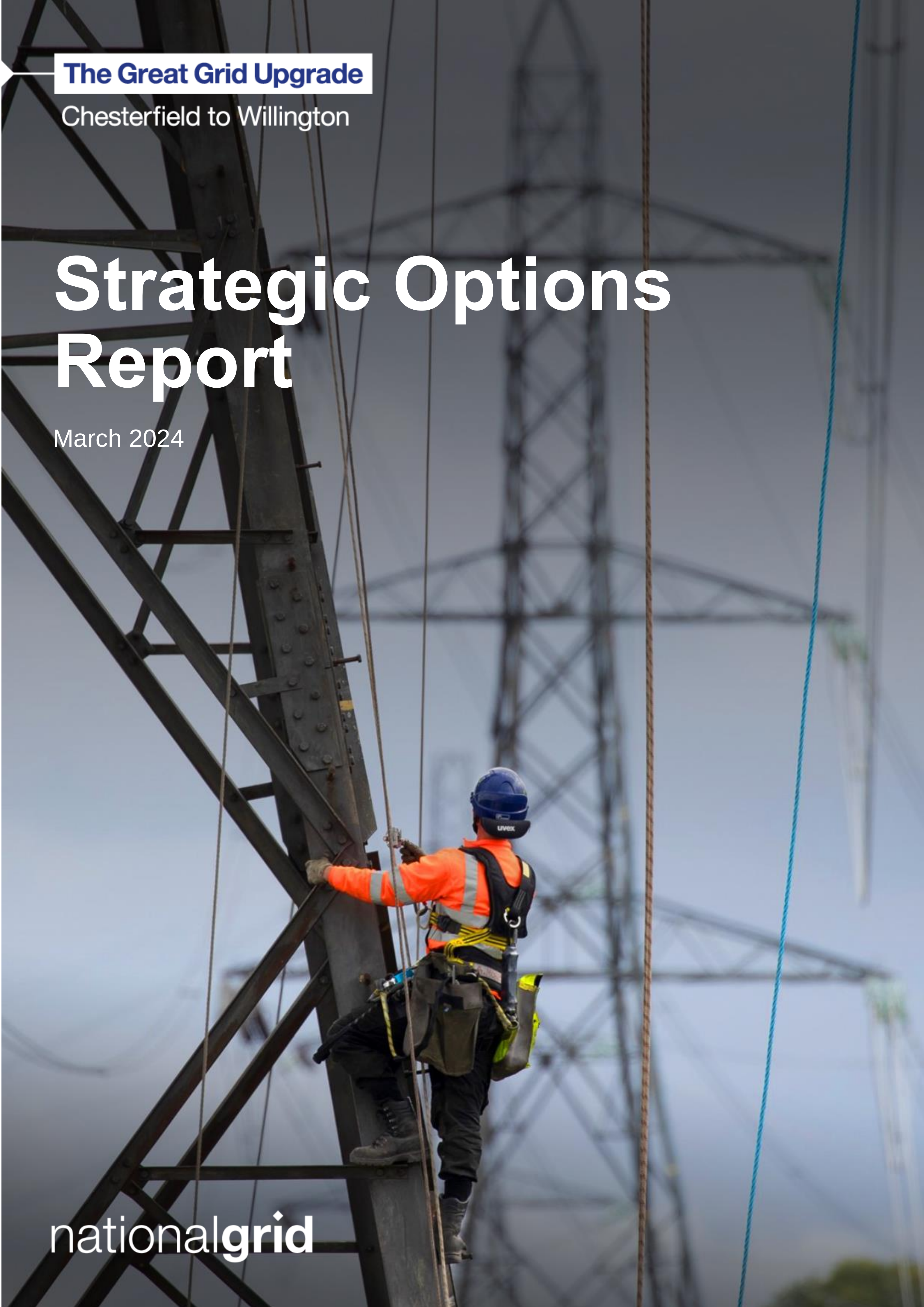

The Great Grid Upgrade

Chesterfield to Willington

Strategic Options Report

March 2024

nationalgrid

Contents

Chesterfield to Willington Document control

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Executive summary

Purpose of this report

This Strategic Options Report 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 below:

Figure A – National Grid Project Lifecycle

This report forms part of the initial 'Options identification and selection' stage.

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 transmission system in England and Wales and holds an electricity transmission licence permitting transmission ownership activities. Our transmission licence requires that we provide 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'). Transmission services include maintaining reliable electricity supplies and offering to construct new transmission system assets for new connections to the National Electricity Transmission System ('NETS').

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.

The Electricity System Operator (ESO)

The Electricity System Operator (ESO) is a separate legal entity to National Grid, but as of 2024 it is still part of the National Grid Group. The ESO facilitates several roles on behalf of the electricity industry, including making formal offers to applicants requesting connection to the NETS. The ESO also manages shortfalls in capacity by reducing power flows and constraining generation. This is achieved by paying generators to reduce their outputs, known as 'constraint costs' (i.e. payments). Ultimately, constraint costs are passed on to consumers and businesses through electricity bills.

The ESO also makes investment recommendations to transmission owners, including National Grid, through an annual network planning cycle and other periodic reviews. This indicates which areas of the transmission system require reinforcement. This includes:

- The Future Energy Scenarios (FES), which take a number of energy industry views as part of a consultation process and develop a set of possible energy growth scenarios;
- The Electricity Ten Year Statement (ETYS), which sets out the network performance and requirements for all of the transmission network in Great Britain over the next 10 years; and
- The Network Options Assessment (NOA), which takes account of the FES and ETYS and considers options for reinforcing the transmission system, where this is economically optimal in comparison to continuing to pay constraint costs to manage shortfalls in capacity.

The ESO published the Holistic Network Design (HND) report in July 2022, accompanied by the 'NOA Refresh' document. The HND sets out a single integrated transmission network design that supports the large-scale delivery of electricity generated from offshore wind, with the NOA Refresh indicating which options are 'HND critical'.

Ofgem has subsequently published the Accelerated Strategic Transmission Investment (ASTI) decision, which aims to facilitate the achievement of Government targets by streamlining the regulatory approval for the HND critical projects.

The need case

National Grid Electricity Transmission (NGET) must comply with Section 9 of the Electricity Act and Standard Condition D3 of its Transmission Licence. As set out in section 2.5, the transmission system must at all times meet the defined minimum levels of security and quality of supply. The NETS SQSS defines criteria relevant to:

- the main interconnected transmission system (MITS);
- generations connections; and
- demand connections.

When required power flows are identified that would exceed the boundary capacity of the transmission system, NGET must resolve the capacity shortfall under the terms of its Transmission Licence.

NGET assesses the adequacy of its transmission system in accordance with the method defined in the NETS SQSS.

Any transmission system is susceptible to faults that interfere with the ability of transmission circuits to carry power. Most faults are temporary, e.g. related to weather conditions such as lightning, 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 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 fault conditions do not result in widespread supply interruptions. The faults we need to design the system to be compliant with are called “secured events”.

When defining the performance required of the NETS in terms of quality and security of supply for secured events, the NETS SQSS states that the following conditions must be met 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.

System planning methodology

The transmission system in the East Midlands Region contains a boundary called B8.

A boundary splits the system into two parts, crossing critical circuit paths that carry power between areas and 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.

Future boundary requirements are assessed using the ESO FES to identify expected future power flows across the boundaries. Power system analysis is conducted by the ESO and NGET to determine the boundary capability, which is the maximum power flow that can be transferred across a boundary whilst maintaining compliance with technical standards.

The boundary assessments completed on the Economy Planned Transfer already account for generation contribution. To ensure representative need for reinforcement, NGET has taken the average requirements to cover 95% of operating conditions of the System Transformation, Consumer Transformation and Leading the Way FES 2022 scenarios. These are the scenarios that meet the government’s 2050 net zero ambition.

Existing transmission network

The transmission system in the Scotland, North of England and Midlands areas was primarily constructed in the 1960s, at the same time as much of the rest of the transmission system. It was designed to connect coastal, in-land, large coal-fired power stations and nuclear power stations in Scotland and the North and Midlands areas of England.

Transmission system changes occurred in the 1990s, in particular to connect gas-fired power stations in the Humber region. In some areas within this region, little or no transmission infrastructure was constructed and there is limited ability to support new generator connections on the coast.

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 Southeast. 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 demand for energy will increase and replace fossil fuel usage.

The existing transmission system in the East Midlands region is shown in Figure B.

Figure B – East Midlands region transmission system and system boundaries

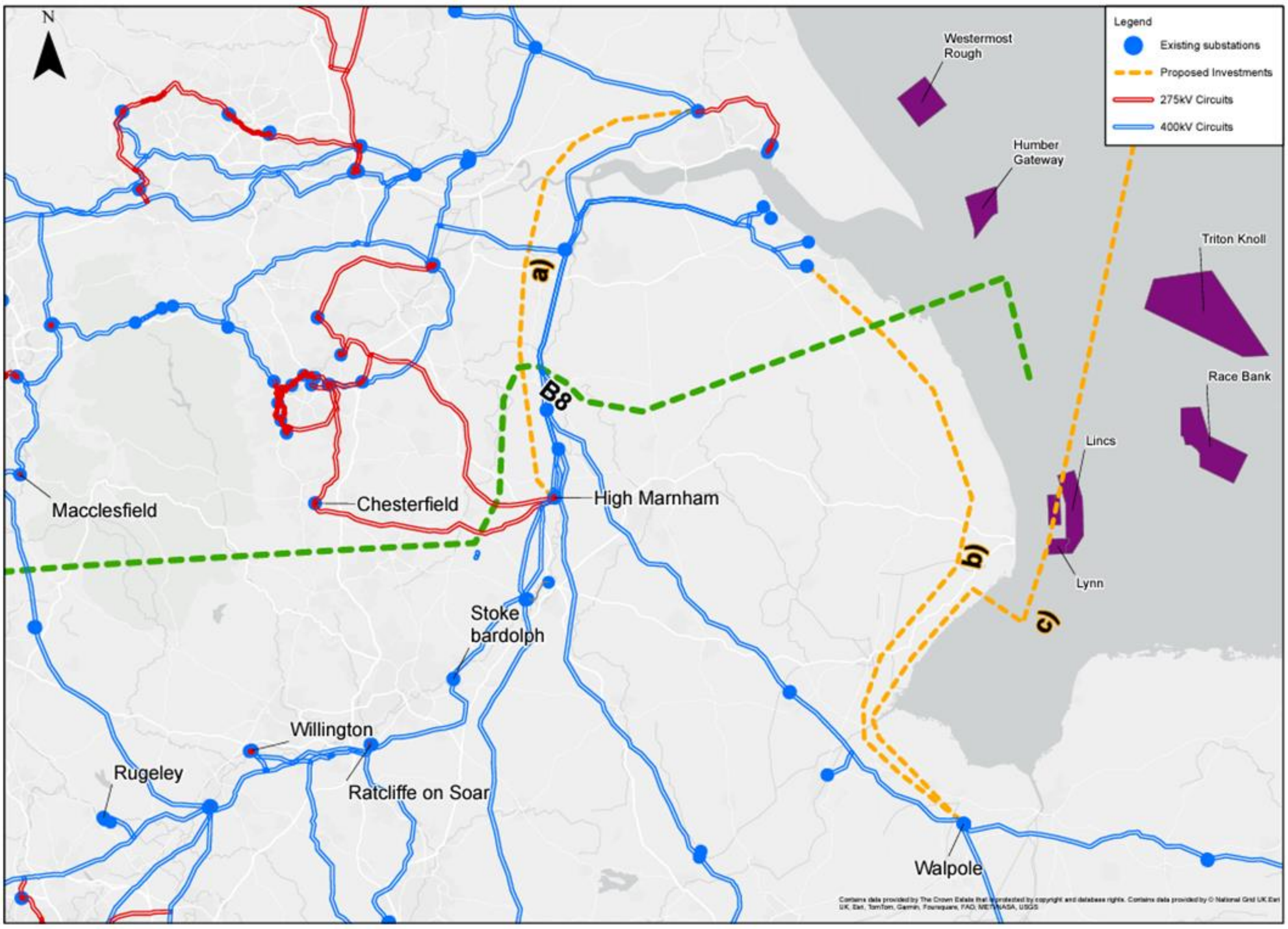


Figure B shows the existing transmission system and the B8 boundary. It also shows proposed investments a), b), and c) described below:

- a) Proposed North Humber to High Marnham Circuit
- b) Proposed Grimsby West to Walpole Circuit.
- c) EGL3 and EGL4 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 West to Walpole Strategic Options Report located on the project website.

For the purposes of this needs 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.

System studies

NGET has evaluated the B8 system boundaries using the Economy Planned Transfer assessment (defined in the NETS SQSS). This is used to determine the expected flow across the boundary and in this case represents the most onerous system boundary condition which must be secured by NGET to meet the requirements set out in the NETS SQSS.

Studies have been undertaken to assess the impact of changes in demand and generation on power flows across each of these boundaries, to determine if these impacts require reinforcement to the transmission system.

The circuit capacity during the winter average cold spell (ACS) period of each of the circuits which cross the B8 system boundary is known. The sum 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 case fault condition (secured event). Following a fault event, each system boundary will see flows across it based upon the circuit parameters and system conditions. When the boundary flow is high enough that any one of the circuits crossing it has reached its maximum flow capacity, the overall boundary is at it’s maximum for compliance with the NGET SQSS. Different fault events have different maximum boundary flow values. The boundary capability is determined by the fault event which has the lowest level of maximum SQSS compliant flow. This fault is the secured event.

As described in the Grimsby West to Walpole Strategic Options Report, the proposed Grimsby West to Walpole circuit mainly provides capacity for the connection of 7,615 MW of generation on the East Coast. This effectively limits the amount of additional energy that flows across this circuit and limits the capacity it provides to the B8 boundary.

Taking account of the increases to 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, the B8 boundary will have a:

- capacity deficit of 6,133 MW and
- capability deficit of 11,579 MW

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

Boundary transfer requirements are generally driven by bulk transfers between regions of the Great Britain. However, local connection can influence both the requirements and options to meet the requirements.

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

Results from our analysis show that these embedded generation connections would:

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

The limited increased fault levels can be managed by the new substations. The substation will be constructed with higher fault level ratings and the remaining system will be managed with operational response times.

Summary of the need case

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 – Additional transmission system boundary capability required by 2035

Areas of transmission system assessed	Additional generation export required from generation group/boundary (MW)	Pre-2035 transmission system capability (MW)	Additional transmission system capability deficit (MW)
B8 – 2035 (Boundary)	30,979 MW	19,400 MW	-11,579 MW

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

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

Initial strategic options analysis

Reinforcements in this area have been 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.

As set out in the need case, including proposed investments, B8 will have a Capability Deficit of -3,448 MW and will be 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 -6,133 MW, a new circuit is required to accommodate future demand and provide impedance reduction.

The January 2022 NOA reviewed an initial suite of options, confirming that the options identified meet the need, and provided a recommendation for the most economic reinforcement based on our options analysis. Chesterfield to Ratcliffe was therefore identified as the most economic reinforcement, however the January 2022 NOA recommended a 'hold' signal for EDN2, as the earliest in-service date was 2031, 2 years before it's optimal delivery date. A hold signal is given if the optimum delivery date of an option is later than it's in service date. Options that receive a hold signal are still 'optimal' and benefits would still be seen from their delivery.

Following this, the July 2022 NOA Refresh found EDN2 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. 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. 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, whilst also considering the technical, environmental, and socio-economic assessments as set out in this strategic options report.

We undertook an initial assessment of the strategic options available to meet the need case. Through this options identification process, we identified the following options for new circuits which satisfied the need as it was defined in the HND:

- 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 point on the Ratcliffe-Willington-Drakelow Route – 63 km
- EDN-10 – New Chesterfield 400 kV Substation to new substation between Willington-Ratcliffe-on-Soar – 50.8 km

We carried out a high-level technical, environmental, and socio-economic assessment of each option, considering a 20 km study area around the strategic option identified. The January 2022

NOA then reviewed our initial options analysis, confirming that the options identified met the need, and provided a recommendation for the most economic reinforcement based on our options analysis. EDN2 Chesterfield to Ratcliffe was therefore identified as the most economic reinforcement; however, the January 2022 NOA recommended a ‘hold’ signal for EDN2, 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.

Following this, the July 2022 NOA Refresh found EDN2 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 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, whilst also considering the technical, environmental, and socio-economic assessments as set out in this Strategic Options Report.

We also evaluated the interactivity between the options considered in this report with other investments identified by the ESO to enable the connection of 50 GW of offshore wind by 2030. Most notable is the EDEU Brinsworth to High Marnham project, which will construct, amongst other things, a new High Marnham 400 kV Substation and uprate the Chesterfield to High Marnham 275 kV double-circuit to 400 kV. This will improve the capability across B8 by providing an additional 3 GW and reduce impedance due to the new circuit.

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 OHLs 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

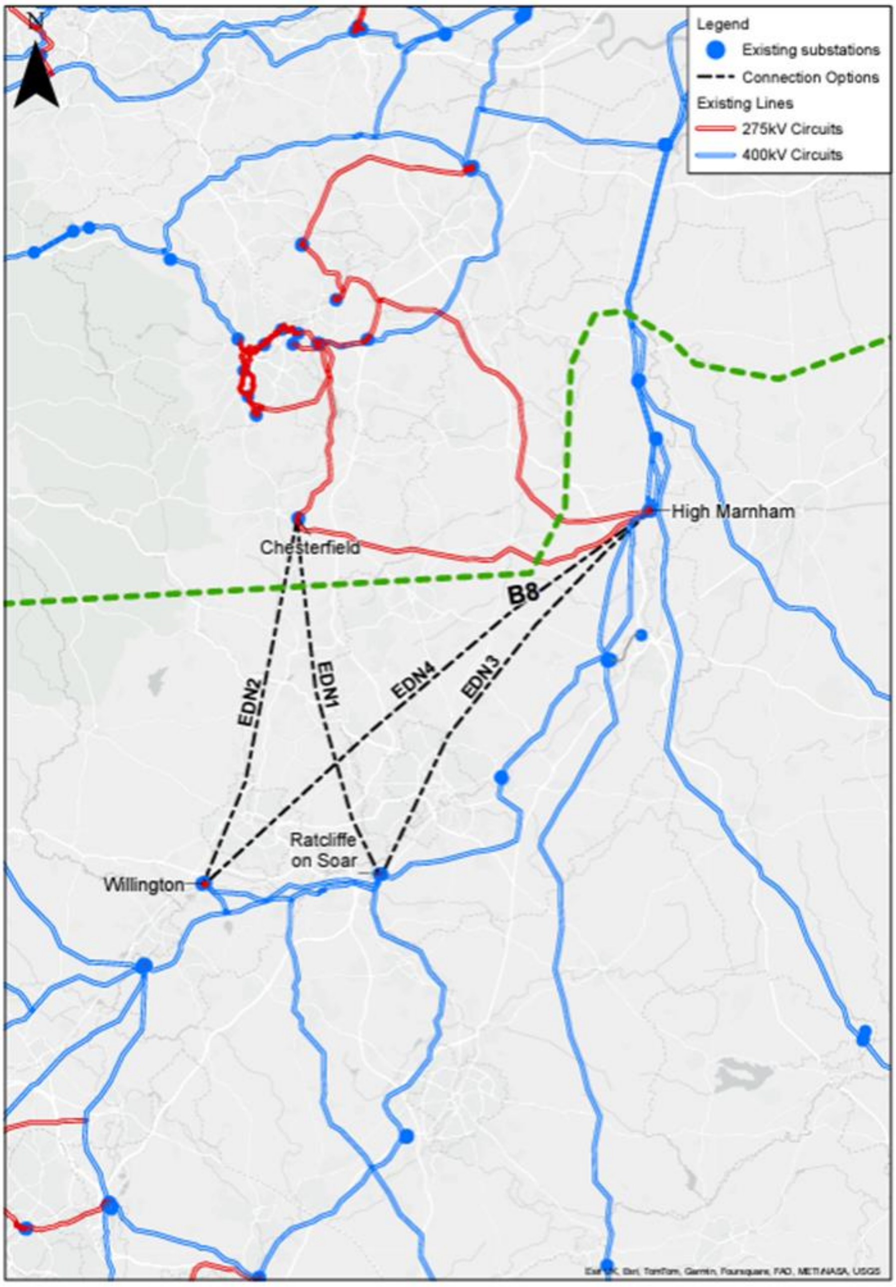
EDN-4 – High Marnham to Willington 78 km

The Brinsworth to High Marnham project will be subject to its own full review of strategic options. However, the substation layouts will be required to consider and accommodate the options presented in this report. This is because the Brinsworth to High Marnham project allows the progression of the identified options through the new High Marnham 400 kV substation and will improve the capacity across B8 through the additional 400 kV circuit. The 3000 MW provided by the Brinsworth to High Marnham project will also help to provide a solution to the 11,579 MW Capability Deficit, as set out above, by also providing impedance reduction, and therefore the full -11,579 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, we have considered the interaction of the Brinsworth 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, to determine the overall optimum developments.

