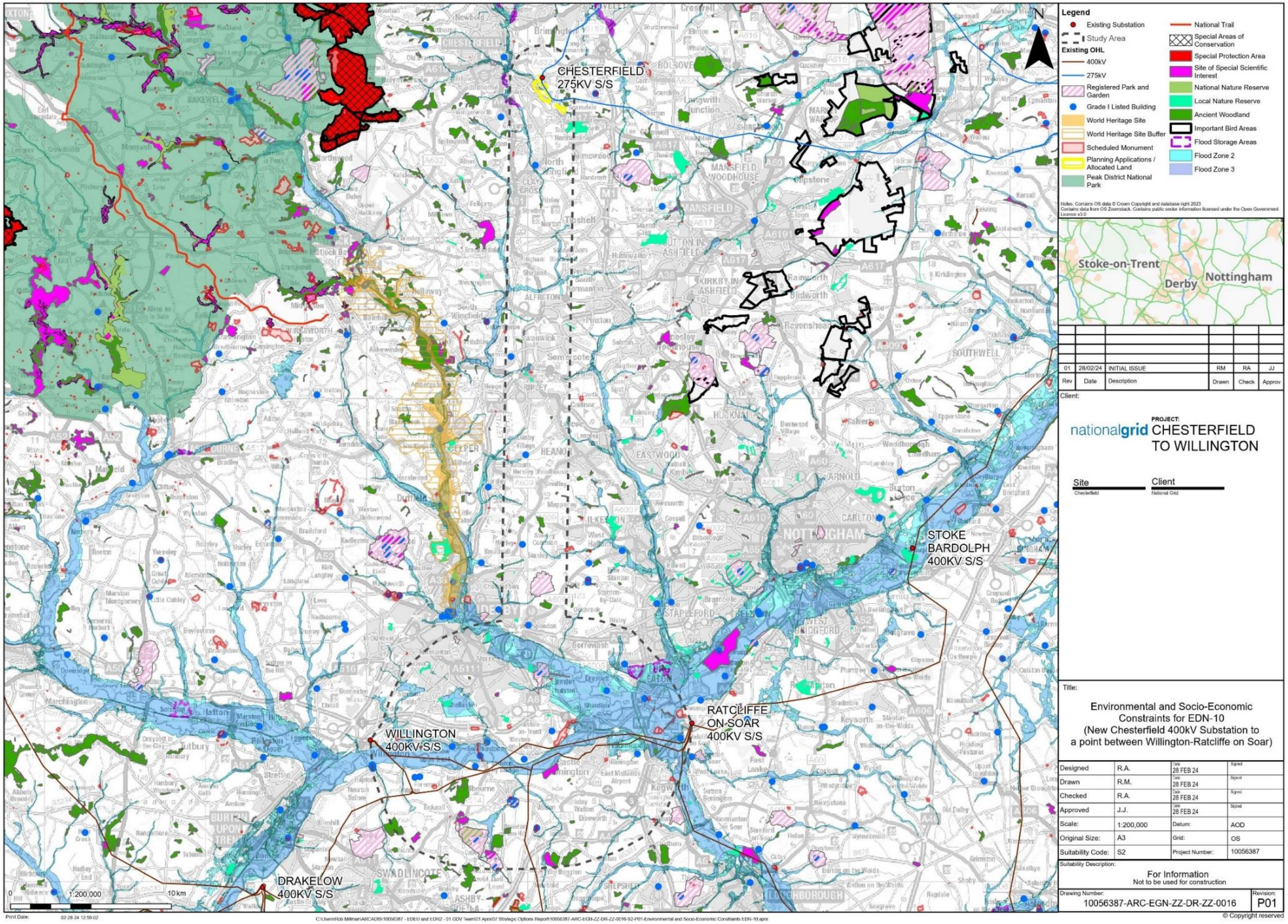

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Planning Applications / Allocated Land
Peak District National Park
National Trail
Special Areas of Conservation
Special Protection Area
Site of Special Scientific Interest
National Nature Reserve
Local Nature Reserve
Ancient Woodland
Important Bird Areas
Flood Storage Areas
Flood Zone 2
Flood Zone 3
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CHESTERFIELD 275KV S/S
STOKE BARDOLPH 400KV S/S
RATCLIFFE ON-SOAR 400KV S/S
WILLINGTON 400KV S/S
DRAKELOW 400KV S/S
Stoke-on-Trent
Derby
Nottingham
01 28/02/24 INITIAL ISSUE RM RA JJ
Rev Date Description Drawn Check Approv
Client:
nationalgrid
PROJECT: CHESTERFIELD TO WILLINGTON
Site
Client
Title:
Environmental and Socio-Economic Constraints for EDN-10 (New Chesterfield 400kV Substation to a point between Willington-Ratcliffe on Soar)
Designed R.A. 28 FEB 24
Drawn R.M. 28 FEB 24
Checked R.A. 28 FEB 24
Approved J.J. 28 FEB 24
Scale: 1:200,000 Datum: AOD
Original Size: A3 Grid: OS
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0 1:200,000 10 km

Appendix H
Beyond 2030
Publication

nationalgrid

Appendix H
Beyond 2030 Publication

H.1 Pathway to 2030 – HND

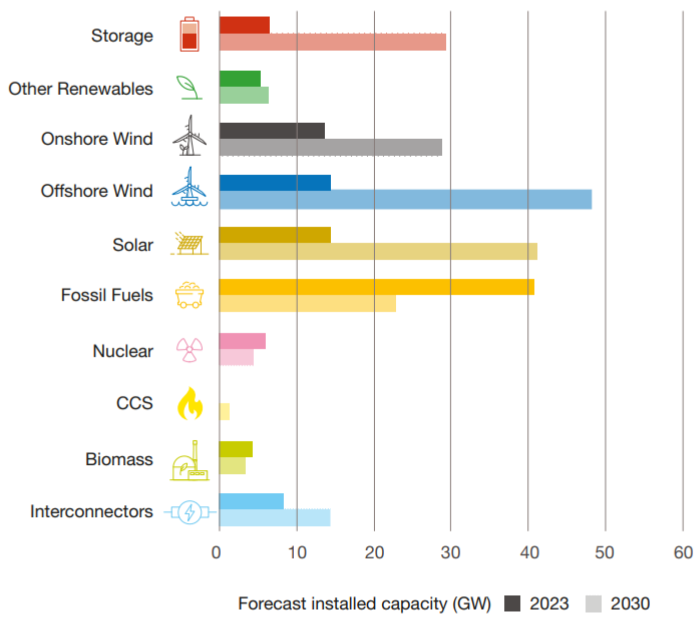
H.1.1 In 2023, 51 per cent of the electricity Great Britain used was generated by zero-carbon sources. It is expected that by 2030, the electricity system will more commonly run on 100 per cent renewable energy sources for measurable time frames, which will be vital to meet the UK government's ambition of having an electricity mix consisting of 95 per cent low-carbon power.

H.1.2 Adjacent to the changes in the electricity network, gas consumption has also been projected to fall by 40 per cent by 2030, which will be realised through the potential to replace natural gas with hydrogen where possible, and the potential to create opportunities to make use of economically efficient and reliable electricity for heating and transport.

