The Great Grid Upgrade

Weston Marsh to East Leicestershire

Strategic Options Report (SOR)

May 2025

nationalgrid

Contents

Weston Marsh to East Leicestershire
Document control

Version History			
Document	**Version**	**Status**	**Description / Changes**
05/2025	0.1	Published	Initial publication for consultation

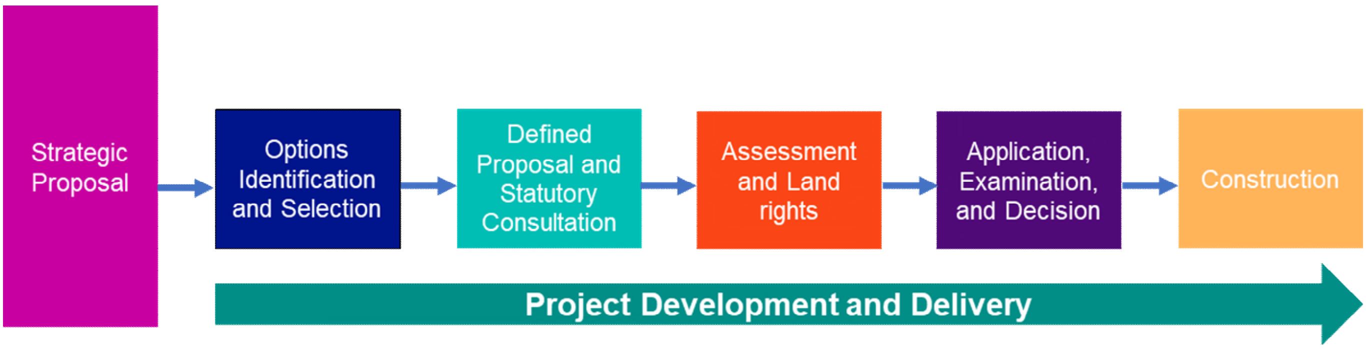
Executive summary

Purpose of the Strategic Options Report

This Strategic Options Report (SOR) provides an overview of the options that we (National Grid Electricity Transmission plc (‘NGET’)) have identified and subsequently evaluated for the project Weston Marsh to East Leicestershire (LRN#), a proposed reinforcement of the network in the Humber and East Coast Regions by means of a new 400 kV (kilovolt) transmission connection.

The stages of NGET’s process-based approach when transmission system works are identified that would require additional consents and/or permissions are shown below:

Figure A – Approach to Consenting Process



This report forms part of the initial ‘Strategic Proposal’ stage.

How the electricity system is planned and operated

NGET is the owner of the transmission system in England and Wales and holds an electricity transmission licence authorising it to participate in the transmission of electricity. NGET’s transmission licence requires that NGET provide an efficient, economic, and co-ordinated transmission system in England and Wales (section 9 Electricity Act 1989 (Electricity Act)). When planning changes to the transmission system, NGET must also have regard to the desirability of preserving amenity (section 38 and Schedule 9 Electricity Act).

NESO (National Energy System Operator) is a separate legal entity to NGET. NESO facilitates several roles on behalf of the electricity industry, including making formal offers to applicants requesting connection to the National Electricity Transmission System (NETS). NESO also manages makes investment recommendations to transmission owners, including NGET, through an annual network planning cycle and other periodic reviews, indicating which areas of the transmission system require reinforcement.

The legislation, policy and regulatory framework

Legislation

In addition to the legal duty to maintain an efficient, economic, and co-ordinated energy transmission system, NGET is subject to a number of statutory duties when developing new infrastructure, including under the:

- Electricity Act 1989
- National Parks and Access to the Countryside Act 1949
- Countryside and Rights of Way Act 2000
- Natural Environment and Rural Communities Act 2006
- Wildlife and Countryside Act 1981

UK Energy Policy

In 2019, the UK Government committed to achieving net zero greenhouse gas emissions by 2050. In addition, in 2024 the UK Government has committed to achieving a clean electricity system by 2030.

These commitments require the UK to move away from fossil fuels and to adopt alternative sources of energy to power homes, transport, and businesses. The Government has set out how it plans to deliver on these commitments within multiple plans including:

- British Energy Security Strategy (BESS, April 2022)
- Powering Up Britain and Powering Up Britain: Energy Security Plan (March 2023)
- Clean Power 2030 Action Plan: A new era of clean electricity (December 2024)

Consenting regimes and national planning policy

Electricity network infrastructure developments

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.

For the purposes of this report, it is assumed that the proposed development would be consented under the Planning Act 2008. The Planning Act 2008 defines developments of new electricity overhead lines of 132 kV and above as Nationally Significant Infrastructure Projects (NSIPs) requiring a Development Consent Order (DCO) (subject to certain statutory thresholds). Applications for a DCO must be determined in accordance with National Policy Statements (NPS) in most cases. National Policy Statements (NPS) set out the need and government policy relating to NSIPs. The NPSs also form the primary basis on which DCO applications are determined by the relevant Secretary of State. Other material considerations can include local planning policies set out in relevant development plans by local planning authorities and national planning policy, for example the National Planning Policy Framework.

Six NPSs for energy infrastructure were designated by the Secretary of State in January 2024. 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.

Part 3 of EN-1 sets out Government policy on the need for new nationally significant energy infrastructure projects and confirms that the UK needs a range of the types of energy infrastructure covered by the NPS and that "substantial weight" should be given to the urgent need for the types of infrastructure covered by the NPS when considering applications for DCOs.

The need case for reinforcement to the transmission system

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, which requires it to develop and maintain an efficient, coordinated and economical system of electricity transmission.

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.

Figure B – The National Electricity Transmission System in the North, Midlands, and East Anglia