These options are all shown in Figure C below:

Figure 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.

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

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. 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 OHL, 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-2 offers technical advantages when compared to EDN-1 and EDN-3 options. Both EDN-1 and EDN-3 propose connections to Ratcliffe 400 kV Substation, which is complex from a technical perspective due to the high number of physical constraints in the area surrounding the 400 kV substation. Considering the number of circuits already connected to the site, the introduction of further circuits will impact the electrical complexity and operation of the site. Comparatively, EDN-2 performs better in terms of routeing and connection to the existing Willington Substation and the ‘to be built’ Chesterfield Substation, providing the least electrical complexity.

The EDN-1 and EDN-3 options pose significant constructability risks in relation to the connection to Ratcliffe. Connection at High Marnham in the EDN-3 option also presents additional capital and on-going operational costs when compared to the other options.

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 6980 MW	overhead line 6980 MW	overhead line 6980 MW	overhead line 6980 MW

Total capital cost including non-circuit works	£217.5m	£220.6m	£269.3m	£331.5m
Circuit 40 yr lifetime NPV cost	£328m	£349m	£417m	£534m

We consider that, overall, EDN-2 currently represents the most advantageous of the options when balancing cost, technical performance, environmental socio-economic effects and physical constraints. The progression of EDN-2 is also enabled through the interaction with the Brinsworth to High Marnham project due to the improved capacity across B8 from the additional circuit. The Brinsworth to High Marnham project also provides an additional 3000 MW, which helps to solve the -11,579 MW Capability Deficit as identified in the need case and also reduces impedance, therefore the full -11,579 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, 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

Introduction

This Strategic Options Review (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'[1] .

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.

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.

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 below. This report provides information about scheme development, to support non-statutory consultation.

Figure 0.1 – The National Grid Project Lifecycle

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)
- Appraisal of strategic options (Section 7, 8, 9,10)
- Strategic options appraisal conclusions (Section 11)
- Interaction with other projects (Section 12)
- Conclusion and next steps (Section 13)

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

This document is also supported by a detailed set of appendices setting out National Grid's obligations, technology assumptions and cost appraisal methodology. The supporting document is called "Strategic options technical appendix 2020/2021 price base".

2. Background to England and Wales electricity transmission system

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Background to England and Wales electricity transmission system

2.1 Background

2.1.1 In 2019, the Committee on Climate Change (CCC) published its Net Zero report 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[2], which increased its pledge to achieve 100% 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[3], 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. The National Infrastructure Commission (NIC) has published a report recommending to the UK Government that renewable generation[4] can be increased to 65% 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[5] 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 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;
- Up to 10 GW of low-carbon hydrogen production capacity by 2030, doubling the previous ambition; and

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[2] 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

[3] 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

[4] Operability of highly renewable electricity systems, National Infrastructure Commission (2021) https://nic.org.uk/studies-reports/operability-highly-renewable-electricity-systems/

[5] 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

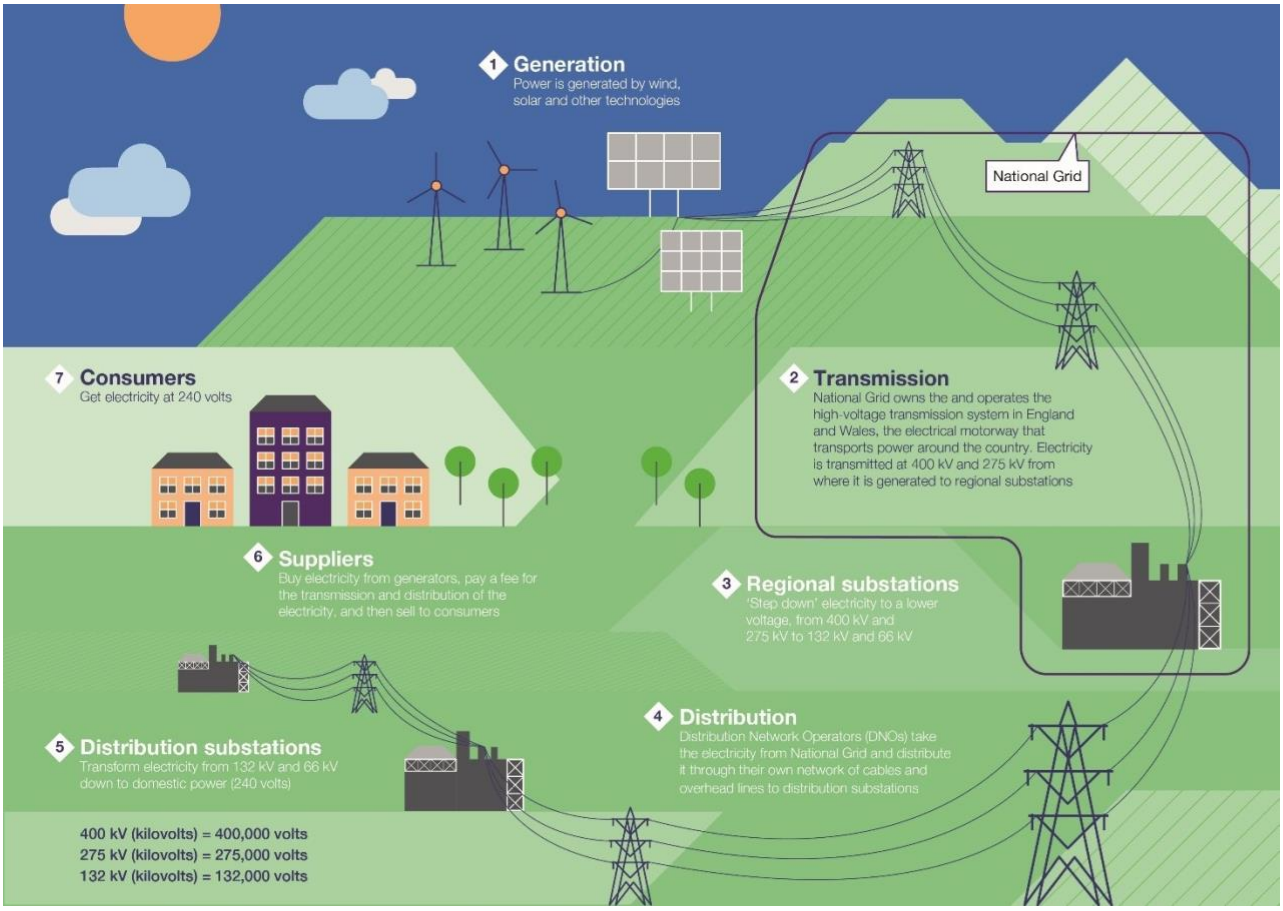
- 600,000 heat pump installations a year by 2028 and improving housing stock insulation.

2.1.4 The Powering Up Britain paper 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 Section 3.1.3

2.1.5 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.

2.1.6 The existing transmission system operates at 400 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 Figure 0.1 below.

Figure 0.1 – The National Grid Project Lifecycle



2.1.7 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.

2.1.8 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[6] (as amended) (the Electricity Act). Providing transmission services in England and Wales, National Grid is regulated by Ofgem.

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 The ESO is a separate legal entity to National Grid, but as of 2023 is still part of the National Grid Group. The ESO facilitates several roles on behalf of the electricity industry, including making formal offers to applicants requesting connection to the National Electricity Transmission System (NETS).

2.2.6 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 approximately 7,200 km of overhead lines and a further 700 km of underground cabling, operating at 400 kV and 275 kV. In

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[6] Electricity Act 1989, c. 29., HM Government (1989 as amended) https://www.legislation.gov.uk/ukpga/1989/29/contents

general, 400 kV circuits have a higher power-carrying capability than 275 kV circuits. These overhead lines and underground cable circuits connect around 340 substations forming a highly interconnected transmission system. Further details of the transmission system including geographic and schematic representations are published by the ESO annually as part of its ERTYS[7].

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 (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 the ESO 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, the ESO 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 the ESO. 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.

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[7] Electricity Ten Year Statement, National Grid ESO (2022) https://www.nationalgrideso.com/document/275611/download

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 National Grid ESO for new or modified connections to the transmission system; the ESO 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 National Grid ESO 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 Electricity System Operator's (ESO) role in the development of the transmission system

2.6.1 The ESO has annual processes to publish the ETYS, which sets out the network performance and requirements for all of the transmission network in Great Britain over the next 10 years.

2.6.2 The ESO also has annual processes to publish the FES[8] which take a number of energy industry views as part of a consultation process and develop a set of possible energy growth scenarios.

2.6.3 Similarly, it has an annual process to publish the Network Options Assessment[9] (NOA), which considers options for reinforcing the transmission system and makes economic recommendations. This document takes account of the ETYS and FES to establish via a Cost Benefit Analysis (CBA) process when it is right to take forward options proposed by transmission owners to increase network capacity. This considers the capital cost of

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[8] Future Energy Scenarios, National Grid ESO (2022) https://www.nationalgrideso.com/future-energy/future-energy-scenarios

[9] Network Options Assessment 2021/22 Refresh, National Grid ESO (2022) https://www.nationalgrideso.com/document/262981/download

the proposal, delivery timescales and constraint costs (as explained further below) avoided by delivering the proposal. This establishes when a proposed reinforcement becomes the most economic, efficient and co-ordinated way to deliver value to Great Britain's energy consumers.

2.6.4 The ESO manages shortfalls in boundary capacity by reducing power flows and constraining generation. This is achieved by paying generators to reduce their outputs, known as 'constraint costs'. Ultimately, constraint costs are passed on to consumers and businesses through electricity bills.

2.6.5 The ESO published the Holistic Network Design[10] (HND) report in summer 2022. It is now engaged in the HND Follow-up Exercise. The HND sets out a single integrated transmission network design that supports the large scale delivery of electricity generated from offshore wind.

2.6.6 The ESO is also undertaking the Offshore Coordination Project, of which the HND is part. This considers how the transmission network is designed and delivered, to ensure that the transmission connections for offshore wind generation are delivered in the most appropriate way considering the increased ambition for offshore wind to achieve net zero. It considers environmental, social and economic costs.

2.6.7 Subsequent to the ESO reinforcements identified in HND and NOA refresh, Ofgem have published the Accelerated Strategic Transmission Investment[11] (ASTI) decision, which aims to facilitate achieving government targets by streamlining the regulatory approval and funding process for ASTI projects. This project is identified as an ASTI project.

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[10] National Grid ESO. (2022). Pathway to 2030. A holistic network design to support offshore wind deployment for net zero. National Grid ESO (2022) https://www.nationalgrideso.com/future-energy/pathway-2030-holistic-network-design

[11] Decision on accelerating onshore electricity transmission investment | Ofgem

3. Need case

Need case

3.1 Minimum standards of security and quality of supply to be maintained

3.1.1 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. As set out in Section 2.5, the transmission system must at all times meet defined minimum levels of security and quality of supply. The NETS SQSS defines criteria relevant to:

- the main interconnected transmission system (MITS);
- generations connections; and
- demand connections.

3.1.2 When required power flows are identified that would exceed the boundary capacity of the transmission system, NGET must resolve the capacity shortfall under the terms of its Transmission Licence.

3.1.3 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 that transfer between regions of the transmission system. The Planned Transfer (the amount of power which will flow out of the region at ACS peak) is calculated from the ACS Peak Demand and generation in that region, following the modelling approach set out in the NETS SQSS. 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.

3.1.4 Any transmission system is susceptible to faults that interfere with the ability of transmission circuits to carry power. Most faults are temporary, e.g. 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.

3.1.5 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 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”.

3.1.6 When defining the performance required of the NETS in terms of quality and security of supply for secured events, the NETS SQSS states that the following conditions must be met 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.

3.2 Boundaries

3.2.1 A boundary splits the system into two parts, crossing critical circuit paths that carry power between areas and 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.

3.2.2 Future boundary requirements are assessed using the ESO FES to identify expected future power flows across the boundaries. Power system analysis is conducted by the ESO and NGET to determine the boundary capability, which is the maximum power flow that can be transferred across a boundary whilst maintaining compliance with technical standards. Limiting factors on transmission capacity include thermal circuit rating, voltage constraints, and dynamic stability.

3.2.3 The boundary assessments completed on the Economy Planned Transfer already account for generation contribution. To ensure representative need for reinforcement, NGET has taken the average requirements to cover 95% of operating conditions of the System Transformation, Consumer Transformation and Leading the Way FES 2022 scenarios. These are the scenarios that meet the government’s 2050 net zero ambition.

3.3 Existing transmission network

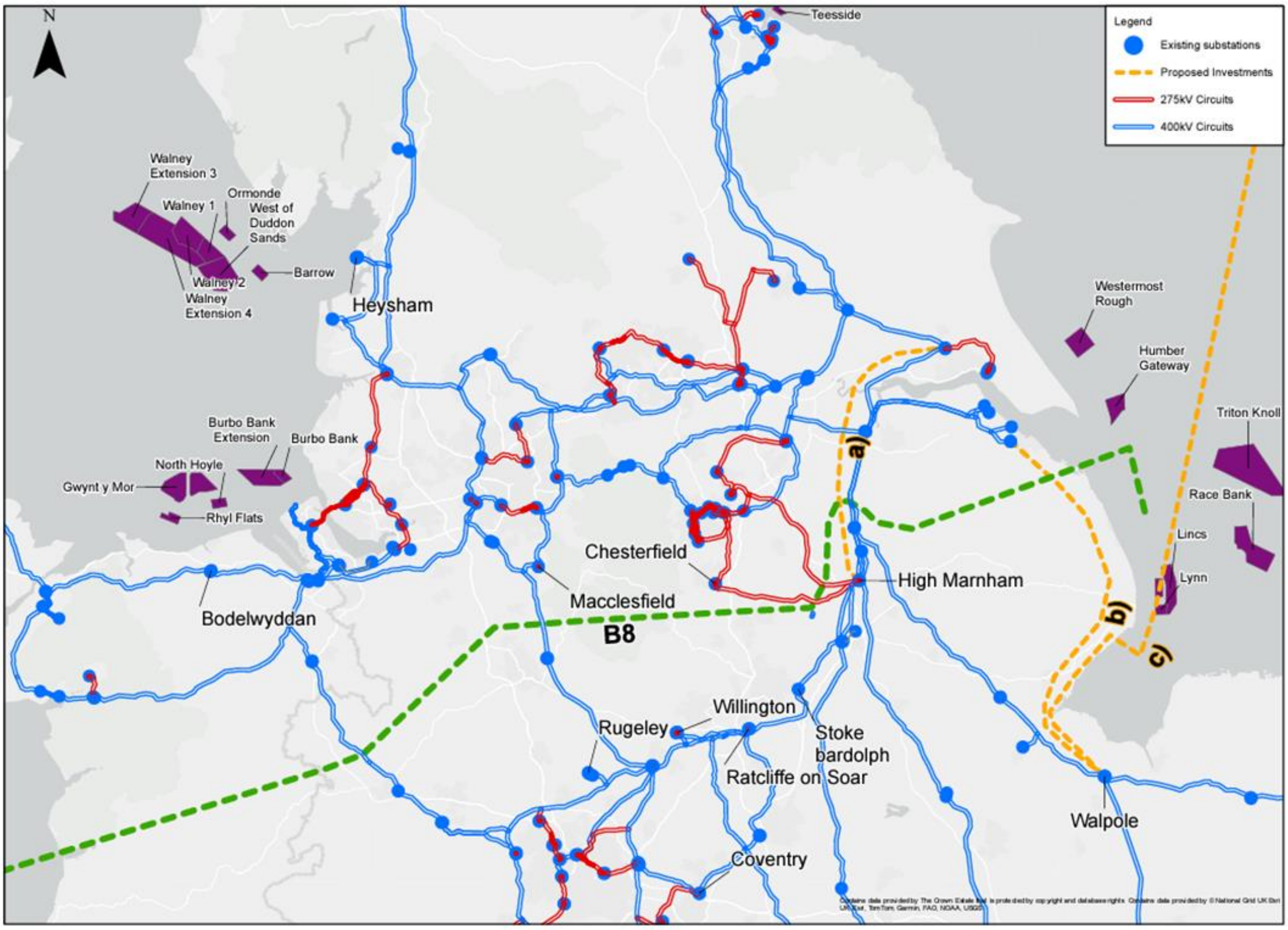
3.3.1 The transmission system in the North of England and Midlands areas was primarily constructed in the 1960s, at the same time as much of the rest of the transmission system. It was designed to connect coastal, in-land, large coal-fired power stations and nuclear power stations the North and Midlands areas in England. The existing transmission system in the North of England and the Midlands is shown in Figure 3.1.

3.3.2 Transmission system changes occurred in the 1990s, in particular to connect gas-fired power stations in the Humber region. In some areas within this region, little or no transmission infrastructure was constructed and there is limited ability to support new generator connections on the coast.

3.3.3 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 Southeast. 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 demand for energy will increase and replace fossil fuel usage.

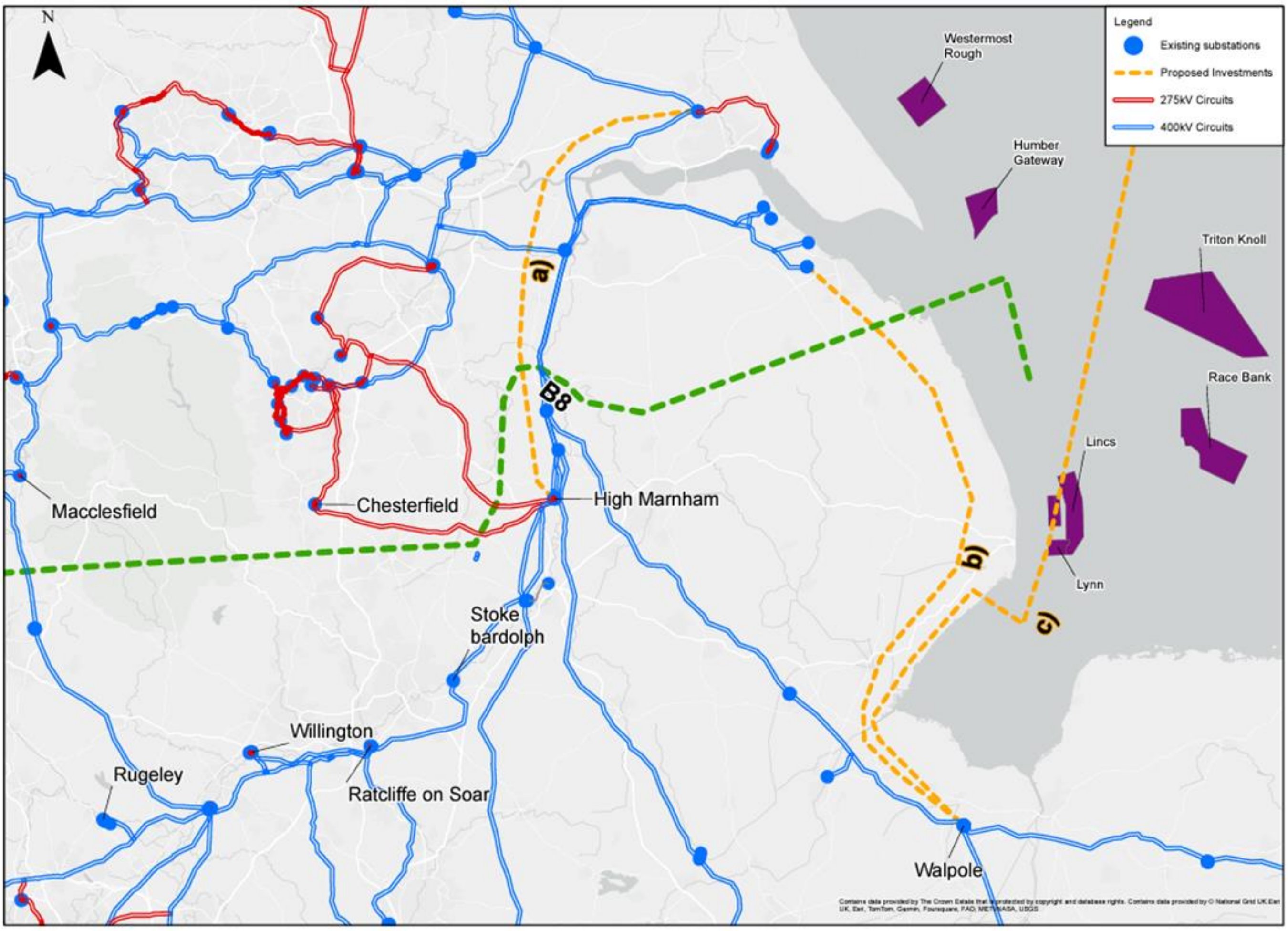
3.3.4 The existing transmission system in the North of England and the Midlands is shown in Figure 0.1. The geography under consideration for the project is shown in Figure 0.2.