H.1.3 This transition can be facilitated through the development of large-scale offshore wind generation, a sector that has seen Great Britain arise as a world leader. Within offshore wind, refinement of the approach used can help reduce the effects of increased infrastructure needs to effectively transfer power across the transmission system. The previous UK government established the Offshore Transmission Network Review with the goal of developing a holistic network design that will ensure the delivery of 50 GW of offshore wind by 2030 remains viable.

H.1.4 The bar chart (**Image H.1**) from the Beyond 2030 report shows the generation mix in 2023 in comparison to the forecasted mix in 2030.

Image H.1: Generation mix comparison (2023 and 2030) [source: Beyond 2030, ESO, March 2024]



H.1.5 ESO’s Pathway to 2030 Holistic Network Design (HND) 2022 plan to connect 23 GW of offshore wind in the transmission system seeks to reduce reliance on imports of gas and reduce CO_2 emissions by up to two million tonnes between 2030 and 2032. To facilitate this growth in the offshore sector, a recommendation of over £60 billion of investment into the transmission system has been made. This investment will comprise of offshore network design and 91 reinforcements to the transmission system, resulting in a holistic approach to network planning.

H.1.6 To enable this plan, engagement with the Great Britain energy regulator, Ofgem, was required. It was concluded that a customer benefit of up to £2.1 billion would be expedited through avoidance of network congestion costs, which led Ofgem to agree on the regulatory acceleration of 26 projects in 2022.