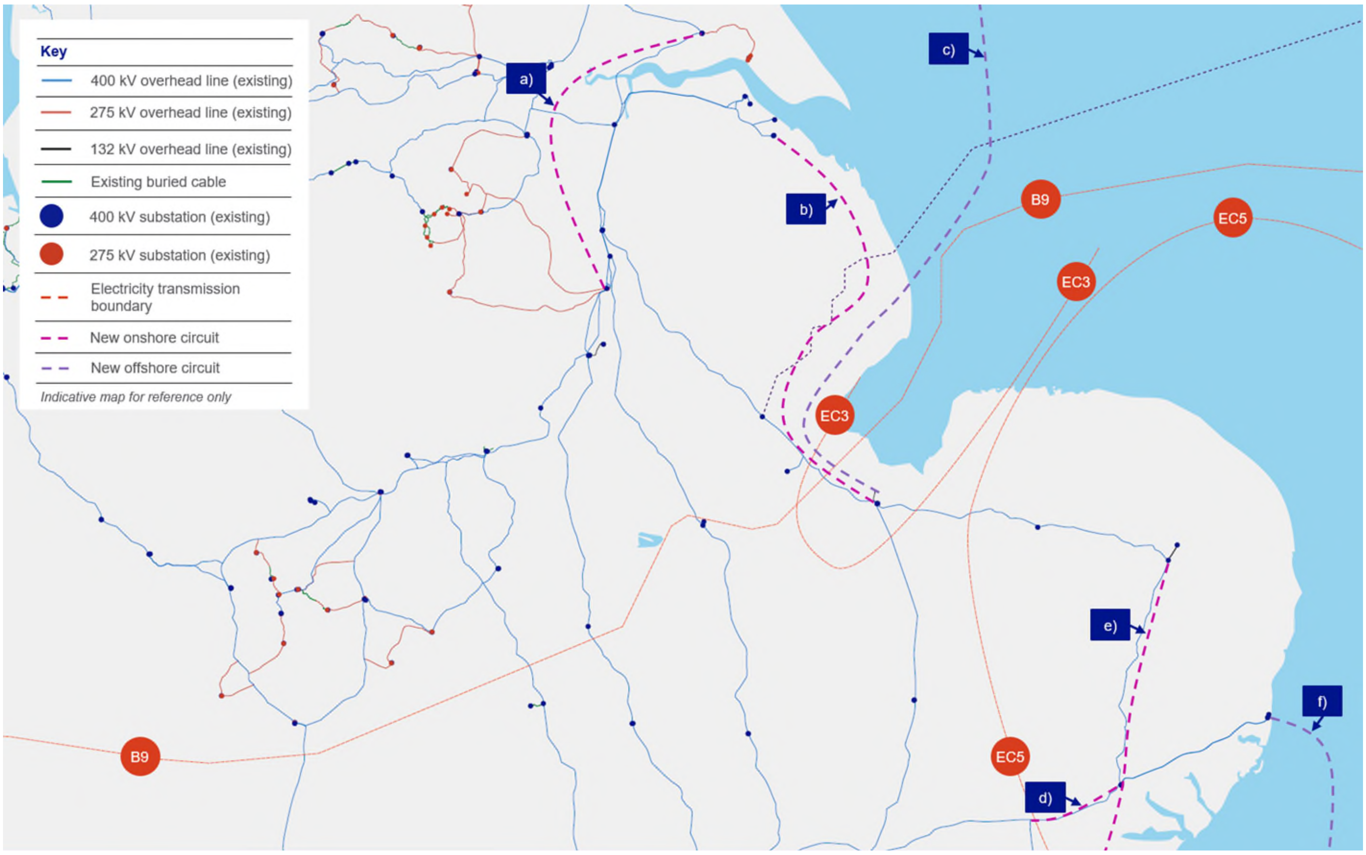


Figure B shows the existing transmission system and the B9, EC3 and EC5 boundary as well as the proposed investments described below:

a) North Humber to High Marnham

b) Grimsby to Walpole

c) Eastern Green Link 3 and 4 (EGL3 and EGL4)

d) Bramford to Twinstead

e) Norwich to Tilbury

f) Sea Link

The proposed new connections b) and c) all cross the B9 boundary along with facilitating generation connections. Connection a) does not cross the B9 boundary but has an impact on power flows in the region. The proposed new connections d), e) and f) all cross the EC5 East Anglia boundary.

NGET's B9 analysis results

Taking account of the increases to B9 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 following capability and capacity for the B9 system boundary will occur

- capability deficit of -5,793 MW (megawatt); and
- capacity surplus of 3,318 MW

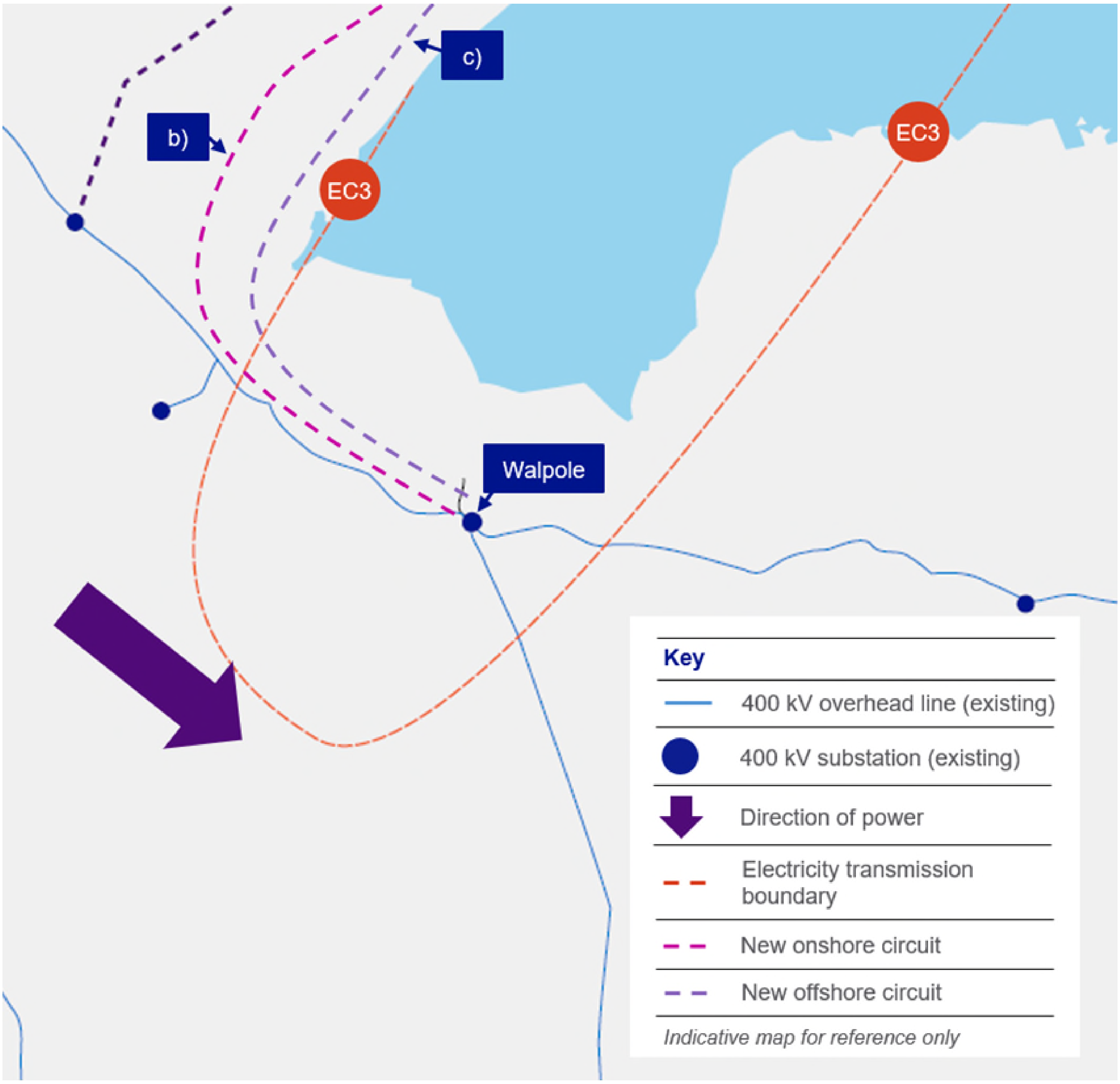
NGET recognises that the capability deficit needs to be addressed to enable the required system transfers.