Figure 0.1 – The National Electricity Transmission System in the North and Midlands



Contains data provided by The Crown Estate that is protected by copyright and database rights. Contains data provided by © National Grid UK Esri UK Esri, TomTom, Garmin, FAO, NOAA, USGS

Figure 0.2 – The South Yorkshire and North Midlands transmission system



Contains data provided by The Crown Estate that is protected by copyright and database rights. Contains data provided by © National Grid UK. Esri UK, Esri, TomTom, Garmin, Foursquare, FAO, METI/NASA, USGS

3.3.5 Figures 3.1 and 3.2 show the existing transmission system and the B8 boundary. Both Figures 3.1 and 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
- c) EGL3 and EGL4 HVDC connections Scotland to England (New Walpole)

3.3.6 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 West to Walpole Strategic Options Report located on the project website.

3.3.7 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 B8 boundary

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

3.4.2 Studies have been undertaken to assess the impact of changes in demand and generation on power flows across the boundary, to determine if these impacts require reinforcement to the transmission system.

3.4.3 The circuit capacity during the winter ACS period of each of the circuits which cross the B8 system boundary is known. The sum of the capacity for all of these circuits provides the pre-fault capacity.

3.4.4 The post-fault capacity is defined by the remaining capacity across a boundary following the worst-case fault condition (secured event). Following a fault event, each system boundary will see flows across it based upon the circuit parameters and system conditions. When the boundary flow is high enough that any one of the circuits is crossing it has reached it’s maximum flow capacity, the overall boundary flow is at its maximum for compliance with the NETS SQSS. Different fault events will have different maximum boundary flow values. The boundary capability is determined by the fault event which has the lowest level of maximum SQSS compliant flow. This fault is the secured event.

3.4.5 For this evaluation of transmission system capability, NGET considered generation and demand requirements that cover 95% of operating conditions of the scenarios set out in the ESO’s FES 2022 which meet the government’s 2050 net zero ambition (the System Transformation, Consumer Transformation and Leading the Way scenarios). Studies were undertaken to assess the impact of these highly likely changes in demand and generation, on power flows across the B8 wider system boundary.

3.5 NGET’s B8 analysis results

3.5.1 Table 0.1 shows the capacities and capabilities applicable to the B8 system boundary in 2035 without reinforcement of the existing transmission system:

Table 0.1 – Existing transmission system capacities and capabilities by 2035

System Boundary	Pre-fault Capacity	Post-fault Capacity	Post-fault Capability
	MW	MW	MW
B8	23,351	17,426	14,000

3.5.2 Table 0.2 shows the capacities and capabilities applicable to system boundaries in 2035 with proposed reinforcements a) and b) and the proposed connection of both new 2GW HVDC connections (EGL 3/4) at the new Walpole Substation:

Table 0.2 – Proposed transmission system capacities and capabilities by 2035

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	19,400

3.5.3 As described in the Grimsby West to Walpole Strategic Options Report, the proposed Grimsby West to Walpole circuit mainly provides capacity for the connection of 7,615 MW of generation on the East Coast. The generation connects at a new substation on the Grimsby to Walpole route. The Grimsby West to Walpole circuit will have a capacity of 6,930MW. 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.

3.5.4 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 in high wind, 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 in Table 0.2 and Table 0.3 to show this impairment.

Table 0.3 – Proposed boundary performance by 2035 including proposed circuits a), b), EGL3 & EGL4.

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	Capacity Deficit	Secured Event Fault
B8 – 2035 (Boundary)	30,979 MW*	19,400 MW	27,531 MW	**-11,579 MW**	**-3,448 MW**	Proposed North Humber – High Marnham 400 kV double-circuit

*ESO Future Energy Scenarios 2022, leading the way boundary requirement in 2035

3.5.5 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 4.3 shows the deficit for the B8 system boundary:

- capacity deficit of 3,448 MW and
- capability deficit of 11,579 MW

3.5.6 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.

3.5.7 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 SOR and need case assessments. These emerging requirements do not affect the need case set out within this report.

3.5.8 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 need to consider the impact of existing and/or contracted distribution system generation connections (embedded generators).

3.5.9 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).

3.5.10 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.

3.5.11 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.

3.5.12 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.

3.5.13 The limited increased fault levels can be managed by new substation constructed having higher fault level ratings and the remaining system being managed with operations response times.

3.5.14 The remainder of the report considered strategic options that resolve the need set out above.

3.6 Need case conclusions

3.6.1 As described in Section 3.5, there is a need to provide additional capacity of 3,448MW and capability of 11,579 MW across the B8 system boundary to ensure the transmission system complies with the NETS SQSS in 2035 and beyond. These requirements are based on the network flows resulting from the FES, developed by the ESO and wider industry. They indicate a range of credible future generation and demand development consistent with UK government climate ambitions.

4. Identification of strategic options

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 Strategic Options Report 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 have been iteratively tested in the ESO's NOA process. As part of the ESO's NOA process, National Grid is required to produce a high-level scope with indicative construction delivery dates and capital costs for each of the options proposed. The ESO also requires us to explain the impact of each option on boundary capability, which we assess 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 2030 to remain compliant with the NETS SQSS. As set out in the need case, including proposed investments, B8 will have a Capability Deficit of -11,579 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 -6,133 MW, a new circuit is required to accommodate future demand and provide impedance reduction.

4.2.3 We undertook an initial assessment of the strategic options available to meet the need case. 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 point on the Ratcliffe-Willington-Drakelow Route – **63 km**
- EDN-10 – New Chesterfield 400 kV Substation to new substation between Willington-Ratcliffe-on-Soar – **50.8 km**

4.2.4 We carried out a high-level technical, environmental, and socio-economic assessment of each option, considering a 20 km study area around the strategic option identified. The January 2022 NOA then reviewed our initial options analysis, confirming that the options identified meet the need, and provided a recommendation for the most economic reinforcement based on our options analysis. EDN2 Chesterfield to Ratcliffe was therefore identified as the most economic reinforcement; however, the January 2022 NOA recommended a 'hold' signal for EDN2, 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.

4.2.5 Following this, the July 2022 NOA Refresh found EDN2 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.

4.2.6 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, whilst also considering the technical, environmental, and socio-economic assessments as set out in this Strategic Options Report.

4.2.7 We also evaluated the interactivity between the options considered in this report with other investments identified by the ESO to enable the connection of 50 GW of offshore wind by 2030. Most notable is the Brinsworth to High Marnham project, which will construct a new High Marnham 400 kV Substation and uprate the Chesterfield to High Marnham 275 kV double-circuit to 400 kV. This will improve the capability across B8 by providing an additional 3 GW and reduce impedance due to the new circuit.

4.2.8 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 OHL 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.

4.2.9 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).

4.2.10 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 technical filter.
- EDN-9 – 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-9 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 OHLs would need to be created, putting construction timescales at risk.
- EDN-10 – 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-10 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

4.2.11 The remaining options are those considered in this Strategic Options Report (EDN-1, EDN-2, EDN-3 and EDN-4). As identified above, the interaction of the Brinsworth to High Marnham project allows the progression of the identified options through the new High Marnham 400 kV Substation and will improve the capacity across B8 through the additional 400 kV circuit. The 3000 MW provided by the Brinsworth to High Marnham project will also help to provide a solution to the 11,579 MW Capability Deficit by also providing impedance reduction, and therefore the full -11,579 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.

5. Options assessment process

Options assessment process

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.

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

5.1.2 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.

5.1.3 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.

5.1.4 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.

5.1.5 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.

5.1.6 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; 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.
    - Lifetime circuit costs, including circuit capital cost, cost of losses over 40 years and cost of operation over 40 years.

5.1.7 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)
- 525 kV high-voltage direct current (HVDC) underground cable and converter stations.

5.1.8 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.
- 525 kV HVDC subsea cable and converter stations.

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

5.1.10 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.

5.1.11 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.

5.1.12 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% 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% added to provide variation in route length.

5.1.13 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).

5.1.14 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

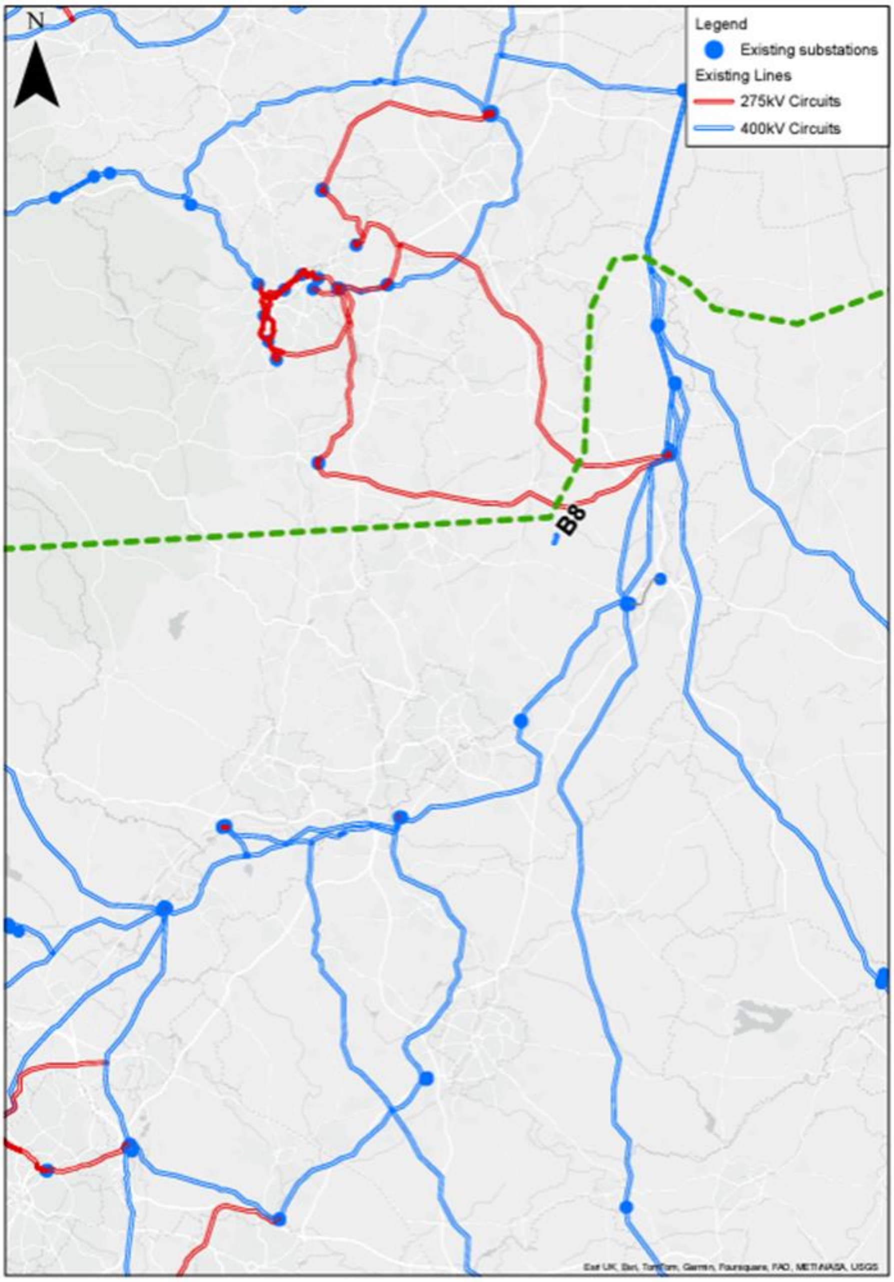
Strategic options overview

6.1 Introduction

6.1.1 As described in Section 3 above, the transmission system need reinforcement to ensure on-going SQSS compliance as the volume of generation connecting in the area and demand increases.

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

Figure 0.1 – Considered East Midlands Transmission System and system boundaries



6.2 Connection options considered for detailed appraisal

6.2.1 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.

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 OHL 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 – Double-circuit OHL from the 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 – Double-circuit OHL from the 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 Turn In of OHL 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-9 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 OHLs would need to be created, putting construction timescales at risk.

- EDN-10 – Double-circuit OHL from the new Chesterfield 400 kV Substation to the new 400 kV Substation between Ratcliffe-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-10 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.

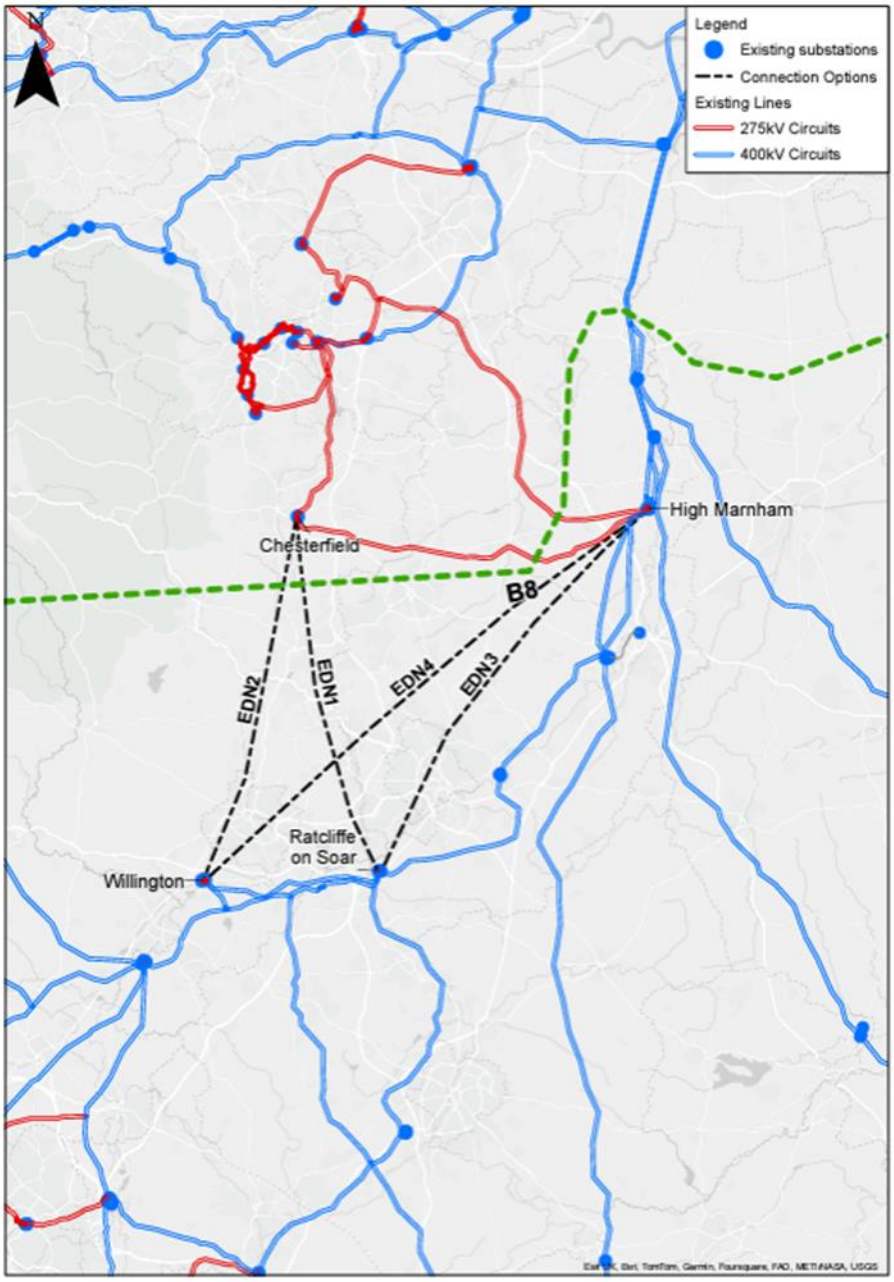
6.3 Options for strategic options assessment

6.3.1 This report considers those options that continue to meet the need case outlined in Section 3 and have not been discounted based on the technical or benefits filter. 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)
- EDN-4 – High Marnham to Willington (78 km)

6.3.2 The remaining options are enabled through the interaction with the Brinsworth to High Marnham project through the improved capacity across B8. The Brinsworth to High Marnham project also provides an additional 3000 MW, which helps to provide a solution to the -11,579 MW Capability Deficit as identified in the need case and also reduces impedance, therefore the full -11,579 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.