H.1.7 The essential transmission opportunities to enable delivery of the plan in 2030 are presented in **Image H.2**. Notably, Grimsby to Walpole and North Humber to High Marnham are both HND essential.

Image H.2: Network infrastructure to be delivered by 2030 [source: Beyond 2030, ESO, March 2024]

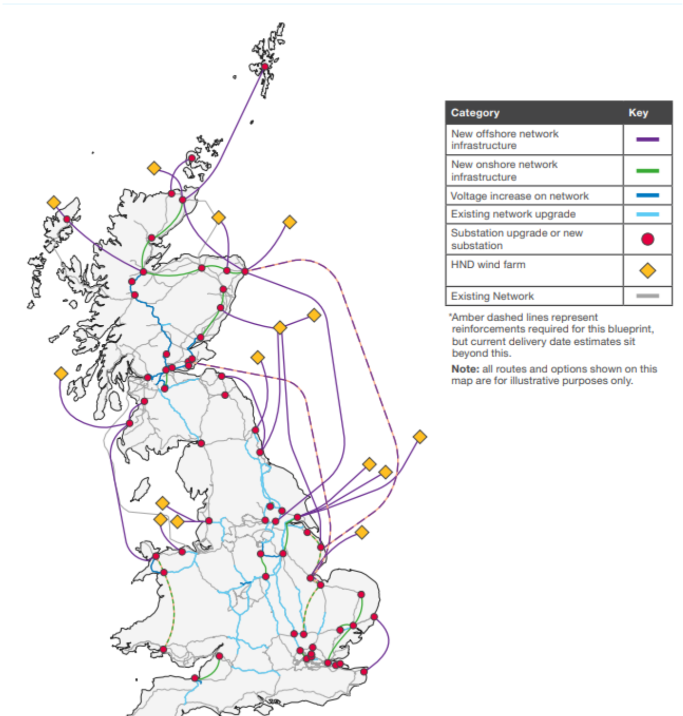


Figure 7. Map of network infrastructure to be delivered by 2030

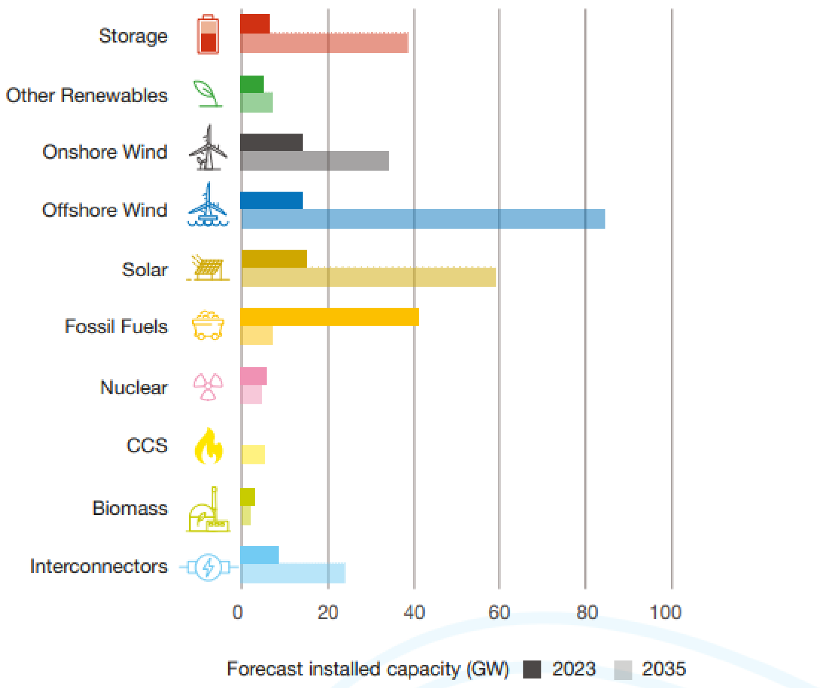
H.2 Beyond 2030 – HND FUE

H.2.1 Scoping beyond 2030, by 2035, several processes will be fully electrified and will be realised even in everyday life activities. New internal combustion engine cars will not be sold, with only Electric Vehicles (EVs) and other zero-carbon transport options being newly available for purchase. In addition, domestic gas boilers will not be installed in new homes from 2025. The above will result in an uptake of up to approximately 30 million EVs present and up to 13 million heat pumps installed domestically and within businesses, with overall electricity demand expected to rise by 64 per cent, in comparison to 2023.