From 2035 further increases in boundary requirements are expected, and this is reflected in NGET's existing contractual commitments. To address these needs, additional reinforcements to these boundaries are expected across Central England and Wales which will supplement them 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.

EC3 Boundary

The EC3 boundary is a more localised boundary where specific pinch points on the system occur. Figure C below shows the existing system with the proposed connections b) Grimsby to Walpole and C) EGL3 and EGL4 HVDC connections from Scotland.

Figure C – EC3 Boundary



As shown in Figure C above the system is formed by the following proposed connections flowing in from the north:

- Bicker Fen – Spalding North – Walpole double circuits;
- Grimsby West – Walpole double circuits; and
- EGL3 and EGL4 connections.

The following circuits then flow south and east from Walpole:

- Walpole to Burwell Main double circuits; and
- Walpole to Necton double circuits.

The power flow is dominated by a flow created by high generation areas in the north and east coast offshore connections, towards the demand centres in the south and midlands of the country.

Double circuit faults, where the circuits will switch off the system, lead to overloads far beyond the maximum capacity of a 6,930 MW double circuit. 6,930 MW represents the largest size circuits National Grid accommodates on the system, each circuit carrying 3,465 MW or 5,000 Amps of current. This is the normal operating rating of the majority of 400 kV equipment on the transmission network.

Therefore, as the overloads are above this level, NGET needs additional infrastructure to remain compliant with the NETS SQSS (Security and Quality Supply Standard) which requires the system not to be overloaded following a secured event on the transmission system such as the double circuit faults described above.

The deficit against the highest overloads is for an additional double circuit capacity up to 6,930 MW to relieve overloads on the local EC3 boundary following faults.

Need case conclusion

1.1.1 There are three distinct issues that need to be resolved by the system reinforcements to meet both our licence obligations and progress compliance with the NETS SQSS. The issues that must be resolved are;

- Provision of 5,793 MW of boundary capability to the B9 boundary
- Provision of 6,930 MW capacity to the EC3 boundary
- Connect the east to west corridors to alleviate power flow constraints in the east coast

How we identify and appraise potential strategic options

Once the need case has been established, there is a requirement to consider the many ways in which the Project can be delivered. Before NGET undertakes any further work, a technical compliance filter is applied to make sure that all the potential strategic options being considered would work on the network, rejecting any that would not meet technical standards or would not work in practice, including ensuring compliance with NETS SQSS.

The criteria for any potential strategic option to be considered further and not discontinued are:

- an environmental benefit;
- a technical system benefit; and
- a socio-economic benefit.

The appraisal of all potential strategic options led to six being selected to take forward for detailed appraisal. These are indicated in Table A, as shown below.

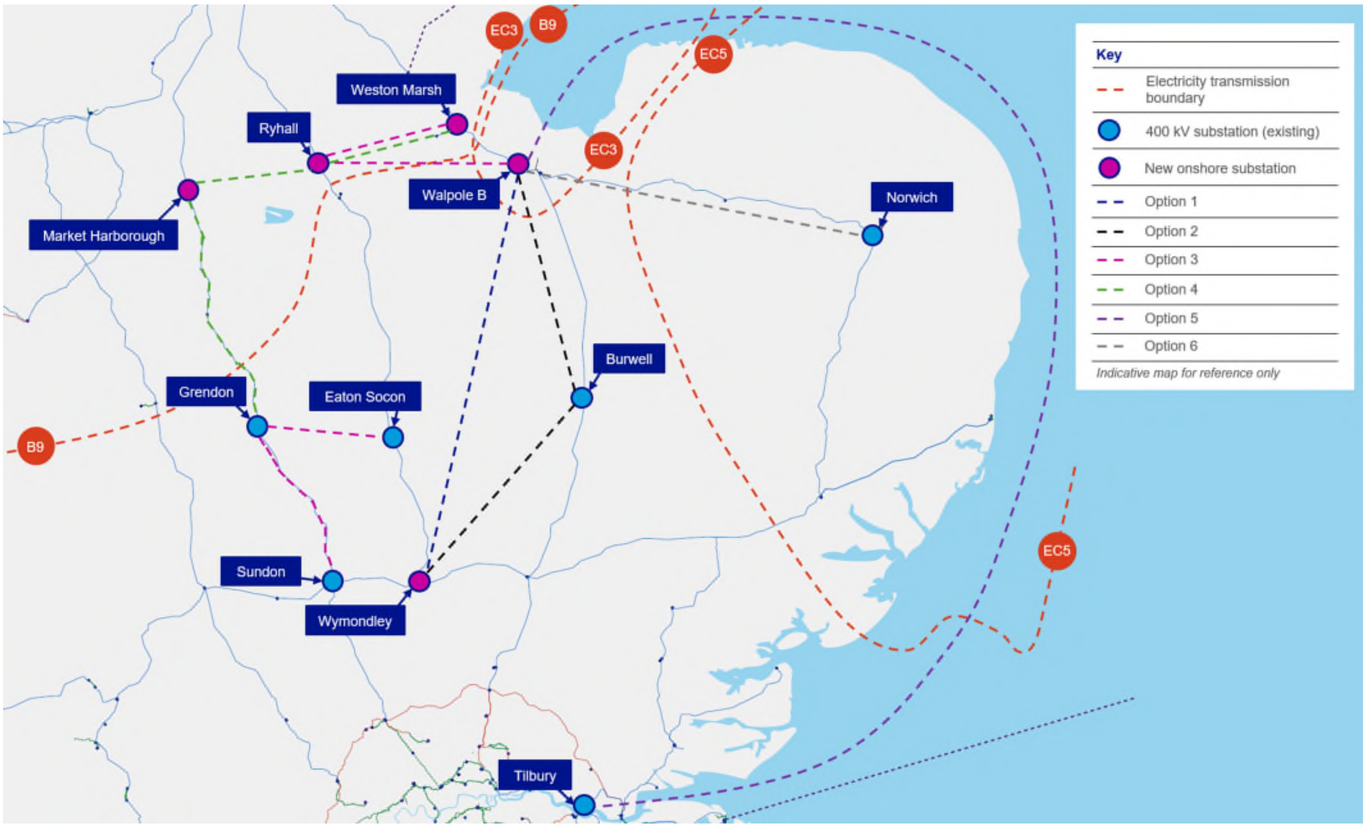
Table A – Proposed strategic options for appraisal