Figure 0.2 – Options Considered



6.4 Updated costs

6.4.1 The costs for both onshore and offshore 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

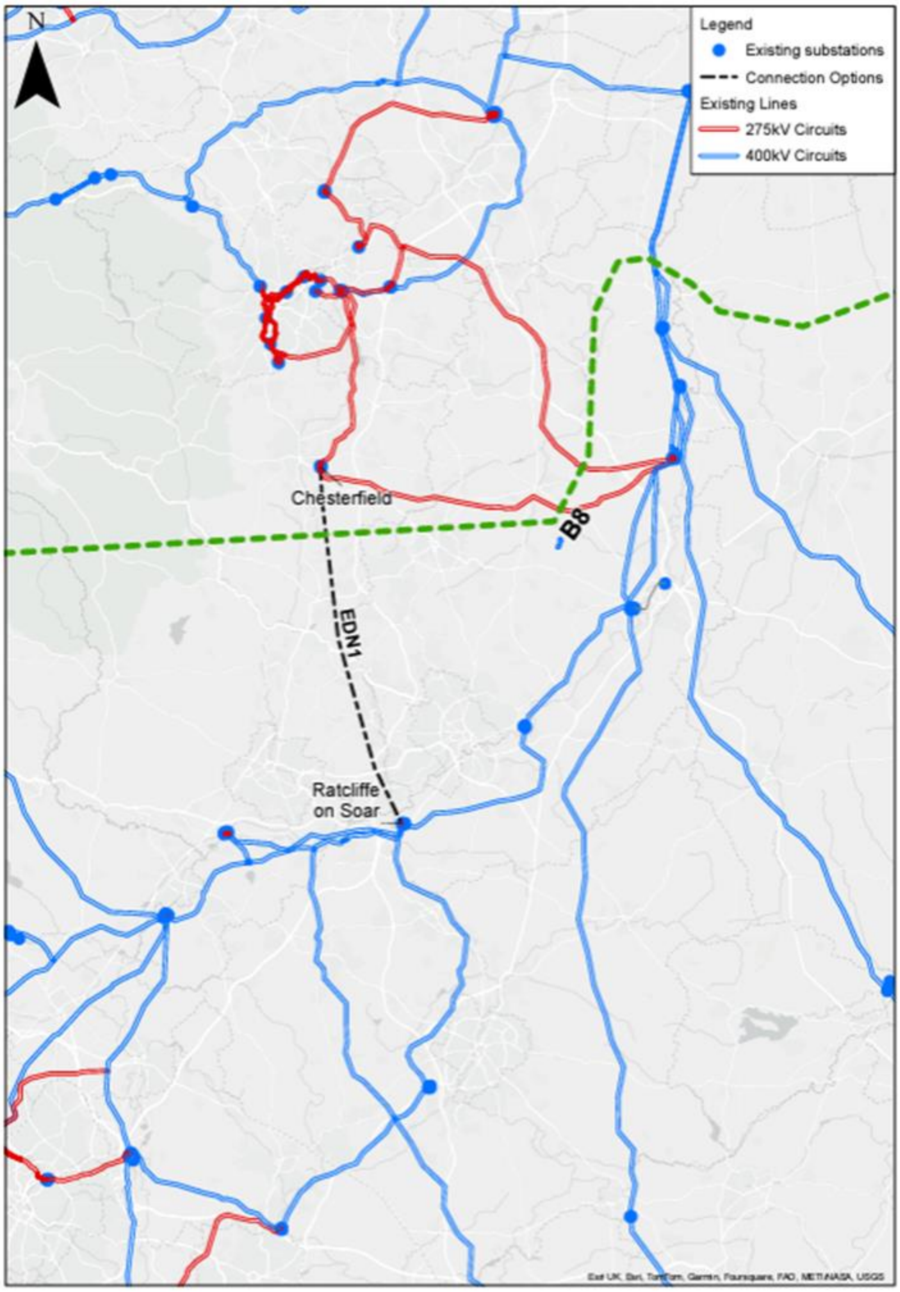
nationalgrid

EDN-1 – Chesterfield to Ratcliffe-on-Soar

7.1 Introduction

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 Figure 0.1 below.

Figure 0.1 – 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 a 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 on 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 a route has not been defined at this strategic stage, the option would likely be close to the Peak District Moors (South Pennine Moors Phase 1) Special Protection Area (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 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 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 Zone 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.

7.3 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 operational Ratcliffe-on-Soar Coal Power Station, owned by Uniper. Anticipated for decommissioning in the latter half of the 2020s, the coal power station's anticipated closure in 2024 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 approved in July 2023 (unless legally challenged). The future development emphasis includes energy production, manufacturing, and industry, with a requirement for operational businesses to qualify for full Freeport benefits by September 2026. Retention of existing National Grid assets is specified in the LDO.

7.3.7 The prevalence of EMF status and the recently approved LDO provides a potential land use constraint as it means that actions contrary to these plans carry a high risk of socio-political 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 includes the following:

- as part of Brinsworth to High Marnham Project, a new Chesterfield 400 kV Substation is proposed to be built and there are 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.
- Ratcliffe Substation is an indoor substation located on the location of Ratcliffe Coal Fired Power Station. The substation already hosts eight transmission circuits on four sets of double-circuit towers. Ratcliffe also provides demand connections providing supplies to Nottingham and surrounding areas.
- The connection to Ratcliffe 400 kV is complex from a technical perspective due to the high number of physical constraints in the area surrounding the 400 kV substation. Also, with the number of circuits already connected to the site, introducing further circuits will impact the electrical complexity and operation of the site.
- The indoor substation building would require modification to connect new circuits and asbestos is present. Further, the Ratcliffe-on-Soar Power Station site is due to be redeveloped in parallel to the project timescales creating additional construction interface. The complexity of adding additional circuits to the substation would require

connections to be made to different sides of the site, which would involve structural modification to the existing substation infrastructure.

7.4.3 As set out in Section 5, we undertake a cost[12] evaluation of the following four technologies for onshore options evaluation:

- 400 kV AC overhead line
- 400 kV AC underground cable
- 400 kV AC GIL
- 525 kV high-voltage direct current (HVDC) underground cable and converter stations

7.4.4 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 6930 mega volt ampere (MVA)
  - Or;
  - 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 6930 MVA.
- Substation works
  - Modification of the existing Ratcliffe Substation to make two new circuit connections to new substation bays either side of the site.
  - Two new connection bays at the new Chesterfield 400 kV Substation.

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[12] These estimates are prepared before detailed design work has been carried out and do not take into account technical disadvantages and physical constraints of detailed routeing and siting

Table 0.1 – 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 OHL**	**AC Cable**	**AC GIL**	**HVDC**
New Circuit 48 km	New Circuit across B8	£191.0m	£2,038.0m	£2,076.5m	£2048.1m
Total Capital Cost		**£217.5m**	**£2,064.5m**	**£2,103.0m**	**£2,074.6m**

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

7.4.5 Table 0.2 below 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 “Strategic options technical appendix 2020/2021 price base” Appendix D.

Table 0.2 – EDN-1 Lifetime circuit cost summary

	EDN-1 AC OHL	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
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**

7.4.6 Based on the above environmental 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.

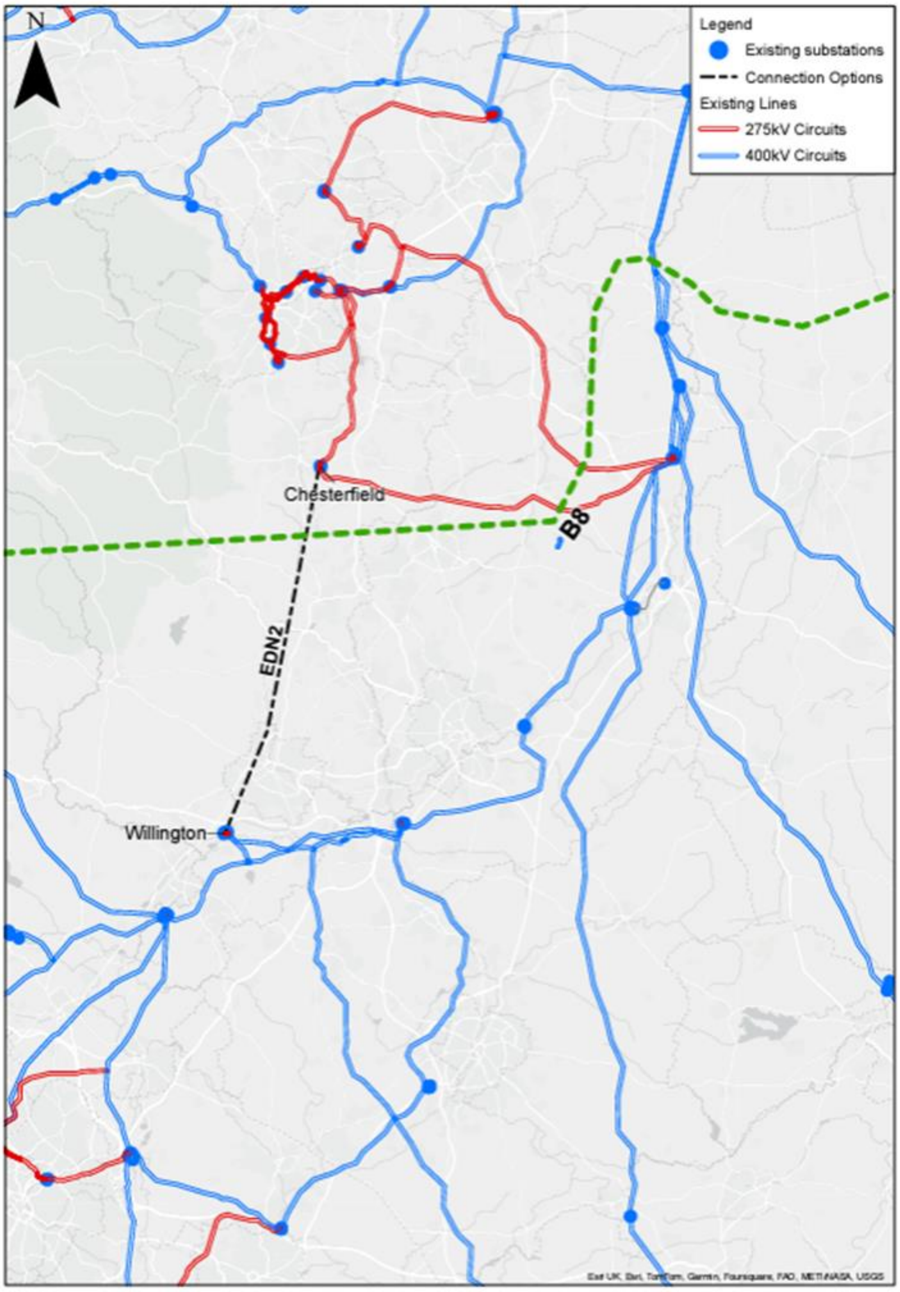
8. EDN-2 – Chesterfield to Willington

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 Figure 0.1 below.

Figure 0.1 – 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 a preferred route has not been identified at this 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 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 Zone 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.

8.3 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), one major visitor attraction (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 OHLs.

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 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.

8.4 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 include the following:

- A new Chesterfield 400 kV substation is proposed to be built as part of the Brinsworth to High Marnham Project 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.
- 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 OHL corridor in the vicinity of Willington.

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
- 525 kV high-voltage direct current (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 6930 mega volt amperes (MVA) or;
    - 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 6930 MVA.
- **Substation works**
    - 2 new connection bays at the new Chesterfield 400 kV Substation
    - Two-bay extension to the existing Willington 400 kV Substation

Table 0.1 – 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 OHL**	**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**

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

8.4.5 Table 0.2 below 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 “Strategic options technical appendix 2020/2021 price base” Appendix D.

Table 0.2 – EDN-2 Lifetime circuit cost summary

	EDN-2 AC OHL	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**

8.4.6 Based on the above environmental and technical appraisal, alongside capital and circuit lifetime circuit costs, the preferred option is EDN-2. EDN2 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.

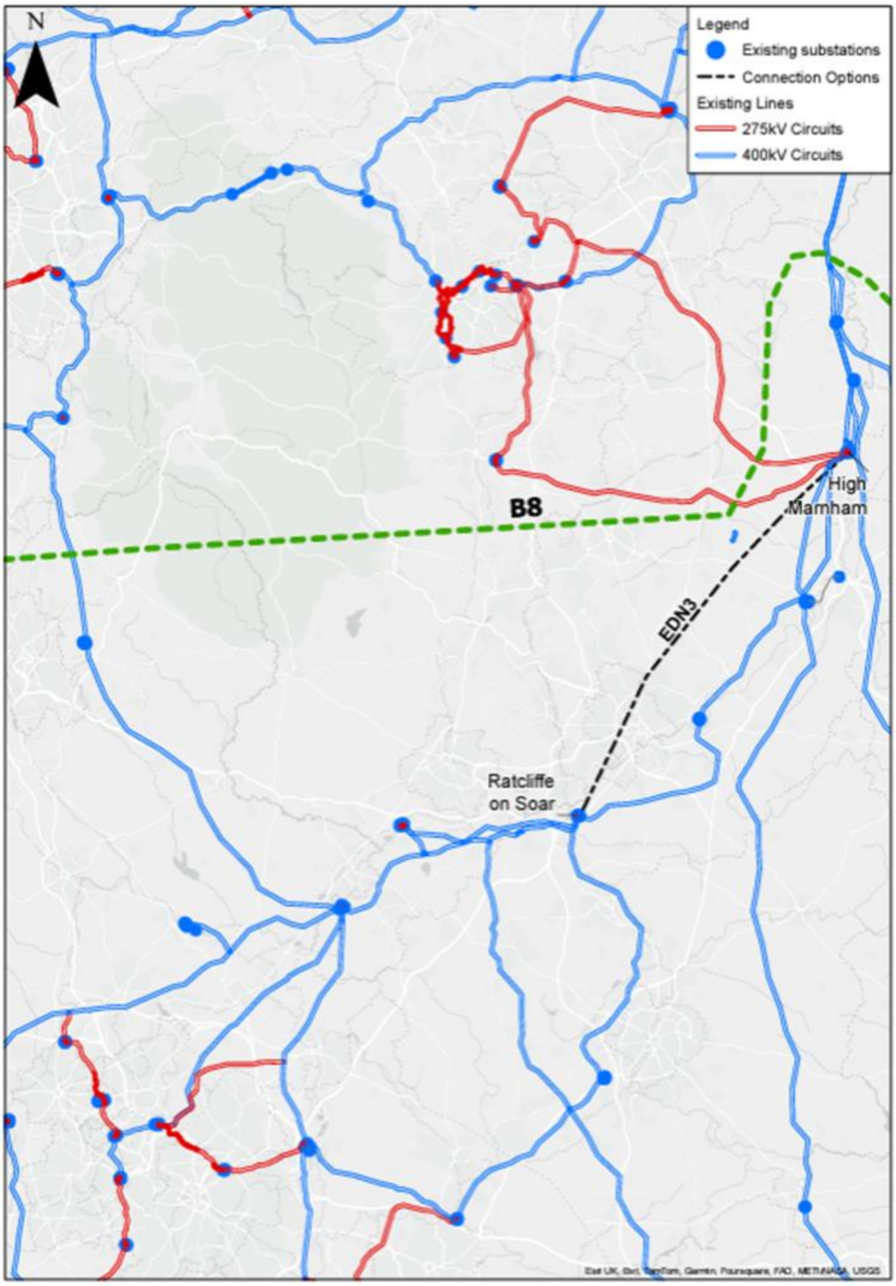
9. EDN-3 – High Marnham to Ratcliffe-on-Soar

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

9.1 Introduction

9.1.1 Option EDN-3 involves the connection of new transmission circuit connections between the new High Marnham 400 kV Substation and existing Ratcliffe 400 kV Substation, with a route length of approximately 61 km as shown in Figure 0.1 below.

Figure 0.1 – EDN-2 Chesterfield to Willington



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 a route has not been defined at 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 Zone 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.

9.3 Socio-economic appraisal

Settlements and populations

9.3.1 There are 12 settlements within the study area for EDN-3 including Nottingham, Ossington, Norman-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.

Land use

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

9.3.6 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 operational Ratcliffe-on-Soar Power Station, owned by Uniper. Anticipated for decommissioning in the latter half of the 2020s, the coal power station's expected closure in 2024 marks the initiation of its redevelopment phase. Following the decommissioning of the coal power station in 2024, the site is to be redeveloped under the UK Government's 2022 Freeports Programme initiative.

9.3.7 Rushcliffe Borough Council has prepared a Local Development Order (LDO) for the site, outlining a planning framework and masterplan approved in July 2023 (unless legally challenged). The future development emphasis includes energy production, manufacturing, and industry, with a requirement for operational businesses to qualify for full Freeport benefits by September 2026. Retention of existing National Grid assets is specified in the LDO.

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

Infrastructure

9.3.9 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.

9.3.10 Option EDN-3 also crosses multiple railway networks including 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.

9.3.11 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 includes the following:

- A new High Marnham 400 kV Substation is proposed to be built as part of the Brinsworth to High Marnham Substation works to uprate existing 275 kV infrastructure to 400 kV. Due to the number of circuits connecting at High Marnham, additional technical complexities would occur which may result in the Brinsworth to High Marnham Project incurring significant and additional substation costs
- Ratcliffe Substation is an indoor substation located on the location of Ratcliffe Coal Fired Power Station. The substation already hosts eight transmission circuits on four sets of double-circuit towers. Ratcliffe also provides demand connections providing supplies to the Nottingham and surrounding areas.
- The connection to Ratcliffe 400 kV is complex from a technical perspective due to the high number of physical constraints in the area surrounding the 400 kV substation. Also, with the number of circuits already connected to the site, introducing further circuits will impact the electrical complexity and operation of the site.
- The indoor substation building would require modification to connect new circuits and asbestos is present. Further, the Ratcliffe-on-Soar Power Station site is due to be redeveloped in parallel to the project timescales creating additional construction

interface. The complexity of adding additional circuits to the substation would require structural modifications to the existing substation.

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 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
- 525 kV HVDC underground cable and converter stations

9.4.5 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 6930 mega volt amperes (MVA) or;
  - 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 6930 MVA.
- Substation works
  - Modification of existing Ratcliffe Substation to make two new circuit connections to new substation bays either side of the site.
  - Two additional new bays at High Marnham to connect the new OHL to the substation and additional works to manage circuit complexity at High Marnham.

9.4.6 Table 0.1 below sets out the capital costs for option EDN-3 considering substation works and each technology option.

Table 0.1 – 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	£26.5m			
New circuits		**AC OHL**	**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		**£269.3m**	**£2,636.5m**	**£2,665.4m**	**£2,195.1m**

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

9.4.7 Table 0.2 below 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 "Strategic options technical appendix 2020/2021 price base", Appendix D.

Table 0.2 – EDN-1 Lifetime circuit cost summary

	EDN-3 AC OHL	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**

9.4.8 Based on the above environmental and technical appraisal, alongside capital and circuit lifetime circuit costs, the 61 km connection between High Marnham Substation and Ratcliffe-on-Soar 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.

10. EDN-4 – High Marnham to Willington

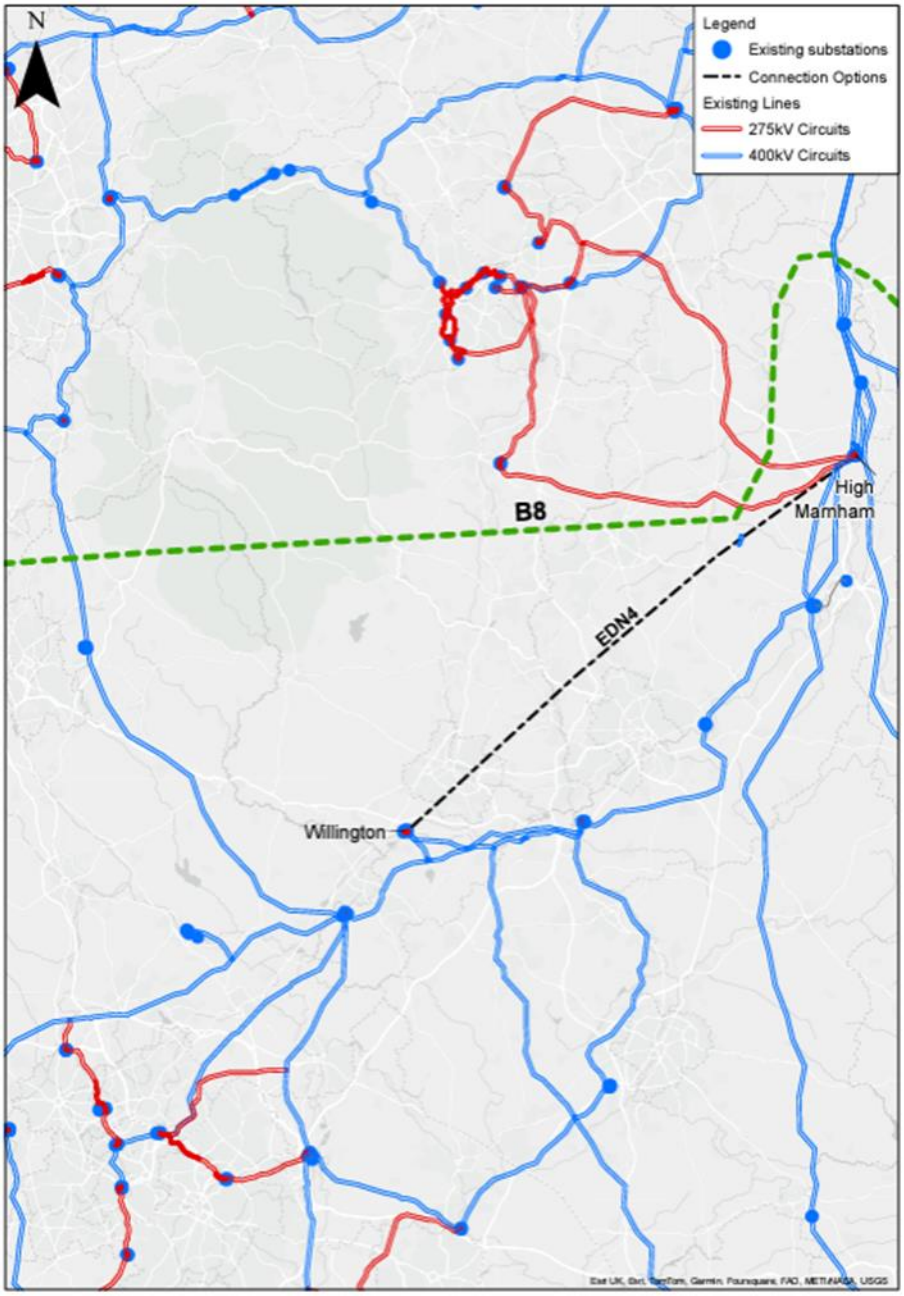
nationalgrid

EDN-4 – High Marnham to Willington

10.1 Introduction

10.1.1 Option EDN-4 involves the connection of new transmission circuit connections between a new High Marnham 400 kV Substation and the existing Willington 400 kV Substation with a route length of approximately 78 km as shown in Figure 0.1 below.