H.2.2 The potential realised through innovation in technology development will enable further increase in the renewable energy capacity within power industries. As an example, clean hydrogen is forecasted to have a production capacity of up to 22 GW by 2035.

H.2.3 The bar chart (**Image H.3**) from the Beyond 2030 report shows the generation mix in 2023 in comparison to the forecasted mix in 2035.

Image H.3: Generation mix comparison (2023 and 2035) [source: Beyond 2030, ESO, March 2024]



H.2.4 As it stands, the HND scheme is not sufficient by itself to reinforce the transmission system within the Pathway to 2030, as more electricity will be generated than the network can efficiently support and transport. Therefore, the UK government requested ESO to further develop the HND and enable a set of recommendations for a greater amount of offshore wind generation to connect to the network.

H.2.5 ESO have undertaken a network assessment of options to facilitate an efficient high-level network design, in cooperation with Great Britain's TOs. This design implements a further 21 GW of offshore wind generation which will establish Great Britain as the owner of the largest offshore fleet in Europe. The design will be a set of holistic recommendations of measurable scale with over three times as much undersea cabling (compared to current infrastructure) needed by 2035. With this in place, power flows can be further balanced across the transmission system, enhancing energy security and reliability of supply.

H.2.6 Development of network infrastructure is required through this network design and will need to consider minimising impacts on the environment and communities. These impacts can be reduced via optimisation of network designs, early community engagement, innovative solutions and sufficient financial incentives and community packages.

H.2.7 **Image H.4** depicts the network infrastructure to be delivered beyond 2030 within the transmission system.

Image H.4: Network infrastructure to be delivered beyond 2030 [source: Beyond 2030, ESO, March 2024]

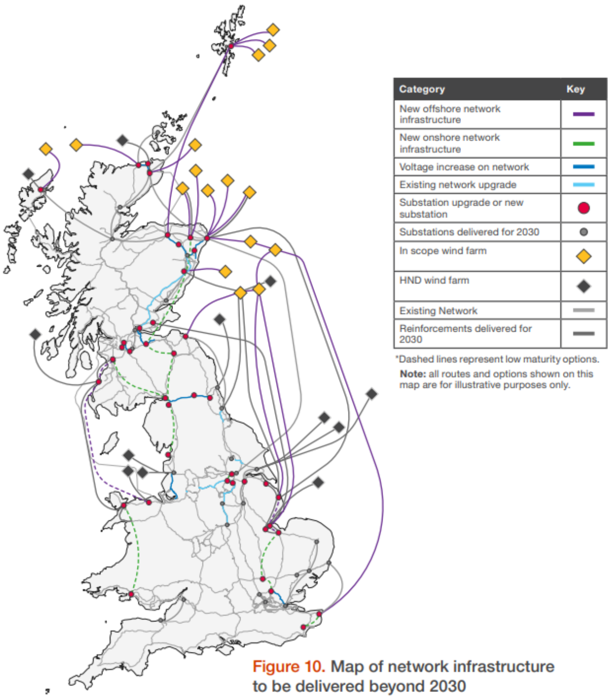


Figure 10. Map of network infrastructure to be delivered beyond 2030

H.3 Way Forward

H.3.1 The Beyond 2030 report builds on the 2022 HND and is a key step towards the effort to upgrade Great Britain's electricity transmission infrastructure. Both publications support the ambition of connecting a total of 86 GW of offshore wind as well as an array of other low-carbon technologies, potentially adding up to £15 billion to the economy. The plan also aims to produce significant supply chain benefits, create jobs, and facilitate greater energy security.

H.3.2 Central to achieving these goals is the UK government's Transmission Acceleration Action Plan from November 2023, which outlines a series of activities to reduce network delivery times and gain societal consent for the transformational infrastructure changes.

H.3.3 The Beyond 2030 report also sets out the key role of strategic demand – utilising efficient placement of generation to potentially reduce future infrastructure needs. The TOs will commence the Detailed Network Design phase to optimise the Beyond 2030 report’s proposed designs. Continued coordination among project developers is crucial to minimise environmental and community impacts. Continued alignment with broader industry and policy changes to facilitate the decarbonisation of Great Britain's electricity system is crucial and will facilitate the necessary transition to whole energy system planning to meet rising energy needs.

National Grid plc
National Grid House,
Warwick Technology Park,
Gallows Hill, Warwick.
CV34 6DA United Kingdom

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