Proposed strategic option title	Option description
Option-1 Walpole B to new Wymondley	100 km new 400 kV transmission connection
Option-2 Walpole B to new Wymondley (via Burwell Main)	120 km new 400 kV transmission connection
Option-3 Weston Marsh/Walpole B to new Ryhall and Eaton Socon to Grendon	60 km new 400 kV transmission connection and 40 km reconductoring existing Grendon to Sundon 400 kV connection
Option-4 Weston Marsh to new Market Harborough (via new Ryhall)	60 km new 400 kV transmission connection, 55 km reconductoring new Market Harborough to Grendon 400 kV connections
Option-5 Walpole B to Tilbury	360 km subsea HVDC connection
Option-6 Walpole B to Norwich	90 km new 400 kV transmission connection

These six options potentially achieve the need case for reinforcement in the Humber and East Coast Region and present an environmental benefit; a technical system benefit; a capital and lifetime cost benefit (which includes the consideration of initial capital costs and long-term maintenance and operating costs) or a socio-economic benefit are proposed for detailed appraisal. For each appraisal, a 2 km study area is considered; this is the zone within which the environmental and socio-economic effects of options will be described.

The six options that have been subject to environmental, socio-economic, cost, and technical appraisal are summarised in Figure D.

Figure D – Indicative Overview of all Strategic Options



The results of our strategic options assessment

NGET has determined that the preferred strategic option to best address the Project need case and take forward at this stage is Option 4 for the following reasons:

- From an environmental perspective, Option 4 does not have any Special Protection Areas, Ramsar sites, RSPB Important Bird Areas or National Nature Reserves within the 2 km study area. Option 4 does not cross any designated heritage assets. Finally, Option 4 only crosses and potentially impacts one settlement.
- From a socio-economic perspective, Option 4 is the only option that does not cross any National Cycle Routes. Option 4 crosses three CRoW Open Access Lands with a further two within the 2 km study area and does not impact any inalienable land. There are four crossings of National Grid Infrastructure and no NSIPs. Option 4 crosses six road networks and three rail networks. Finally, there is also one military site, and one airstrip located within the 2 km study area.
- From a technical perspective, Option 4 provides uplift to the B9 boundary. The option provides increased system flexibility due to the proposal to implement two circuits out of new Weston Marsh and new Ryhall and mitigates the overloading of the Ryhall-Eaton Socon circuit under fault conditions. In terms of the technology solution implemented, OHL (Overhead Line) technology is well established and does not add uncertainty of constructability risk to the project. However, the length of the OHL to be reconductored between Market Harborough and Grendon is increased when compared with Option 3.

- From a cost perspective, Option 4 has a capital cost of £597.8m and a lifetime circuit cost of £411.0m. Option 4 provides a median capital cost while also having the second lowest lifetime circuit cost out of all options, which adds significant weight to the option in terms of the cost factor.

Conclusions and next steps

This SOR presents the findings of NGET's options appraisal process and is intended to provide a clear justification for NGET's preferred strategic option.

To enhance capability and post-fault capacity between boundaries B9 and EC3, and to provide the required capacity to the Humber and East Coast generation groups, NGET's proposal is to take forward Option 4. NGET will continue to review this work, considering any significant changes and consultation feedback.

The Project will proceed to the next development stage, which includes confirming the preferred technology for Option 4, identifying a preliminary route corridor, and establishing a graduated swathe for potential development locations. This will be presented in a non-statutory consultation to gather feedback and inform the project's further development.

Further information regarding the Project and its development can be found on the project website[1].

[1] Weston Marsh to East Leicestershire project website
https://nationalgrid.com/the-great-grid-upgrade/weston-marsh-to-east-leicestershire

1. Introduction

1.1 Purpose of the Strategic Options Report

1.1.1 This Strategic Options Report (SOR) has been prepared by National Grid Electricity Transmission plc (NGET) as part of the ongoing strategic options assessment and decision-making process involved in promoting new transmission projects. It presents the findings of our options appraisal process and is intended to provide a clear justification and evidence for our decision-making of a preferred strategic option for the project Western Marsh to East Leicestershire (LRN#). The Project proposes a reinforcement of the network in the Humber and East Coast Regions by means of a new 400 kV (kilovolt) transmission connection. This report has been prepared in accordance with 'Our Approach to Consenting[2]'.

1.1.2 The Government has committed to achieving a fully decarbonised UK electricity system by 2030, subject to security of supply. The way electricity is generated in the UK is changing rapidly, with a transition to cheaper, cleaner, and more secure forms of energy like new offshore windfarms. We need to make changes to the network of overhead lines, pylons, cables, and other infrastructure that transports electricity around the country, so that everyone has access to the clean electricity from these new renewable sources. Details on the need for the Project is described in Chapter 4 of this report.

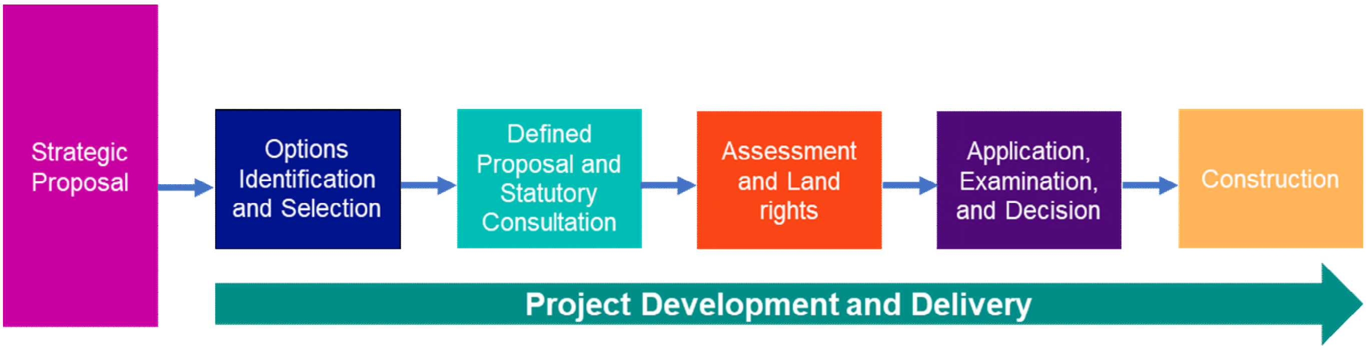
1.1.3 The consideration of strategic options is part of a process to inform the selection of the preferred option and the Project that is proposed by the Development Consent Order (DCO) application. That process will be influenced by considerations of other emerging energy projects and by evolving customer requirements.

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

1.1.5 As set out in Our Approach to Consenting, the following are the key stages in the project development and delivery process for major infrastructure projects: Strategic Proposal, Options Identification and Selection, Defined Proposal and Statutory Consultation, Assessment and Land Rights, Application, Examination and Decision, and Construction. The identification of a strategic proposal establishes the scope of the Project which commences with Options Identification and Selection. This document forms part of the "Strategic Proposal" and is at the very start of the process as shown in Figure 1.1 below.