Figure 0.1 – 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 Mapleback 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 Zone 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.

10.3 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 Kneesal.

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. 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 OHL, 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 and Duffield to Peartree 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 includes the following:

- A new High Marnham 400 kV Substation is proposed to be built as part of the Brinsworth to High Marnham Substation works to uprate existing 275 kV infrastructure to 400 kV. Due to the number of circuits connecting at High Marnham, additional technical complexities would occur which may result in the Brinsworth to High Marnham Project incurring significant and additional substation costs
- 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 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 OHL for this option, the construction duration would be increased.

10.4.3 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
- 525 kV HVDC underground cable and converter stations

10.4.4 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 6930 mega volt amperes (MVA) or;
  - 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 6930 MVA.
- **Substation works**

- Two additional new bays at High Marnham to connect the new OHL to the substation and additional works to manage circuit complexity at High Marnham.
- Two-bay extension to the existing Willington 400 kV Substation

Table 0.1 – 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	£21.1m			
New circuits		**AC OHL**	**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		**£331.5m**	**£3,362.6m**	**£3,395.4m**	**£2,347.3m**

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

10.4.5 Table 0.2 below 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 “Strategic options technical appendix 2020/2021 price base” Appendix D.

Table 0.2 – EDN-4 Lifetime circuit cost for each technology option

	EDN-4 AC OHL	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**

10.4.6 Based on the above environmental and technical appraisal, alongside capital and circuit lifetime circuit costs, the preferred option for EDN-4, 78 km connection between a new High Marnham 400 kV Substation and Willington 400 kV 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

Strategic options appraisal conclusions

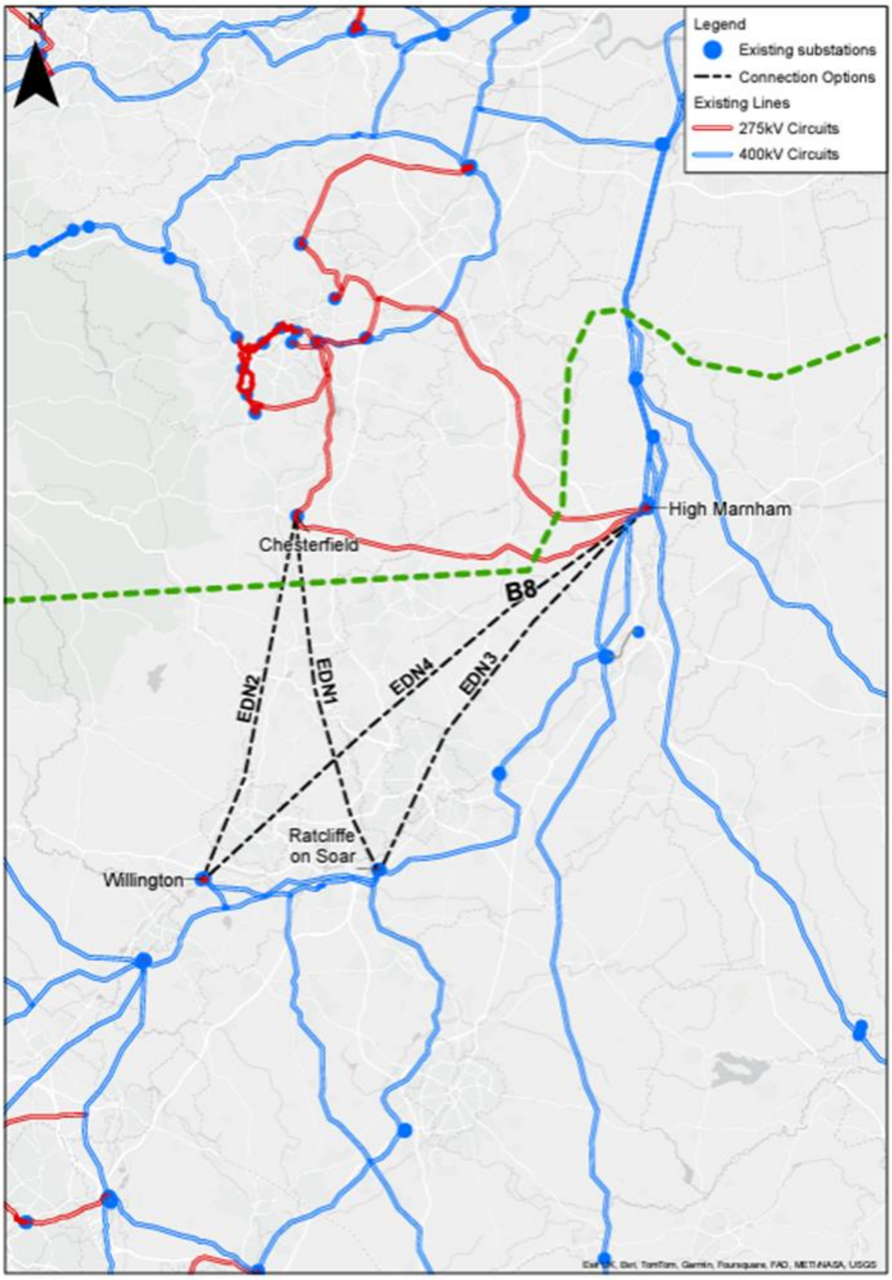
11.1 Introduction

11.1.1 This Strategic Options Report 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)
- EDN-4 – High Marnham to Willington (78 km)

These are shown in Figure 11.1 below.

Figure 0.1 – Strategic Options Considered



11.1.2 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.
- 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 below. 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 0.1 – OAST Tables 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.
	Landscape & 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	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 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

Topic		EDN-1	EDN-2	EDN-3	EDN-4
			reduce the potential for adverse landscape and visual effects.	There would however be opportunities through more detailed routeing and design to reduce the potential for adverse landscape and visual effects.	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 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.	This option intersects the Derwent Valley Mills World Heritage Site. There is potential for direct impacts to 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 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.	There are nine Registered Parks and Gardens present within the study area. In addition to this, there are also 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.	There are several designated heritage assets within the study area for this option, including five Registered Parks and 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 Zone 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	The route would intersect the River Derwent. The overhead line would therefore need to cross the river and associated areas of Flood Zone 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	The route would intersect the River Trent. The overhead line would therefore need to cross the river and associated areas of Flood Zone 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 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 Zone 2 and 3. The project should be designed to ensure infrastructure is placed

Topic		EDN-1	EDN-2	EDN-3	EDN-4
		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.	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.	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.	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 this option could be routed around Derby.	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 anticipated that a route for this option could be routed around Nottingham.	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 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 Gelding Country Club, 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. The area also falls under Rushcliffe Borough Council's approved LDO for the site prioritising future development in energy, manufacturing, and industry, with a requirement for	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	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	The Willington Power Station is located within the 2 km study area of the strategic option. Adopting appropriate routeing of the OHL, and the appropriate selection of sites for construction compounds

Topic		**EDN-1**	**EDN-2**	**EDN-3**	**EDN-4**
		businesses to be operational to qualify for full Freeport benefits by September 2026. 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.	may continue into operation, depending on appropriate routeing of OHLs.	located within the EMF. The area also falls under Rushcliffe Borough Council's approved LDO for the site prioritising future development in energy, manufacturing and industry, with a requirement for businesses to be operational to qualify for full Freeport benefits by September 2026. 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.	and working areas will likely minimise any impacts to the power station.
	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, 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 Sites of Special Scientific Interest (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 Zone 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.

11.3 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. The connection to Ratcliffe 400 kV is complex from a technical perspective due to the high number of physical constraints in the area surrounding the 400 kV substation. Furthermore, with the number of circuits already connected to the site, introducing further circuits will impact the electrical complexity and operation of the site. The indoor substation building would require modification to connect new circuits and asbestos is present. The Ratcliffe-on-Soar Power Station site is due to be redeveloped in parallel to the project timescales creating additional construction interface. The complexity of adding additional circuits to the substation would require connections to be made to different sides of the site, which would involve structural modification to the existing substation.

11.3.3 Options EDN-3 and EDN-4 propose connections to the new High Marnham Substation. Connection to this new 400 kV substation at High Marnham being built to accommodate uprating of existing 275 kV circuits to 400 kV would require extension of the site. With the number of circuits proposed to connect to this site, the additional circuits would increase the electrical and technical complexity of the connection and more land would need to be acquired than currently proposed.

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 Brinsworth 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 OHL 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, a limited number of existing and proposed circuits do not require additional works to limit electrical complexity.

11.4 Cost considerations

11.4.1 Table 0.2 below provides a comparison of options based on the most economical technology choice for each option (i.e. AC OHL in each case).

Table 0.2 – 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 6980 MW	overhead line 6980 MW	overhead line 6980 MW	overhead line 6980 MW
Total capital cost including non-circuit works	£217.5m	£220.6m	£269.3m	£331.5m
Circuit 40 yr lifetime NPV cost	£328m	£349m	£417m	£534m

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

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

11.4.4 The narrow cost difference between EDN-1 and EDN-2 means that either could be the lowest cost option depending upon the final routeing and connection costs that arise as a project is developed to delivery standard.

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 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.

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 by comparison to EDN-2. Those options are also physically more constrained in terms of routeing due to constraints into Ratcliffe-on-Soar Substation. Given this fact and the lower electrical complexity of EDN-2, this option would be preferred from a technical cost and complexity assessment.

11.5.4 Therefore, we consider that, overall, EDN-2 represents the most advantageous of the options when balancing cost, technical performance, and environmental and socio-economic effects.

12. Conclusion and next steps

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 Brinsworth to High Marnham Project due to the improved capacity across B8 from the additional circuit. The Brinsworth to High Marnham project also provides an additional 3000 MW, which helps to solve the -11,579 MW Capability Deficit as identified in the need case and also reduces impedance, therefore the full -11,579 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 will now be taken forward to the next stage of development, including a non-statutory consultation to seek feedback from consultees and help shape the further development of the project.

13. Appendices

Appendix A
Summary of National Grid Electricity Transmission Legal Obligations

1.1 Electricity Transmission Licence

1.1.1 The Electricity Act 1989 (the ‘Electricity Act’) defines transmission of electricity within GB 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’).

1.1.2 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.

1.1.3 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.

1.1.4 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

1.2.1 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.

1.2.2 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".

1.2.3 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.

1.2.4 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.

1.3 National Grid's Transmission Licence Requirements

1.3.1 Condition B12: System Operator – Transmission Owner Code

1.3.2 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).

1.3.3 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.

1.3.4 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).

1.3.5 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.

1.3.6 Condition D17: Whole Electricity System Obligations

1.3.7 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

1.1 Electricity Network Infrastructure Developments

1.1.1 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.

1.1.2 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.

1.1.3 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[13]. The 2011 National Policy Statements 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[14]. National Grid will continue to monitor the relevant policy position as our work on the development consent order application progresses.

1.1.4 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.

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[13] National Policy Statements for energy infrastructure National Policy Statements for energy infrastructure – GOV.UK (www.gov.uk)

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

1.2 Demonstrating the Need for a Project and Assessment Principles Applied by Decision Maker

1.2.1 National Policy Statements are produced by government and set out the UK Government's objectives for the development of nationally significant infrastructure. The extant National Policy Statements relevant to energy network infrastructure are EN-1 Overarching National Policy Statement for Energy, EN-3 National Policy Statement for Renewable Energy, and EN-5 National Policy Statement 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 published as part of the 2024 Statutory Consultation. The main themes are provided below:

1.2.2 Taken together, they provide the primary basis for decisions on applications for electricity networks infrastructure which are classified as Nationally Significant Infrastructure Projects. Where relevant (e.g. in the case of the consideration of development in nationally designated landscapes), these are referred to in this Strategic Options Report.

1.2.3 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).

1.2.4 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.

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

1.2.6 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).

1.2.7 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.

1.2.8 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.

1.2.9 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).

1.2.10 Figure 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

1.1.1 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.

1.1.2 The majority of electricity systems throughout the world are AC systems. Consumers have their electricity supplied at different voltages depending upon the amount of power they consume e.g. 230V 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.

1.1.3 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.

1.1.4 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.

1.1.5 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).

1.1.6 This appendix provides generic information about each of these four technologies. Further information, including a more detailed technical review is available in a series of factsheets that can be found at the project website referenced at the beginning of this Report.

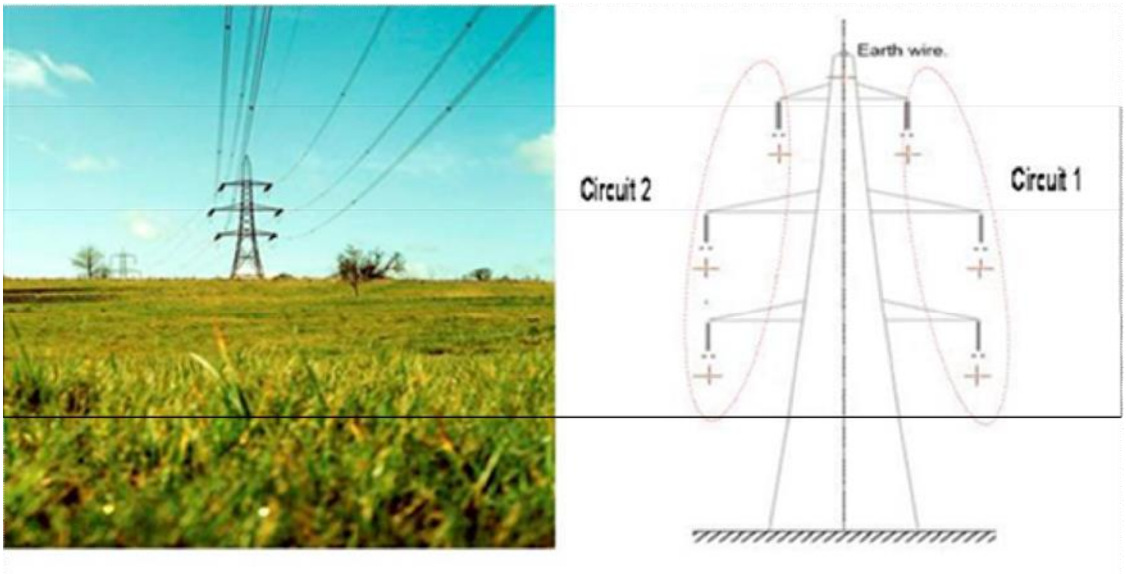
1.2 Overhead lines

1.2.1 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.

1.2.2 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).

1.2.3 Figure 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.

Figure C.1 – Example of a 400 kV Double Circuit Tower



1.2.4 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.

1.2.5 With the conclusion of the Royal Institute of British Architects (RIBA) pylon design competition[15] 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. Figure C.2, below, shows an image on the monopole design called the T pylon that was developed by National Grid.

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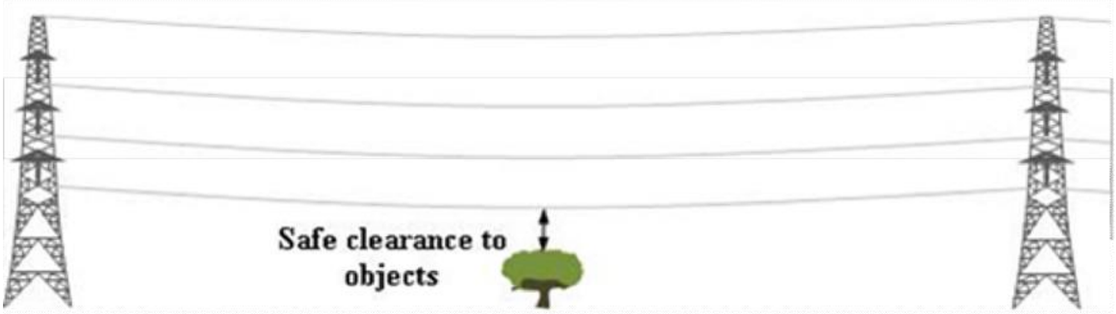
[15] Pylon Design an RIBA competition, https://www.architecture.com/awards-and-competitions-landing-page/competitions-landing-page/pylon

Figure C.2 – The T pylon

1.2.6 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 Figure C.3 .

Figure C.3 – Safe height between lowest point of conductor and other obstacle (“Safe Clearance”)



1.2.7 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 tower versus the number of towers; this is a decision based on both visual and economic aspects. The typical ‘standard’ span length used by National Grid is approximately 360m.

1.2.8 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.

1.2.9 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.

1.2.10 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.

1.2.11 Each of the three main components that make up an overhead line has a different design life, which are:

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

1.2.12 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.

1.3 Underground Cables

1.3.1 Underground cables at 275 kV and 400 kV make up approximately 10% 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.

1.3.2 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.

1.3.3 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). Figure C.4 shows a cross section of a transmission cable and a joint that is used to connect two underground cables.

Figure C.4 – Cable Cross Section and Joint

1.3.4 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. Figure C.5 shows two examples of cable sealing end compounds.

Figure C.5 – Cable Sealing End Compounds

1.3.5 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.

1.3.6 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.

1.3.7 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.

1.3.8 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.

1.3.9 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).

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

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

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

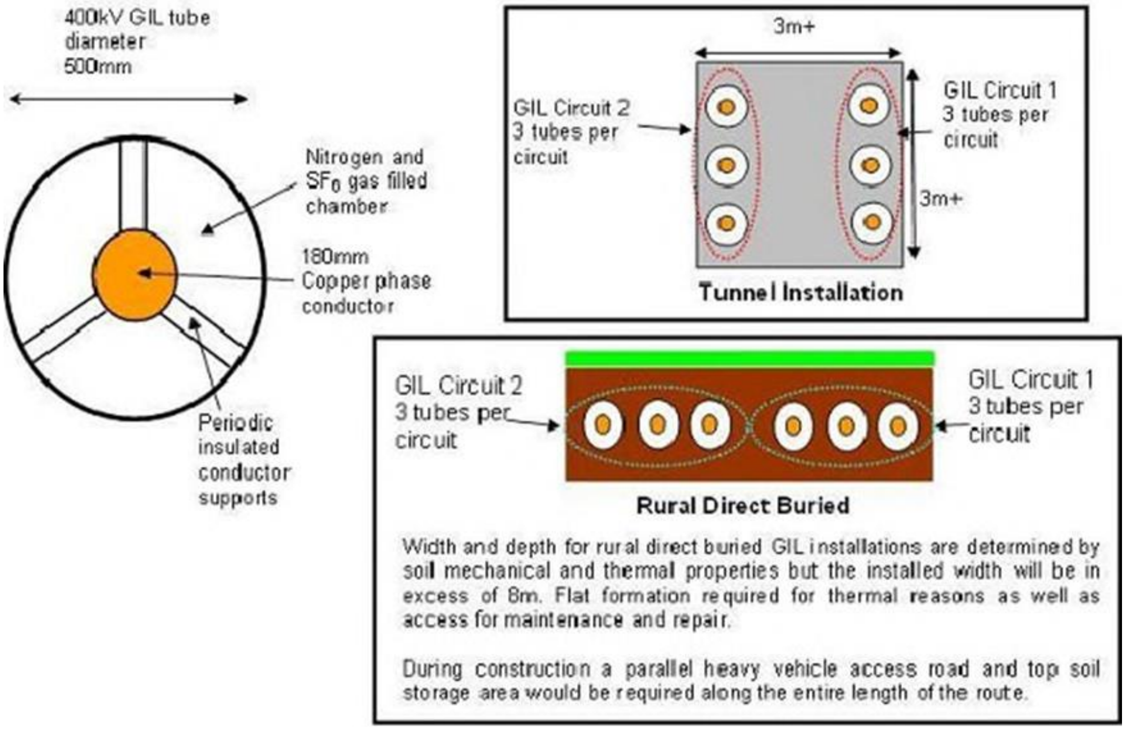
1.3.13 Asset replacement is generally expected at the end of design life. However, National Grid’s asset replacement decisions (that are made at the end of design life) will also take account of actual asset condition and may lead to actual life being longer than the design life.