[2] Our Approach to Consenting, National Grid, April 2022
www.nationalgrid.com/electricity-transmission/document/142336/download

Figure 1.1 – Approach to the consenting process



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

1.2 Structure of this report

1.2.1 The report is structured as follows:

- Chapter 1 Introduction
- Chapter 2 How the electricity transmission system is planned and operated
- Chapter 3 The legislative, policy and regulatory framework
- Chapter 4 The case for reinforcement of the transmission system
- Chapter 5 Options identification and selection process
- Chapter 6 The results of NGET's appraisal of strategic options
- Chapter 7 Conclusions and next steps

1.2.2 This document is also supported by a detailed set of appendices setting out our obligations, technology assumptions and cost appraisal methodology as follows:

- Appendix A: Glossary of terms and acronyms
- Appendix B: Summary of National Grid Electricity Transmission legal obligations
- Appendix C: Requirement for Development Consent Order
- Appendix D: Technology overview
- Appendix E: Economic appraisal
- Appendix F: Mathematical principles used for AC loss calculation
- Appendix G: Beyond 2030 publication

1.2.3 This SOR is part of an iterative process, investigating prospective opportunities. The conclusions of this report will, in due course, be supplemented by feedback from consultation exercises, along with other elements such as design evolution. Consistent with Our Approach to Consenting, we will continue to assess relevant technical, environmental, socio-economic and cost factors as part of ongoing appraisals.

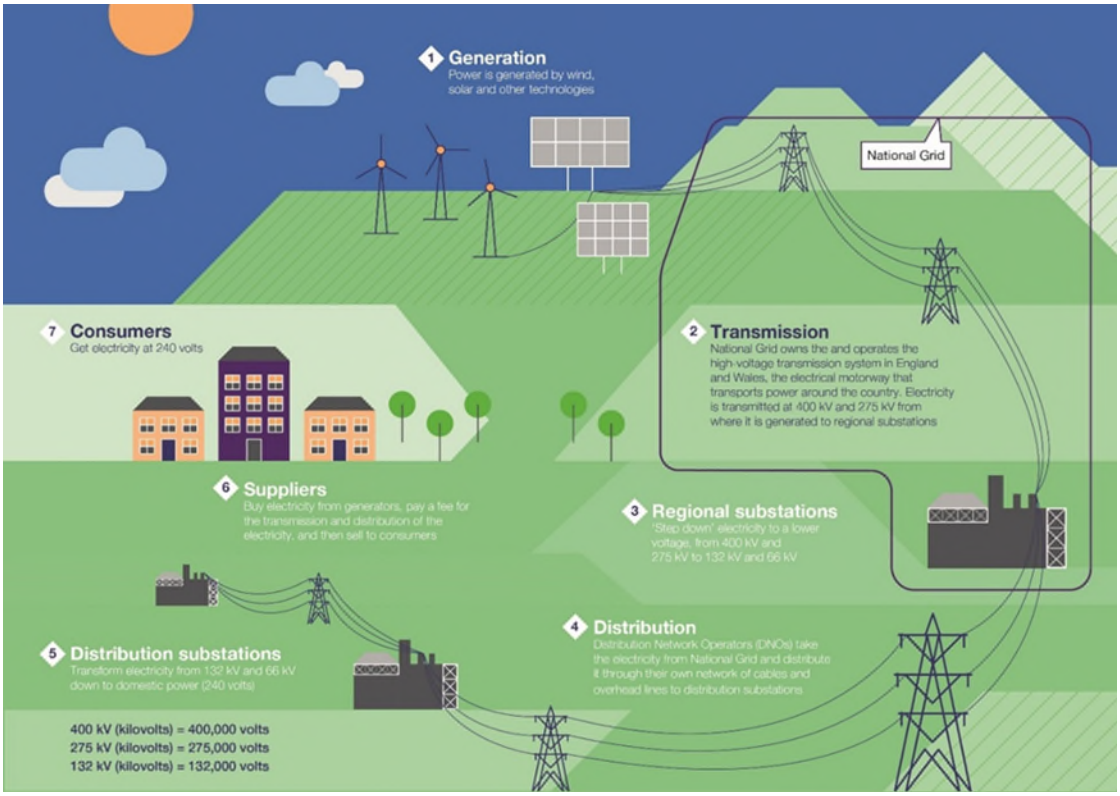
2. How is the electricity transmission system planned and operated?

2.1 The transmission system

2.1.1 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 in Great Britain operates at 400 kV and 275 kV and transports bulk supplies of electricity from generating stations to demand centres. Lower voltage distribution systems operate at 132 kV and below in England and Wales and are mainly used to transport electricity from substations (interface points with the transmission system) to the majority of end customers as presented in Figure 2.1.

> *What is demand?*
>
> *Demand is electricity used by domestic and non-domestic consumers, for example the electricity used within the home or by businesses.*

Figure 2.1 – The electricity system from generator to consumer



2.1.2 There are three Transmission Owners (TOs) for the Great Britain network. NGET is the TO for the transmission network in England and Wales. SP Energy Networks is the TO for Southern Scotland and SSEN is the TO for Northern Scotland and Scottish Islands Groups.

2.1.3 The generation directly connected to the electricity transmission system tends to be of two types: low carbon energy (nuclear, wind farms, solar, hydro) and large fossil fuel powered generation. This is also supplemented by new storage technologies such as battery storage.

2.1.4 Substations provide points of connection to the transmission system for power generation stations, distribution networks, transmission connected demand customers (e.g., large industrial customers) and interconnectors. Circuits connect 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.

What are interconnectors?

Interconnectors are transmission links that connect the electricity networks in two countries to allow for the transfer of electricity across borders. Currently the Great Britain system has interconnectors with France, Netherlands, Belgium and other countries.

2.1.5 Much of the 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 generation stations and interconnectors with other countries' transmission systems.

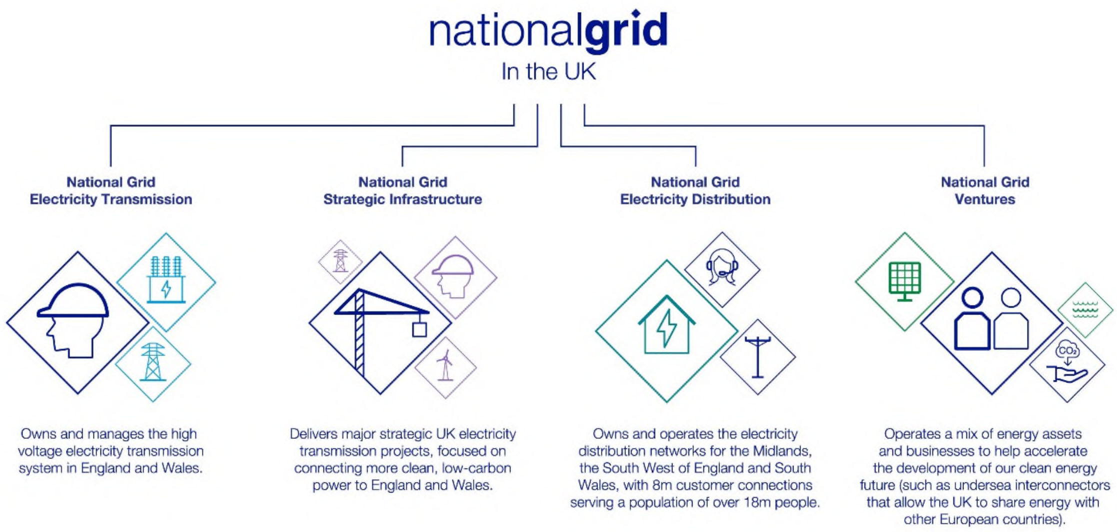
2.1.6 A single electricity market serves the whole of Great Britain. In this competitive wholesale market, generators and suppliers trade electricity on a half hourly basis. Generators produce electricity and sell it in the wholesale market. Suppliers purchase electricity in the wholesale market and supply to end customers.

2.1.7 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, Belgium, Denmark, the Netherlands and other countries are used to import electricity to and/or export electricity from Great Britain's transmission system.

2.2 Roles and responsibilities

2.2.1 In maintaining and operating the electricity transmission system, there are multiple parties involved. The following sections provide an overview of the roles and responsibilities for the Department for Energy Security and Net Zero (DESNZ), the Office of Gas and Electricity Markets (Ofgem), NGET and National Energy System Operator (NESO).

Figure 2.2 – Roles and responsibilities within National Grid



2.3 The role of National Grid Electricity Transmission

2.3.1 NGET, as the TO, owns, builds and maintains the high voltage transmission system in England and Wales and is part of the National Grid Group of companies.

2.3.2 Our transmission system consists of approximately 7,200 km of overhead lines and 700 km of underground cabling, operating at 400 kV and 275 kV. In general, 400 kV circuits have a higher power carrying capability than 275 kV circuits. These overhead line and underground cable circuits connect around 340 transmission substations forming a highly interconnected transmission system.

2.3.3 Transmission of electricity in Great Britain requires permission by a licence granted under Section 6(1)(b) of the Electricity Act 1989 (as amended) (the Electricity Act). NGET has been granted a transmission licence (the Transmission Licence) and is therefore bound by legal obligations, which are primarily set out in the Electricity Act and the Transmission Licence.

2.3.4 Our legal obligations include duties under Section 9, Section 38 and Schedule 9 of the Electricity Act. In summary, these require us to:

- Develop and maintain an efficient, co-ordinated, and economical system of electricity transmission. This requires us to invest in upgrading the electricity transmission system, delivering new infrastructure such as overhead lines and substations that will connect increasing amounts of low carbon power as required to meet future demand and supply as well as wider Energy Policy. This includes working with NESO to help large energy projects connect to the transmission system so their electricity can flow through the network and power homes and businesses.
- 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.

2.4 The role of the Department for Energy Security and Net Zero

2.4.1 The Department for Energy Security and Net Zero (DESNZ) is the ministerial department with primary responsibility for energy. It sets the policy landscape for the United Kingdom. Details of the Government energy policy are described in Chapter 3.

2.4.2 The Secretary of State for DESNZ is the ultimate decision maker for new electricity transmission network proposals under the Planning Act 2008 (as amended).

2.4.3 This project falls within the category of Nationally Significant Infrastructure Projects (NSIPs), which require a Development Consent Order (DCO) under the Planning Act 2008. Applications for DCOs are submitted to and examined by the Planning Inspectorate and determined by the Secretary of State for DESNZ. Further details are available in Appendix C.

What is net zero?

UK Government's commitment to reduce greenhouse gas emissions to net zero by 2050 as per the Climate Change Act 2008 (2050 Target Amendment) Order 2019. Net zero means any emissions that cannot be avoided would be balanced by schemes to offset an equivalent amount of greenhouse gases from the atmosphere.

2.5 The role of the Office of Gas and Electricity Markets

2.5.1 The Office of Gas and Electricity Markets (Ofgem) is the regulator for gas and electricity markets in Great Britain. It is a non-ministerial Government department and an independent National Regulatory Authority, whose role is to protect consumers as a greener, fairer, energy system is delivered.

2.5.2 Ofgem works with Government, industry, and consumer groups to help deliver net zero from an energy perspective at the lowest cost possible to consumers. For NGET, this means reviewing the need case and the associated investment required to deliver large infrastructure projects.

2.5.3 To deliver the investments proposed within the Holistic Network Design (HND), Ofgem has introduced a new regulatory framework known as Accelerated Strategic Transmission Investment (ASTI). This aims to facilitate achieving Government targets by streamlining the regulatory approval and funding process for projects which require acceleration.

2.5.4 In Ofgem's December 2022 decision on accelerating onshore electricity transmission investment[3], it was confirmed that LRN# is not currently included in the published list of ASTI projects. NGET plans to submit a detailed delivery plan to Ofgem for review and consideration of LRN# being included in the ASTI projects list.

3 Decision on accelerating onshore electricity transmission development, Ofgem https://www.nationalgrideso.com/future-energy/pathway-2030-holistic-network-design

2.5.5 Should LRN# not be included in the ASTI framework, Ofgem will provide instruction to NGET on the regulatory regime which is to be applied to the Project.

2.6 The role of the National Energy System Operator

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

2.6.2 As of 1 October 2024, NESO became a public body owned by the DESNZ. It was formerly part of National Grid PLC and called the Electricity System Operator (ESO).

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

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

2.6.5 NESO, in undertaking this role, engages with NGET for England and Wales as well as the two TOs in Scotland, SSEN and SP Energy Networks.

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

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

What is a boundary?

A boundary notionally splits the system into two parts, crossing critical circuit paths that carry power between the areas where power flow limitations may be encountered. NESO can manage any shortfall in boundary capacity by reducing the power flows. This is achieved by constraining generation and paying for generators to reduce output.

What is constraining generation?

Generation is constrained when the electricity network cannot physically transfer power from one region to another. In these circumstances, NESO, in its system operator role, will ask generators to change their output to maintain system stability. Generators then receive constraint payments to compensate them for the reduction in their demand.

- Future Energy Scenarios: NESO is responsible for an annual process to publish Future Energy Scenarios[4] (FES) which takes energy industry views as part of a consultation process and develops a set of possible energy growth scenarios to

[4] Future Energy Scenarios 2024: NESO Pathways to Net Zero https://www.nationalgrideso.com/future-energy/future-energy-scenarios

2050. In developing FES, NESO takes into consideration the latest pipeline of connections as detailed within the Transmission Entry Capacity (TEC) Register.