1.4 Gas Insulated Lines (“GIL”)

1.4.1 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.

1.4.2 GIL uses a mixture of nitrogen and sulphur hexafluoride (SF6) 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 Figure C.6 below.

Figure C.6 – Key Components of GIL



Width and depth for rural direct buried GIL installations are determined by soil mechanical and thermal properties but the installed width will be in excess of 8m. Flat formation required for thermal reasons as well as access for maintenance and repair.

During construction a parallel heavy vehicle access road and top soil storage area would be required along the entire length of the route.

1.4.3 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.

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

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

1.4.6 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.

1.4.7 There are environmental concerns with GIL as the SF_6[16] gas used in the insulating gas mixture is a potent ‘greenhouse gas’. Since SF6 is an essential part of the gas mixture, GIL installations are designed to ensure that the risk of gas leakage is minimised.

1.4.8 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;

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[16] 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 CO2. www.ipcc.ch/publications_and_data/ar4/wg1/en/ch2s2-10-2.html

- 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.

1.4.9 At decommissioning the SF6 can be separated out from the gas mixture and either recycled or disposed of without any environmental damage.

1.4.10 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[17]. 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.

1.4.11 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.

1.5 High-Voltage Direct Current (“HVDC”)

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

1.5.2 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.…

1.5.3 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.

1.5.4 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.

1.5.5 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

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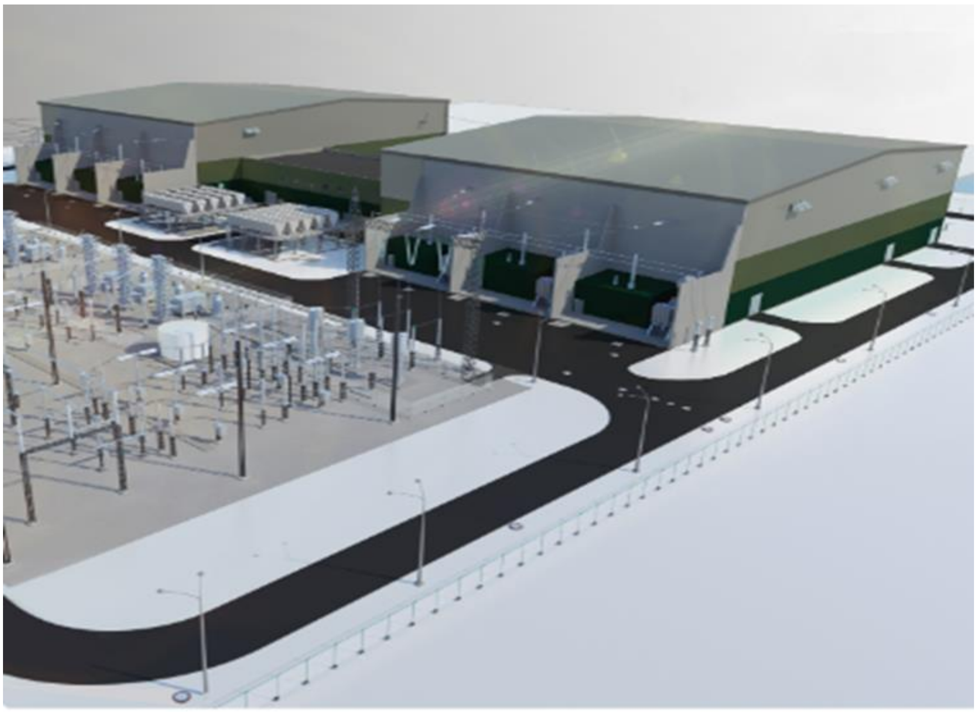
[17] The distances are based on initial manufacturer estimates of tunnel and buried GIL dimensions which would be subject to full technical appraisal by National Grid and manufacturers to achieve required ratings which may increase the separation required. It should be noted that the diagram does not 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.

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.

Figure C.7 – VSC convertor Station



1.5.6 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).
- this allows HVDC cables to be more easily installed for subsea applications than AC cables for a given capacity.

1.5.7 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.

Figure C.8 – HVDC Cable Laying Barge at transition between shore and sea cables

1.5.8 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

1.1.1 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 is considered to be feasible.

1.1.2 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.

1.1.3 The IET, PB/CCI Report[18] 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.

1.2 Lifetime Circuit Costs for Transmission

1.1.4 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:

1.1.5 initial capital cost of developing, procuring, installing and commissioning the new transmission assets, and

1.1.6 net present value (“NPV”) of costs that are expected to be incurred during the lifetime of these new transmission assets

1.3 Lifetime Circuit Costs for Transmission

1.3.1 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.

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[18] 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. http://www.theiet.org/factfiles/transmission-report.cfm

1.3.2 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.

1.4 AC Technology Capital Cost Estimates

1.4.1 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**		
	275kV AC Technologies	400kV AC Technologies	Overhead Line (OHL)	AC Underground Cable (AC Cable)	Gas Insulated Line (GIL)	Overhead Line (OHL)	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	3190MVA (2 x 1595MVA) [2000MVA 2 x 1000MVA for AC Cable only]	3190MVA (2 x 1595MVA)	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 [3190MVA 2 x 1595MVA for AC Cable only]	6380MVA (2 x 3190MVA)	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)
Hi	N/A	6930MVA (2 x 3465MVA)	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. 275kV circuits will often require Super-Grid Transformers (SGT) to allow connection into the 400kV system, SGT capital costs are not included above but described later in this appendix.
5. 275kV AC cable installations above 1000MVA, as indicated in the table above, would require 2 cables per phase to be installed to achieve ratings of 1595MVA per circuit at 275kV.

1.4.2 Table D.2 provides a summary of the capital costs associated with the key[19] components of transmission circuits for each technology option. Additional equipment is required for technology configurations that include new:

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

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

1.5 AC Underground Cable additional equipment

1.5.1 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.

1.5.2 Table D.3 – Reactive Gain Within AC underground cable circuits provides a summary of the typical reactive gain within AC underground cable circuits forming part of the 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 2500 mm^2 cable per phase	5 Mvar/km
Med	275 kV	Two 2500 mm^2 cable per phase	10 Mvar/km
Lo	400 kV	One 2500 mm^2 cable per phase	10 Mvar/km
Med	400 kV	Two 2500 mm^2 cable per phase	20 Mvar/km
Hi	400 kV	Three 2500 mm^2 cable per phase	30 Mvar/km

1.5.3 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.

1.5.4 For example, a 50 km "Med" double circuit would have an overall reactive gain of 1000 Mvar per circuit (2000 Mvar in total for two circuits). The standard shunt reactor size

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

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 circuit or eight 200 Mvar reactors (1600 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.

1.5.5 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.

1.5.6 For the purposes of economic appraisal of Strategic Options, National Grid includes a cost allowance that reflects typical requirements for switching stations. These allowances shown in Table D.4 are:

Table D.4 – Reactive Gain Within AC underground cable circuits

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

1.5.7 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.

1.5.8 Table D.5 below 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	

1.6 Connections between AC 275 kV and 400 kV circuits additional equipment

1.6.1 Equipment that transform voltages between 275kV and 400kV (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 supergrid transformers 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.

1.6.2 Table D.6 below shows the capital cost associated with the SGT requirements.

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

275kV Equipment	**Capital Cost (SGT - including civil engineering work)**
400/275kV SGT 1100MVA (excluding switchgear)	£7.75m per SGT

1.7 High-Voltage Direct Current ("HVDC") Capital Cost Estimates

1.7.1 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 2GW converter size. Higher ratings are achievable using multiple circuits.

1.7.2 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.

1.7.3 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 2GW installations

HVDC Converter Type	**2 GW Total HVDC Link Converter Costs** **(Converter Cost at Each End)**	**2GW** **DC Cable Pair Cost**
Current Source Technology or "Classic" HVDC	£475m HVDC link cost (£237.5m at each end)	£3.09m/km VDC
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 C.4 above.

- 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 2GW Link must be capable of operating at ½ its capacity i.e. 1GW 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% 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…)

1.7.4 Costs can be adjusted from this table to achieve equivalent circuit ratings where required. For example, a “Lo” rating 3190 MW would require two HVDC links of (1.6 GW capacity each), while “Med” and “Hi” rating 6380 MW 6930 MW would require three links with technology stretch of (2.1 2.3 GW each).

1.7.5 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 the cable costs per km.

1.7.6 The capacity of HVDC circuits assessed for this Report is not always exactly equivalent to capacity of AC circuits assessed. However, Table D.8.8 below illustrates how comparisons may be drawn using scaling methodology outlined above.

Table D.8 – Illustrative example using scaled 2GW 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 (3190MW)	£5.82m/km (2 x £2.91/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 (6380MW)	£9.27m/km (3 x £3.09/km)	£1422m (6 x £237m [6 converters 3 each end])	£1602m (6 x £267m [6 converters 3 each end])
Hi	3 x 2.3* GW HVDC Links (6930MW)	£10.32m/km (3 x £3.44/km)	£1818m (6 x £303m [6 converters 3 each end])	£1890m (6 x £315m [6 converter 3 each end])

Notes:

- Costs based on 2GW costs shown in Table C.4 and table shows 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 2GW, so above examples illustrative if technology should become available.

1.8 Indication of Technology end of design life replacement impact

1.8.1 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 assets design life. Typically, transmission assets will be decommissioned and removed only as part of an upgrade or replacement by different assets.

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

1.8.3 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.

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

- OHL - 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% 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.

1.9 Net Present Value Cost Estimates

1.9.1 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
- Electrical losses

1.9.2 For both categories, Net Present Value (“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.

1.9.3 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[20].

1.9.4 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%. However, the Treasury Green Book recommends a rate of 3.5% for the reasons set out below.

1.9.5 “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%. 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.”

1.9.6 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% will discount loss costs, at a lower rate than that of 6.25%. This has the overall effect of increasing the 40 year cost of losses giving a more onerous cost of losses for higher loss technologies.

1.9.7 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.

1.10 Annual Operations and Maintenance Cost

1.10.1 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

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[20] http://www.hm-treasury.gov.uk/d/green_book_complete.pdf Paragraph 5.49 on Page 26 recommends a discount rate of 3.5% calculation for NPV is also shown in the foot note 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 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.

Table D.9 – Annual maintenance costs by Technology

	Overhead Line (OHL)	**AC Underground Cable (AC Cable)**	**Gas Insulated Line (GIL)**	**High Voltage Direct Current (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 400kV system				
275/400 kV SGT 1100 MVA Annual maintenance cost per SGT	£6,719.58 per SGT	£6,719.58 per SGT	£6.719.58 per SGT	N/A

1.11 Annual Electrical Losses and Cost

1.11.1 At a system level annual losses on the National Grid electricity system equate to less the 2% of energy transported. This means that over 98% 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%. The calculations below are used to show how this translates to a transmission route.

1.11.2 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.

1.11.3 The average load of a transmission circuit which is incorporated into the transmission system is estimated to be 34% (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.

1.11.4 This level of circuit utilisation is required because if a fault occurs there need 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.

1.11.5 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 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 Gas Insulated Line (GIL) Type (complete single circuit resistance for conductor set)**
Lo	2 x 570 mm^2 (0.025 Ω/km)	1 x 2500 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 2500 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 2500 mm^2 (0.0043 Ω/km*)	Two tubes per phase (0.0065 Ω/km)
Losses per 200Mvar Reactor required for AC underground cables			
Reactor Losses	N/A	0.4MW per reactor	N/A
Additional losses for 275kV 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

1.11.6 The process of converting AC power to DC is not 100% 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 below 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	2GW DC Cable Pair Losses	2GW 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

1.11.7 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.

1.11.8 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.

1.11.9 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 6380 MVA (two x 3190 MVA).

- Overhead Lines = (2 x 3) x 1565.5 A2 x (40 x 0.0184 Ω/km) = 10.8 MW
- Underground Cable = (2 x 3) x1565.5 A2 x (40 x 0.0065 Ω/km) + (6 x 0.4MW) = 6.2 MW
- Gas Insulated Lines = (2 x 3) x 1565.5 A2 x (40 x 0.0086 Ω/km) = 5.1 MW
- CSC HVDC = 34% x 6380 MW x 1% = 21.7 MW
- VSC HVDC = 34% x 6380 MW x 2% = 43.4 MW

1.11.10 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.

1.11.11 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 6380 MVA (two x 3190 MVA).

- Overhead Line annual loss = 10.8 MW x 24 x 365 x £60/MWhr = £5.7m.
- U ground Cable annual loss = 6.2 MW x 24 x 365 x £60/MWhr = £3.3m.
- Gas Insulated lines 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

1.12 Example Lifetime Circuit Costs and NPV Cost Estimate

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

1.12.2 Table D.12 shows an example for a "Med" capacity route 6380 MVA (2 x 3190 MVA) 400 kV, 40km in length over 40 years.

Table D.12 – Example Lifetime Circuit Cost table (rounded to the nearest £m)

Example 400 kV "Med" Capacity over 40km	Overhead Line (OHL)	AC Underground Cable (AC Cable)	Gas Insulated Line (GIL)	CSC High Voltage Direct Current (HVDC)	VSC High Voltage Direct Current (HVDC)
Capital Cost	£145.6m	£1167.6m	£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

1.1.1 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.

1.1.2 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.

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

1.2 Example Loss Calculation (1) – 40 km 400 kV “Med” Category Circuits

1.2.1 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).

1.2.2 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% of circuit rating as set out in D.40 of Appendix D, which for the each of the two circuits in the “Med” category example is calculated as:

$P = 34\% \times 3190$ MVA $= 1{,}084.6$ 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

1.2.3 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% utilisation loading factor against circuit rating for any AC technology.

1.2.4 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[21] = 0.0065Ω/km x 40 km = 0.26 Ω

Gas Insulated Line = 0.0086Ω/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.

1.2.5 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

1.2.6 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

1.2.7 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

1.3 Example Loss Calculation (2) – 40 km 275 kV "Lo" Category Circuits Connecting to a 400 kV part of the National Grid's transmission system

1.3.1 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.

---

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

1.3.2 The circuit utilisation power (P) which for the each of the two circuits in the “Lo” category example is calculated as:

P = 34% x 1,595 = 542.3 MVA

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

$I = 542.3x10^6/(\sqrt{3} \text{ x } 275x10^3\ ) = 1{,}138.5$ Amps

1.3.3 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:

0.0086Ω/km x 40 km = 0.344 Ω

1.3.4 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 1138.5 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

1.3.5 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[22] is calculated (from information in Appendix D, Table D.10) as 0.2576 Ω.

1.3.6 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:

$I_{HV} = 542.3 \text{ x } 10^6/(\sqrt{3} \text{ x } 400x10^3\ ) = 782.7$ 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 = 84kW

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

1.3.7 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

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

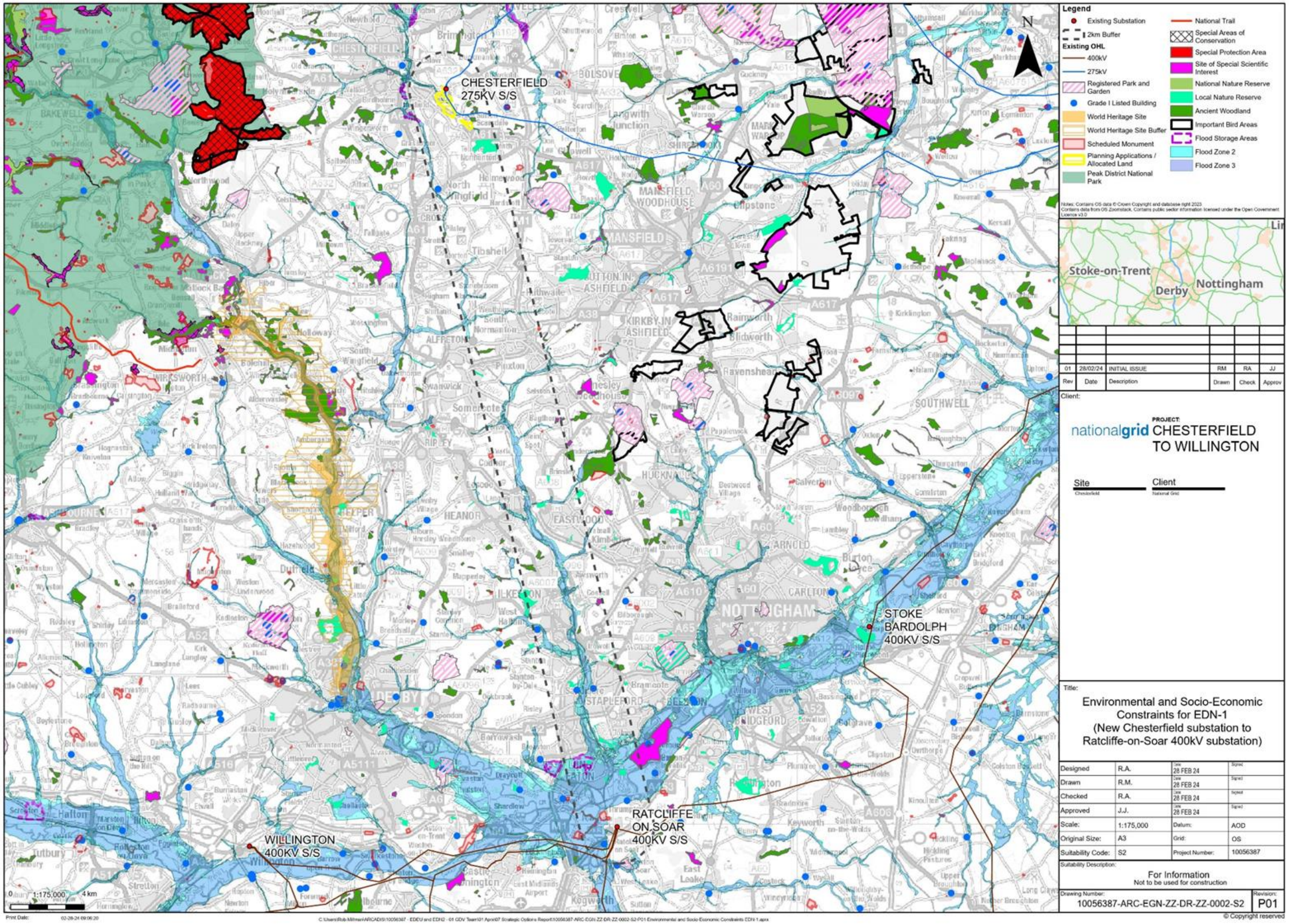
Appendix F
Glossary of Terms and Acronyms