- Network planning: ESO also facilitated an annual process to publish the Electricity Ten Year Statement (ETYS) setting out the network performance and requirements for all transmission in Great Britain over the next 10 years based on the data from the FES. ESO used the ETYS to publish annually the Network Options Assessment (NOA), which considered the economic case for options to reinforce the transmission system and made economic recommendations. The NOA included a Cost Benefit Analysis (CBA) process to determine when it would be appropriate to take forward options proposed by TOs to increase network capacity. The CBA considered the capital costs of the proposal, delivery timescales and constraint costs (as explained in Chapter 5) avoided by delivering the proposal. The NOA was used to establish when a proposed reinforcement became the most economical way to deliver value to Great Britain's energy consumers.
- Network Planning Review (NPR): The Pathway to 2030 Holistic Network Design (HND) and the recommendations set out in the most recent Network Options Assessment (NOA) prepared by ESO were the first steps towards a more centralised, strategic network planning approach that is critical for delivering affordable, clean and secure power, with a view to achieving net zero.
- NESO is currently transitioning from the NOA to a more comprehensive approach, a Centralised Strategic Network Plan[5] (CSNP). The CSNP will aim to foster the holistic development of the NETS, marking a new era in our network planning.
- Connections: NESO facilitates several roles on behalf of the electricity industry, including making formal offers to connection applicants to the electricity transmission system. NGET is obligated to provide the physical connections to the elements of the electricity transmission system that NGET own.

2.6.7 The planning activities undertaken by NESO are currently being updated to support the delivery of the Government's net-zero commitment. In 2022, ESO published the Holistic Network Design (HND) setting out an integrated approach to transmission network design that supports the large-scale delivery of electricity generated from offshore wind to Great Britain by 2030.

2.6.8 As it stands, the HND recommendations are not sufficient by themselves to reinforce the transmission system, as more electricity will be generated than the network can efficiently support and transport. Therefore, the UK Government requested ESO to further develop the HND and enable a set of recommendations to enable a greater amount of offshore wind generation to connect to the network.

2.6.9 The further development of the HND, known as HND FUE (FND Follow Up Exercise), was published by ESO in 2024, in a report titles 'Beyond 2030'. More detail is provided in Appendix G.

2.6.10 The Project was originally recommended by ESO as part of the Network Options Assessment (NOA) published in July 2022 and subsequently recommended to proceed as critical enabling and wider works in the Beyond 2030 report.

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

3. The legislative, policy and regulatory framework

3.1 Overview

3.1.1 We are under a legal duty to maintain an efficient, economic, and co-ordinated energy transmission system. This Chapter of the report provides further detail of the legal duties and the wider policy context to which we operate within including government energy policy and national planning policy. This includes ensuring that the delivery of energy is affordable, our networks are resilient, and enable transition to a net zero carbon economy having regard to the environment and society that we operate in.

3.2 Why is NGET required to reinforce the transmission system?

3.2.1 Our duties are placed upon us by the Electricity Act 1989 ('the Electricity Act') and under the terms of our Transmission Licence. Those duties, and terms of particular relevance to the development of the proposed connection described in this report are set out below.

3.2.2 As part of our Transmission Licence requirements, the transmission infrastructure needs to be capable of providing and maintaining a minimum level of security and quality of supply and of transporting electricity to and from customers. We are required to ensure that the transmission system remains capable as customer requirements change.

3.2.3 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 the capacity of all the circuits.

3.2.4 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.

3.2.5 The transmission system needs to cater for demand, generation and interconnector changes. These customers can apply to the National Energy System Operator (NESO) for new or modified connections to the transmission system. The relevant transmission owner must then assess the generation group to ensure that the transmission system is sufficient in the area to accommodate the existing and proposed generation. Upon completion of the assessment, NESO will make a formal offer of connection.

3.2.6 Where power flows are constrained by the transmission system across a specific number of circuits, this is termed a ‘boundary’ by NESO. Such boundaries are used in the Electricity Ten Year Statement (ETYS) to identify constraints which may require changes to the transmission system in the next 10 years. Where the ‘boundary capacity’ is exceeded against the standards of the Security and Quality of Supply Standard (SQSS), we must resolve the capacity shortfall.

What is the SQSS?

It is an industry standard that sets out the criteria and methodology for planning and operating the onshore and offshore electricity transmission system. It details the planning criteria for the connection of generation and demand groups onto the transmission system. It defines the performance required of the transmission system in terms of Quality and Security of Supply for secured events. This means that at all times:

- *Electricity system frequency should be maintained within statutory limits;*
- *No part of the National Electricity Transmission System (NETS) should be overloaded beyond its capability;*
- *Voltage performance should be within acceptable statutory limits; and*
- *The system should remain electrically stable.*

NESO is the code administrator of the SQSS and there is a panel made up of industry experts that are responsible for ensuring that the SQSS is up to date and manages any changes. Any changes to the SQSS are overseen by Ofgem.

3.2.7 Where capacity and capability of the transmission system are not sufficient, either from a generation group or across a boundary, we are required to reinforce the network. We do this by either modifying the existing network (if possible) and/or constructing additional transmission infrastructure to resolve the shortfall.

3.3 NGET's statutory duties

3.3.1 This section details the statutory duties most relevant to the development of new infrastructure. These duties are considered in NGET's approach to identifying options and the selection process. This is shown in NGET's review of potential strategic options and the application of the appraisal factors, as reported in Chapter 5 of this report.

3.3.2 The relevant statutory duties are:

- Electricity Act 1989
- National Parks and Access to the Countryside Act 1949
- Countryside and Rights of Way Act 2000
- Natural Environment and Rural Communities Act 2006
- Wildlife and Countryside Act 1981

Electricity Act 1989

3.3.3 When developing new infrastructure, NGET is required to comply with the following duties.

3.3.4 Section 9(2) of the Electricity Act (General duties of licence holders) states:

"*it shall be the duty of the holder of a licence authorising him to participate in the transmission of electricity: (a) to develop and maintain an efficient, co-ordinated and economical system of electricity transmission…;"*

3.3.5 Section 38 and Schedule 9 of the Electricity Act state that:

"(1) In formulating any relevant proposals, a licence holder…

- (a) shall 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

- (b) shall do what he 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."

National Parks and Access to the Countryside Act 1949

3.3.6 Section 11A (1A) of the National Parks and Access to the Countryside Act 1949 imposes a duty on certain bodies and persons in respect of National Parks. National Grid, for the purpose of this provision, is a 'relevant authority' by virtue of being a 'statutory undertaker' such that the duty applies to it. The duty provides as follows:

"(1A) In exercising or performing any functions in relation to, or so as to affect, land in any National Park in England, a relevant authority other than a devolved Welsh authority must seek to further the purposes specified in section 5(1) and if it appears that there is a conflict between those purposes, must attach greater weight to the purpose of conserving and enhancing the natural beauty, wildlife and cultural heritage of the area comprised in the National Park."