AC		Alternating Current
AC Cable		AC Underground Cable
ACS		Average cold spell
ASTI		Accelerated Strategic Transmission Investment
CBA		Cost Benefit Analysis
CCC		Committee on Climate Change
CNP		Critical national priority
Conductor		Used to transport power
CSC		Current Source Converter
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		The 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 Network Infrastructure
EN-6		National Policy Statement for Nuclear Power Generation
ETYS		Electricity Ten Year Statement
ESO		Electricity System Operator
FES		Future Energy Scenarios
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

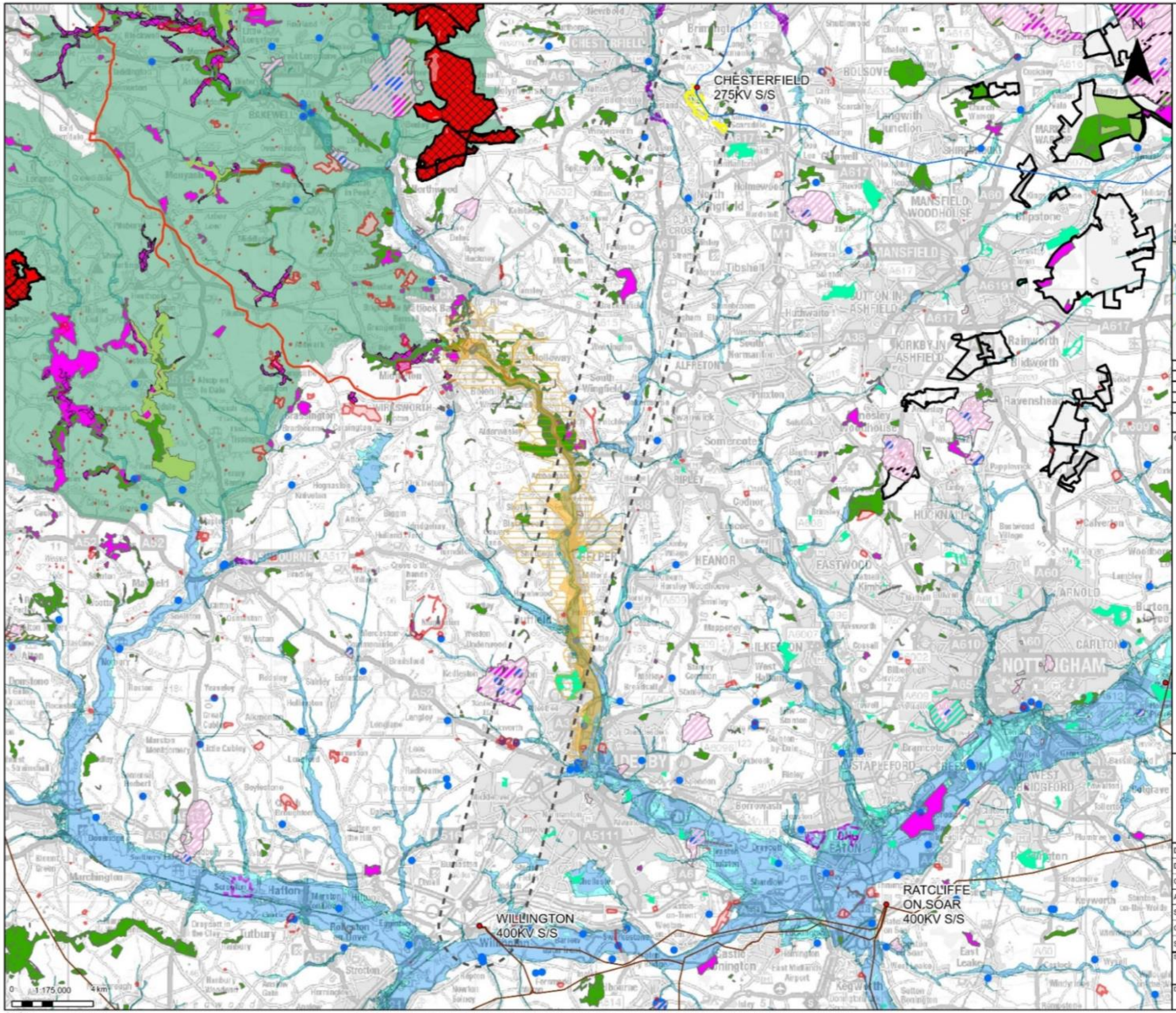
Insulators		Used to safely connect conductors to pylons
IPC		Infrastructure Planning Commission
LDO		Local Development Order
MITS		Main interconnected transmission system
MVA		Mega volt ampere
National Grid		National Grid Electricity Transmission plc
NGET		National Grid Electricity Transmission
NPV		Net Present Value
NETS		National Electricity Transmission System
NETS SQSS		National Electricity Transmission System Security and Quality of Supply Standard
NGESO		Operator of National Electricity Transmission System
NIC		National Infrastructure Commission
NOA		Network Options Assessment
NPFF		National Planning Policy Framework
NPS		National Policy Statements
NSIP		Nationally Significant Infrastructure Project
Ofgem		The Office of Gas and Electricity Markets
OHL		Overhead Line
(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)
SPA		Special Protection Area
Span length		Distance between adjacent pylons
STC		System Operator – Transmission Owner Code
SGT		Super-Grid Transformer
The Authority		Gas and Electricity Markets Authority, the governing body of Ofgem
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)

Appendix G Socio-Economic Study Maps



Environmental and Socio-Economic Constraints for EDN-1 (New Chesterfield substation to Ratcliffe-on-Soar 400kV substation)



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Client:

nationalgrid

PROJECT:
CHESTERFIELD
TO WILLINGTON

Site
Chesterfield

Client
National Grid

Title:

Environmental and Socio-Economic
Constraints for EDN-2
(New Chesterfield substation to
East Willington 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
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Original Size:	A3	Grid:	OS
Suitability Code:	S2	Project Number:	10056387

Suitability Description:

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Drawing Number: 10056387-ARC-EGN-ZZ-DR-ZZ-0003-S2

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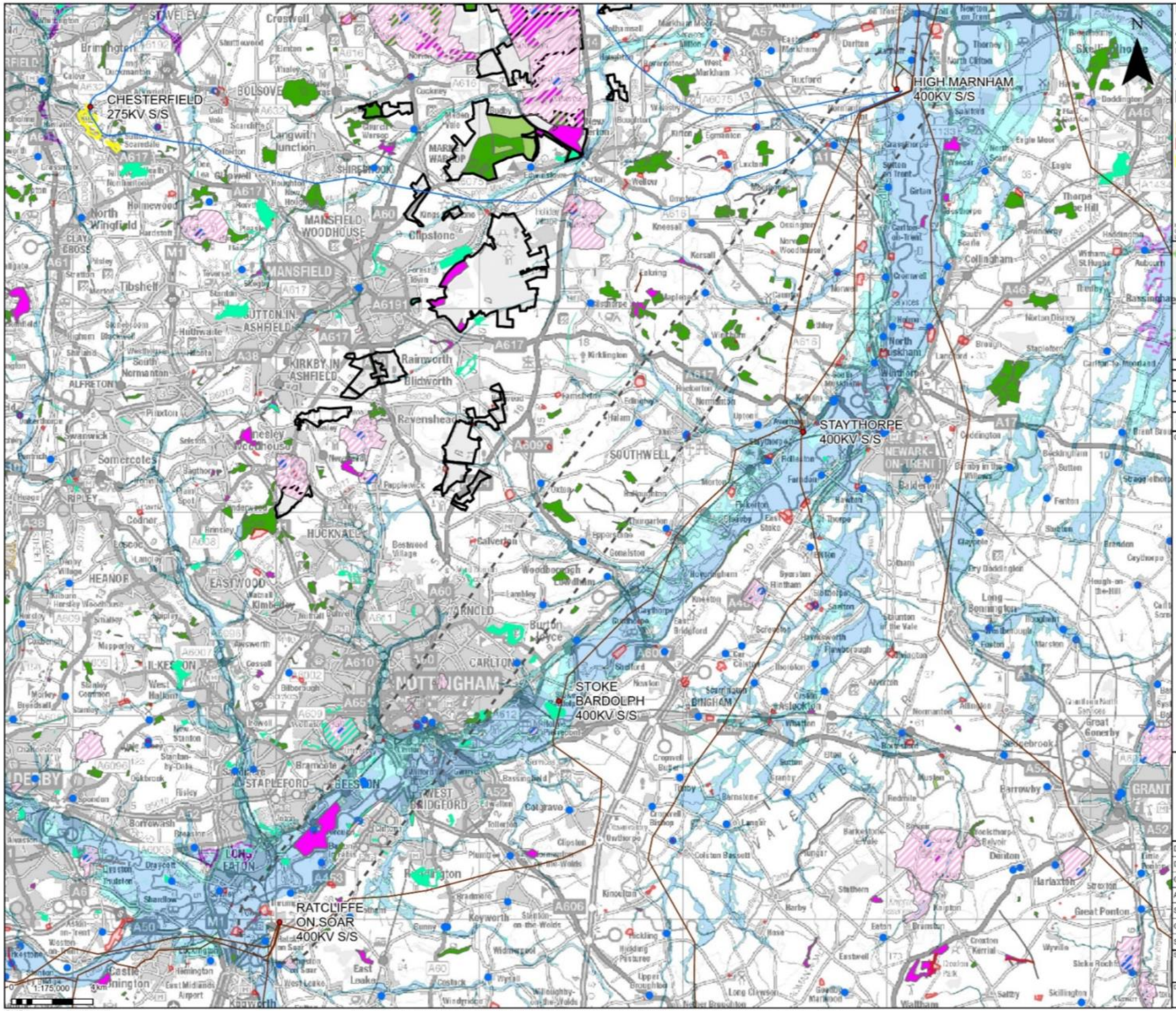

Legend

- ● Existing Substation
- ▭ Study Area
- **Existing OHL**
- — 400kV
- — 275kV
- ▨ Registered Park and Garden
- ● 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

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Client:

nationalgrid

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CHESTERFIELD
TO WILLINGTON

Site: Chesterfield

Client: National Grid

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Environmental and Socio-Economic
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(New High Marnham substation to
Ratcliffe-on-Soar 400kV substation)

Designed	R. Allen	Date: 28 FEB 24	Signed:
Drawn	R. Millman	Date: 28 FEB 24	Signed:
Checked	R. Allen	Date: 28 FEB 24	Signed:
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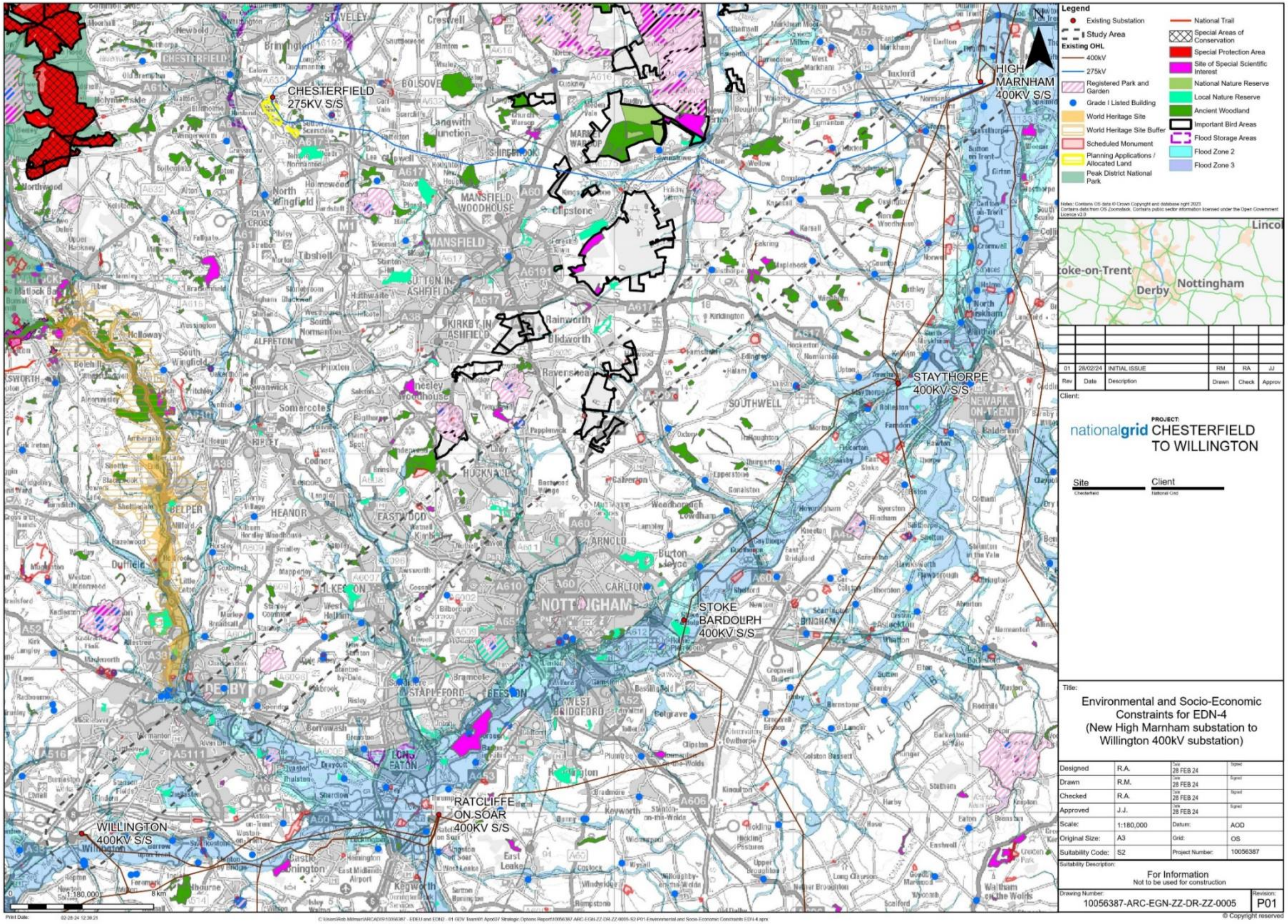
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STOKE BARDOLPH 400KV S/S
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WILLINGTON 400KV S/S
CHESTERFIELD
MANSFIELD
NOTTINGHAM
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Legend
● Existing Substation
Study Area
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400kV
275kV
Registered Park and Garden
● Grade I Listed Building
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Peak District National Park
National Trail
Special Areas of Conservation
Special Protection Area
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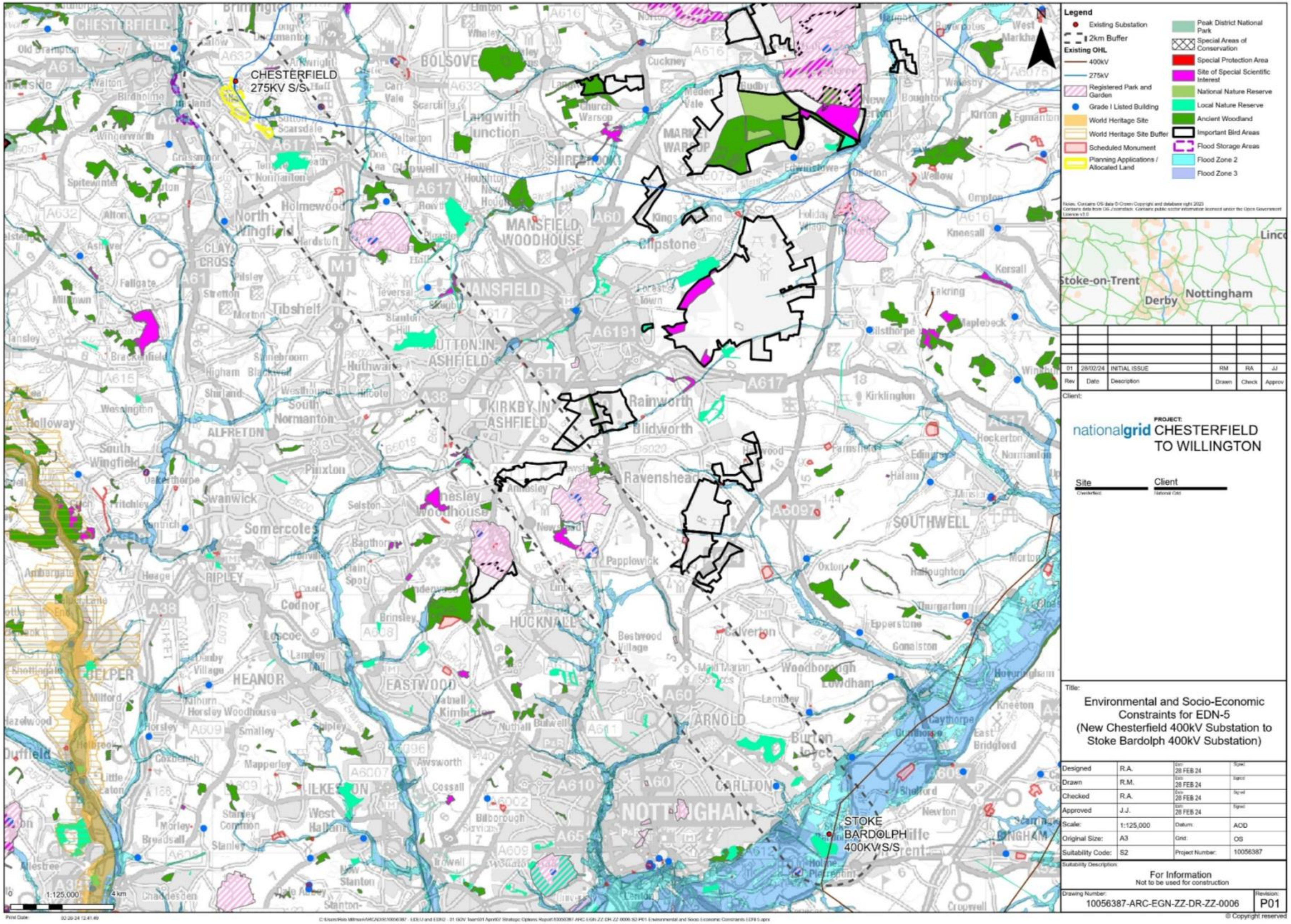
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CHESTERFIELD
BOLSOVER
MANSFIELD WOODHOUSE
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ALFRETON
RIPLEY
HEANOR
BELPER
EASTWOOD
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CARLTON
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Planning Applications / Allocated Land
Peak District National Park
Special Areas of Conservation
Special Protection Area
Site of Special Scientific Interest
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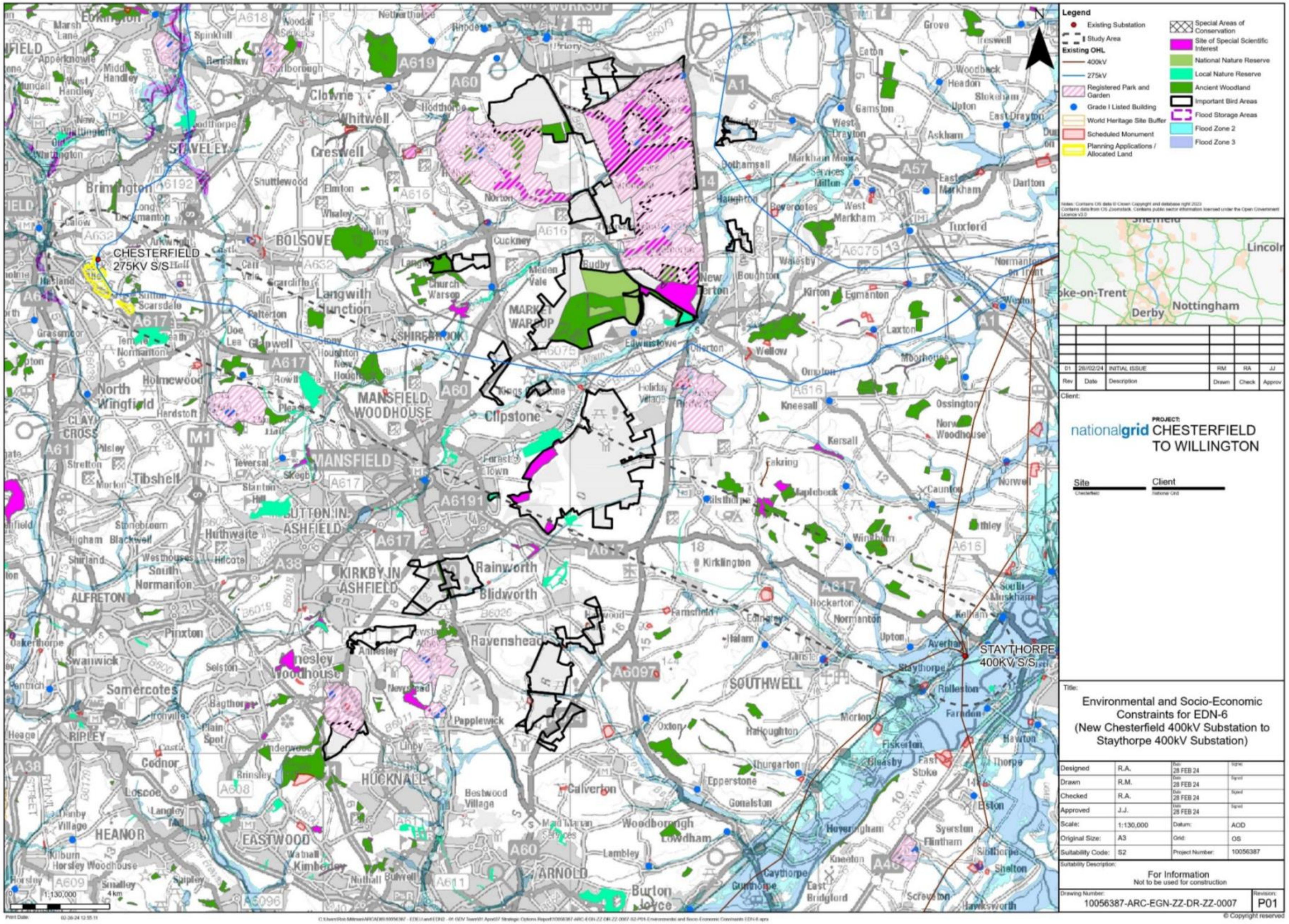


Rev	Date	Description	Drawn	Check	Approv
01	28/02/24	INITIAL ISSUE	RM	RA	JJ

Client:

nationalgrid

PROJECT:
CHESTERFIELD TO WILLINGTON

Site: Chesterfield

Client: National Grid

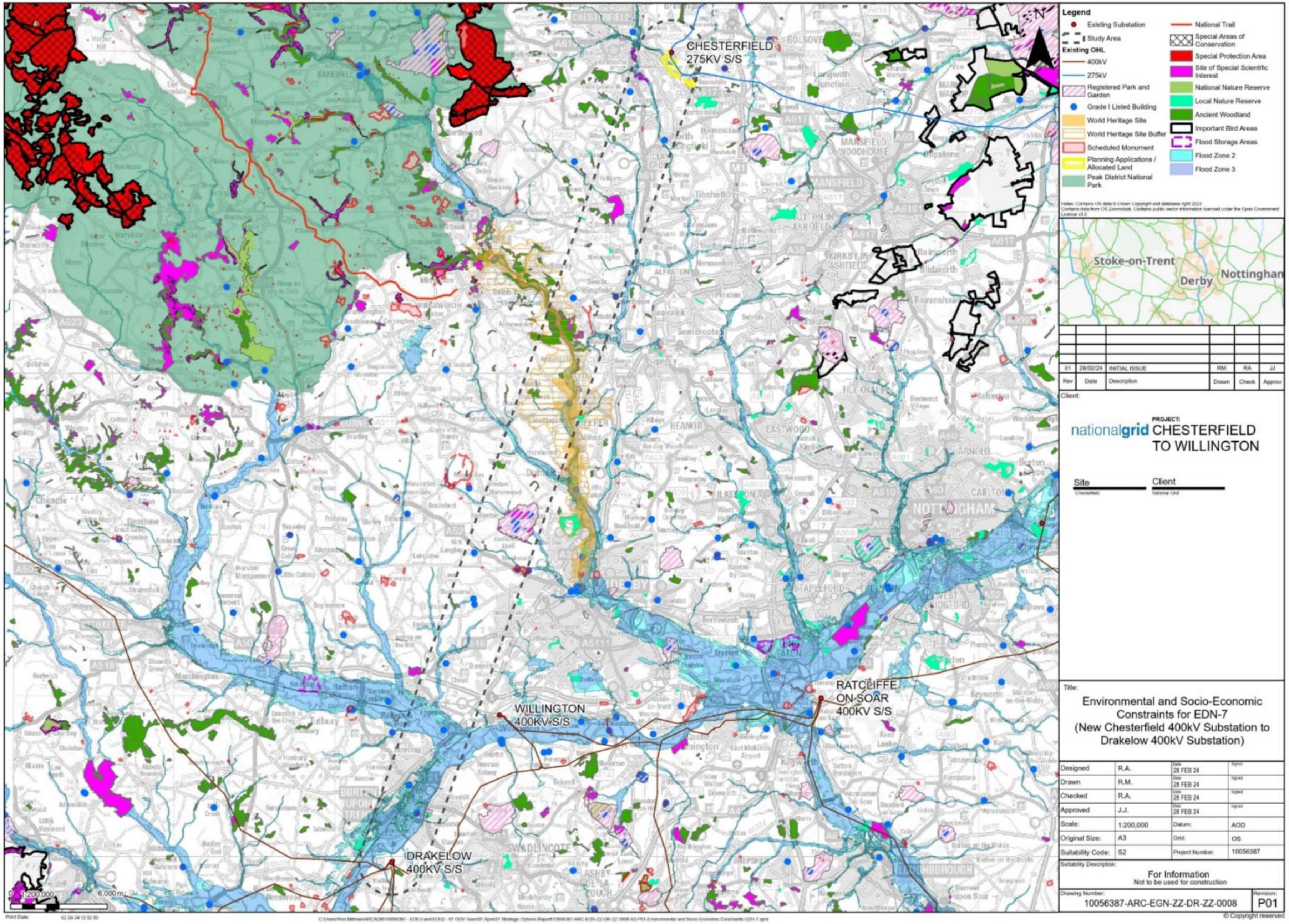
Title:
Environmental and Socio-Economic Constraints for EDN-6 (New Chesterfield 400kV Substation to Staythorpe 400kV Substation)

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:	1:130,000	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-0007

Revision: P01



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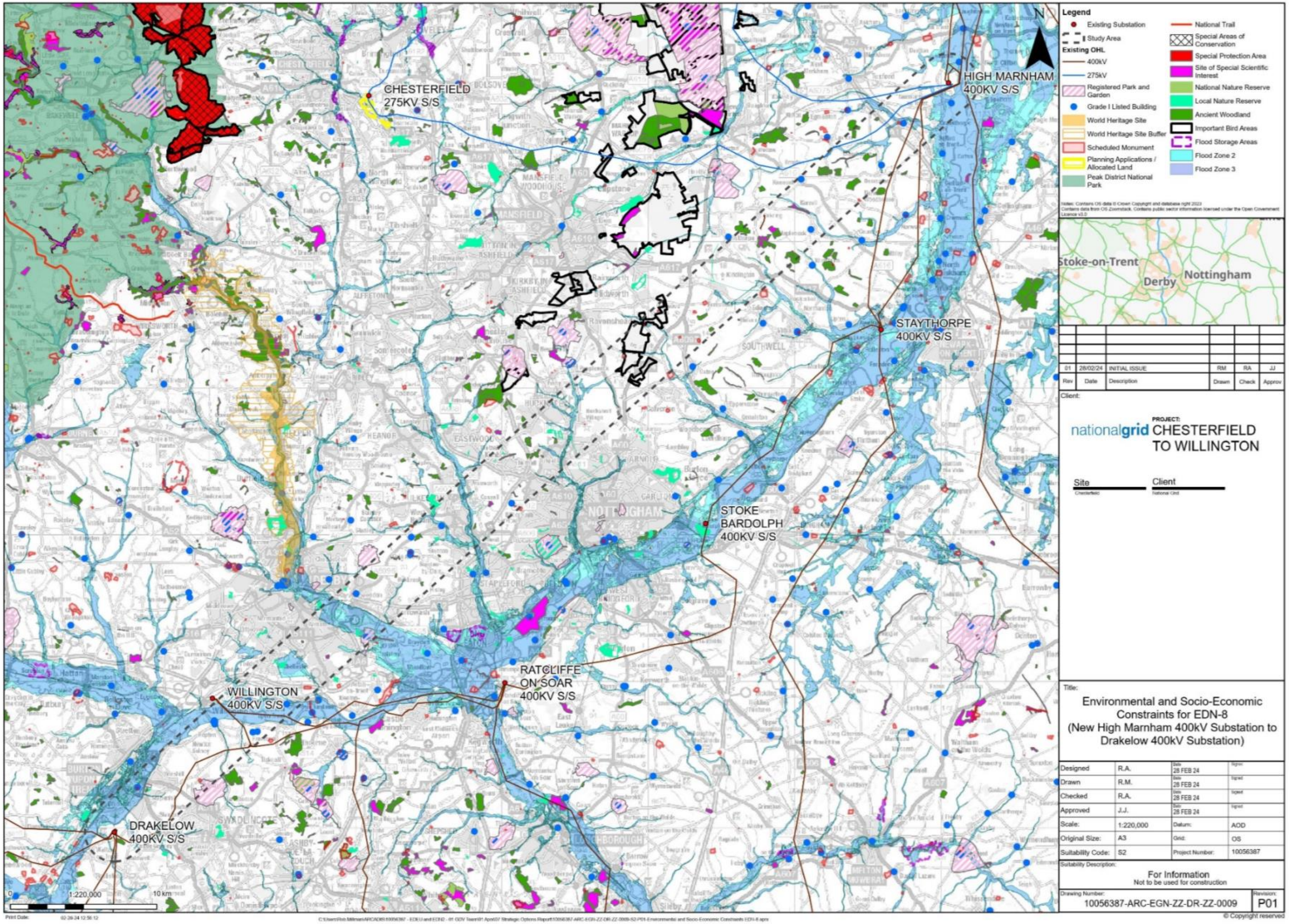
Title:

Environmental and Socio-Economic Constraints for EDN-7 (New Chesterfield 400kV Substation to Drakelow 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:	1:200,000	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-0008
Revision: P01



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Rev	Date	Description	Drawn	Check	Approv
01	28/02/24	INITIAL ISSUE	RM	RA	JJ

Client:

nationalgrid

PROJECT:
CHESTERFIELD
TO WILLINGTON

Site: Chesterfield

Client: National Grid

Title:

Environmental and Socio-Economic
Constraints for EDN-8
(New High Marnham 400kV Substation to
Drakelow 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:	1:220,000	Datum:	AOD
Original Size:	A3	Grid:	OS
Suitability Code:	S2	Project Number:	10056387

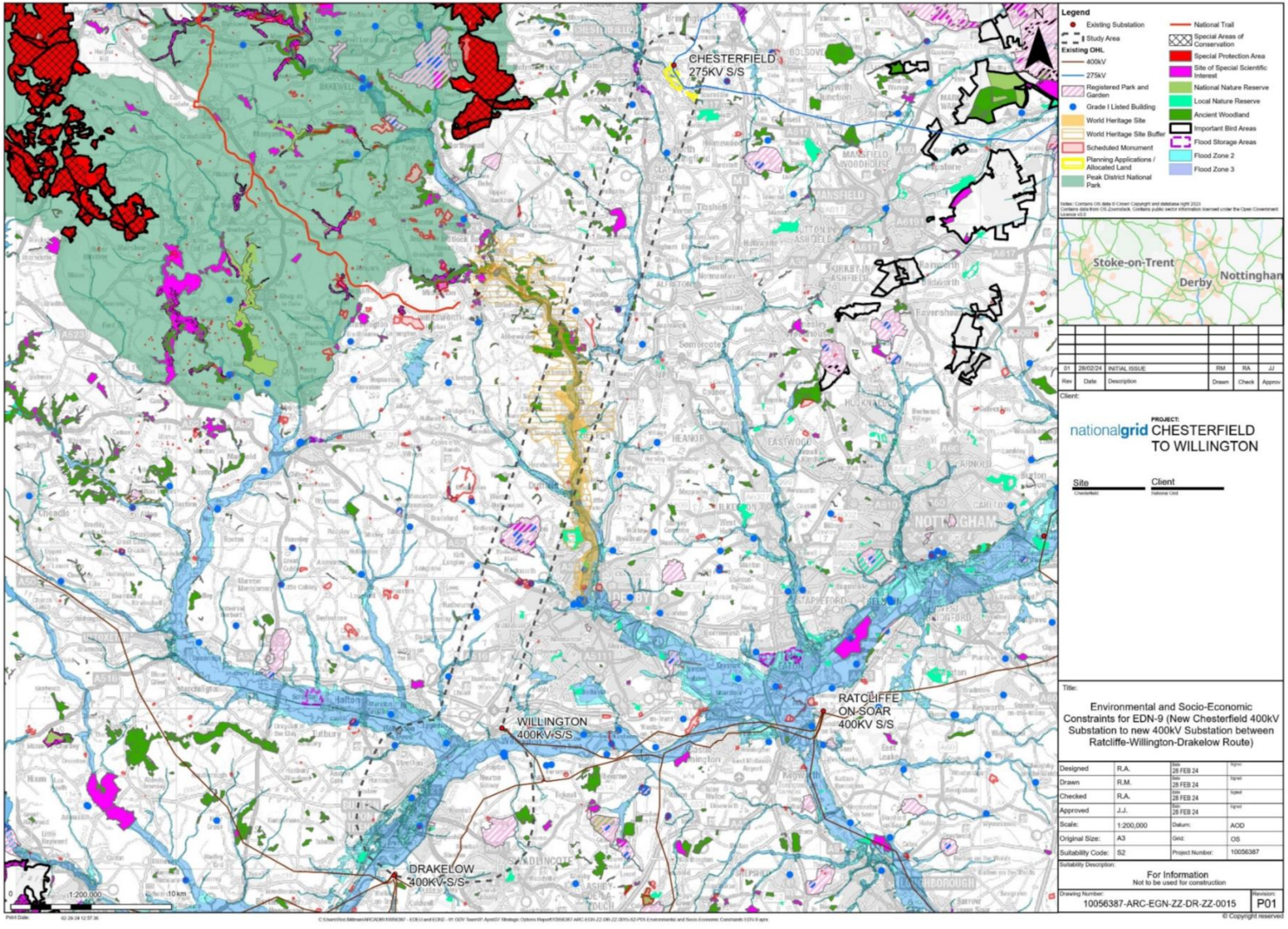
Suitability Description:

For Information
Not to be used for construction

Drawing Number: 10056387-ARC-EGN-ZZ-DR-ZZ-0009

Revision: P01

Print Date: 02-28-24 12:56:12

CHESTERFIELD 275KV S/S
WILLINGTON 400KV S/S
RATCLIFFE-ON-SOAR 400KV S/S
DRAKELOW 400KV S/S
N
Legend
● Existing Substation
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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Stoke-on-Trent
Derby
Nottinghan
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:
Environmental and Socio-Economic Constraints for EDN-9 (New Chesterfield 400kV Substation to new 400kV Substation between Ratcliffe-Willington-Drakelow Route)
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: | 1:200,000 | 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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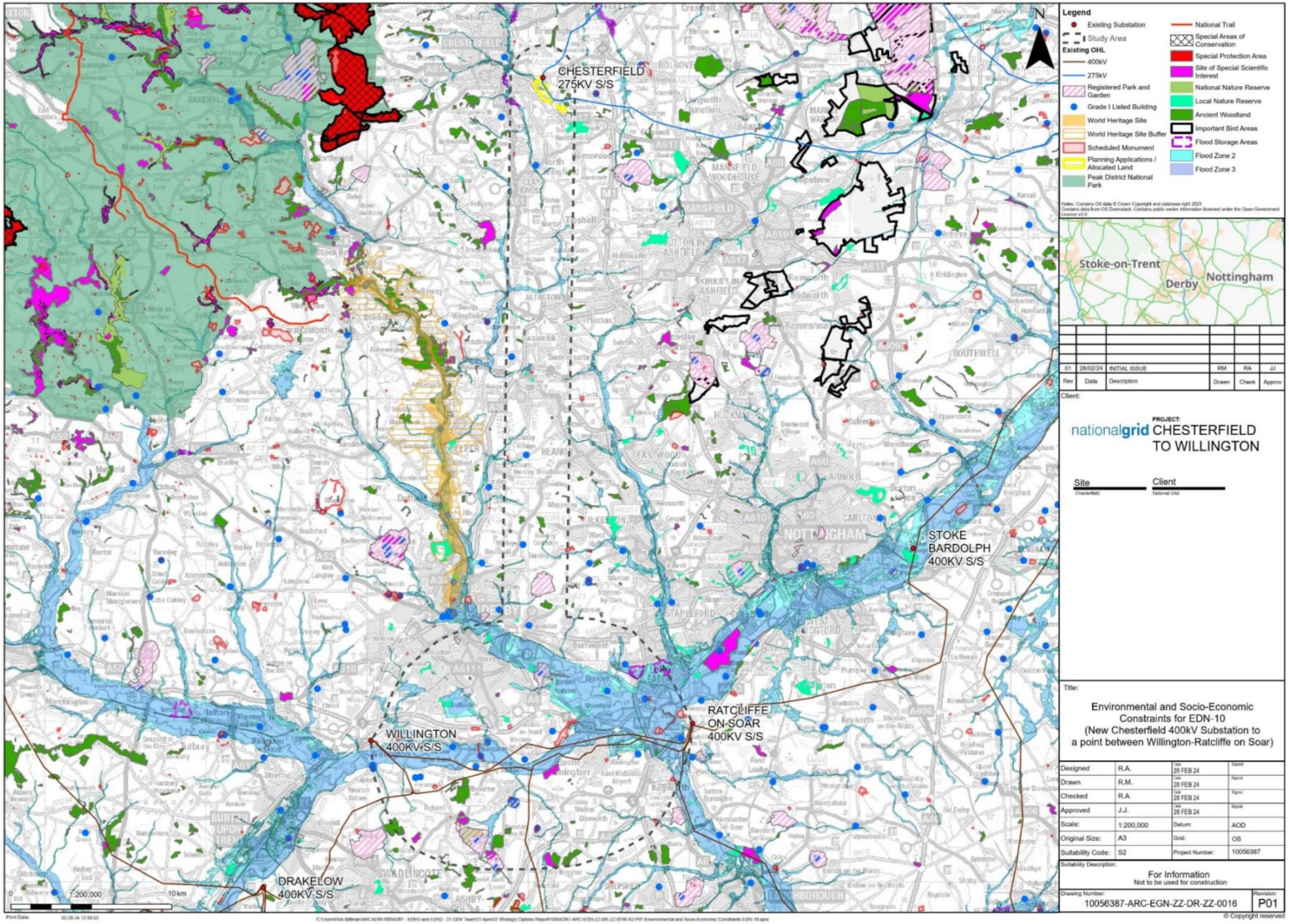
1:200,000
10 km



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Rev	Date	Description	Drawn	Check	Approv
01	28/02/24	INITIAL ISSUE	RM	RA	JJ

Client:

nationalgrid

PROJECT:
CHESTERFIELD TO WILLINGTON

Site: Chesterfield

Client: National Grid

Title:

Environmental and Socio-Economic Constraints for EDN-10 (New Chesterfield 400kV Substation to a point between Willington-Ratcliffe on Soar)

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:	1:200,000	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-0016

Revision: P01

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Warwick Technology Park,
Gallows Hill, Warwick.
CV34 6DA United Kingdom

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