3.3.7 Section 5 sets out the statutory purposes of the National Park, as follows:

"(1) The provisions of this Part of this Act shall have effect for the purpose—

(a) of conserving and enhancing the natural beauty, wildlife and cultural heritage of the areas specified in the next following subsection; and

(b) of promoting opportunities for the understanding and enjoyment of the special qualities of those areas by the public."

Countryside and Rights of Way Act 2000

3.3.8 Section 85 of the Countryside and Rights of Way Act 2000 imposes a duty on public bodies in respect of areas of outstanding natural beauty. National Grid, for the purpose of this provision, is a 'relevant authority' by virtue of being a 'statutory undertaker', such that the duty applies to it. The duty provides as follows:

"(A1) In exercising or performing any functions in relation to, or so as to affect, land in an area of outstanding natural beauty in England, a relevant authority other than a devolved Welsh authority must seek to further the purpose of conserving and enhancing the natural beauty of the area of outstanding natural beauty."

Natural Environment and Rural Communities Act 2006

3.3.9 Section 40 of the Natural Environment and Rural Communities Act 2006 imposes a duty in respect of biodiversity. National Grid, for the purposes of this provision, is a 'public authority' by virtue of being a 'statutory undertaker' such that this duty applies to it. The duty provides as follows:

"(A1) For the purposes of this section "the general biodiversity objective" is the conservation and enhancement of biodiversity in England through the exercise of functions in relation to England.

(1) A public authority which has any functions exercisable in relation to England must from time to time consider what action the authority can properly take, consistently with the proper exercise of its functions, to further the general biodiversity objective."

Wildlife and Countryside Act 1981

3.3.10 Section 28G of the Wildlife and Countryside Act 1981 imposes a duty on 'statutory undertakers' in respect of sites of special scientific interest. The duty provides as follows:

"(1) An authority to which this section applies (referred to in this section and in sections 28H and 28I as "a section 28G authority") shall have the duty set out in subsection (2) in exercising its functions so far as their exercise is likely to affect the flora, fauna or geological or physiographical features by reason of which a site of special scientific interest is of special interest.

(2) The duty is to take reasonable steps, consistent with the proper exercise of the authority's functions, to further the conservation and enhancement of the flora, fauna or geological or physiographical features by reason of which the site is of special scientific interest."

3.4 Government energy policy

3.4.1 In 2019, the UK Government committed to achieving net zero greenhouse gas emissions by 2050. In 2024, the UK Government also committed to achieving a clean electricity system by 2030.

3.4.2 These commitments require the UK to move away from fossil fuels and to adopt alternative sources of energy to power our homes, transport and businesses. The Government has set out how it plans to deliver on these commitments within multiple plans including:

- November 2020: Prime Minister's Ten Point Plan for a Green Industrial Revolution[6].
- December 2020: Energy White Paper: Powering our Net Zero Future[7].
- October 2021: Net Zero Strategy: Build Back Greener[8].

[6] The Ten Point Plan for a Green Industrial Revolution, HM Government, November 2020 https://assets.publishing.service.gov.uk/media/5fb5513de90e0720978b1a6f/10_POINT_PLAN_BOOKLET.pdf

[7] Energy White Paper: Powering our Net Zero Future, HM Government, December 2020 https://assets.publishing.service.gov.uk/media/5fdc61e2d3bf7f3a3bdc8cbf/201216_BEIS_EWP_Command_Paper_Accessible.pdf

[8] Net Zero Strategy: Build Back Greener, HM Government, October 2021 https://assets.publishing.service.gov.uk/media/6194dfa4d3bf7f0555071b1b/net-zero-strategy-beis.pdf

- April 2022: British Energy Security Strategy[9] (BESS). This document is built on the Net Zero Strategy and was published in response to the Russian invasion of Ukraine and the 2022 energy price crisis.
- March 2023: Powering Up Britain[10] and Powering Up Britain: Energy Security Plan[11]. These documents provide an update of the strategy for secure, clean and affordable British energy for the long-term future.
- December 2024: Clean Power 2030 Action Plan: A new era of clean electricity[12]. This document provides the strategic initiative aimed at transitioning to cleaner energy sources and reducing carbon emissions.

3.4.3 Key ambitions contained within these plans to achieve net zero include:

- Up to 50GW of offshore wind connected by 2030 including 5GW of which will be offshore floating wind.
- Up to eight nuclear reactors being progressed, with up to 24GW to be achieved by 2050.
- Up to 10GW of low carbon hydrogen production capacity by 2030, doubling the previous ambition.
- 600,000 heat pump installations a year by 2028 and improving housing stock insulation.

3.5 National Policy Statements

Requirement for Development Consent Order

Electricity Network Infrastructure Developments

3.5.1 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.

3.5.2 The Planning Act 2008 defines developments of new electricity overhead lines of 132 kV and above and which meet all of the other criteria in section 14 of the Planning Act

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[9] British Energy Security Strategy, HM Government, April 2022 https://assets.publishing.service.gov.uk/media/626112c0e90e07168e3fdba3/british-energy-security-strategy-web-accessible.pdf

[10] Powering up Britain, HM Government, March 2023 https://assets.publishing.service.gov.uk/media/642468ff2fa8480013ec0f39/powering-up-britain-joint-overview.pdf

[11] Powering up Britain: Energy Security Plan, HM Government, March 2023 https://assets.publishing.service.gov.uk/media/642708eafbe620000f17daa2/powering-up-britain-energy-security-plan.pdf

[12] Clean Power 2030 Action Plan: A new era of clean electricity, UK Government, December 2024 https://assets.publishing.service.gov.uk/media/677bc80399c93b7286a396d6/clean-power-2030-action-plan-main-report.pdf

2008 as nationally significant infrastructure projects ('NSIPs') requiring a DCO. Such an order may also incorporate consent for other types of work that are associated with new overhead line infrastructure development, and these may be incorporated as part of a DCO that is granted. Applications for a DCO must be determined in accordance with National Policy Statements ("NPSs") in most cases.

3.5.3 Six NPSs for energy infrastructure were designated by the Secretary of State in January 2024. 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.

3.5.4 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.

Demonstrating the need for a project

3.5.5 Part 3 of EN-1 sets out Government policy on the need for new nationally significant energy infrastructure projects. Paragraphs 3.2.1 and 3.2.2 confirm that the UK needs a range of the types of energy infrastructure covered by the NPS to ensure the supply of energy always remains secure, reliable, affordable, and consistent with achieving net zero emissions in 2050 for a wide range of future scenarios. Paragraph 3.2.7 states that "substantial weight" should be given to the urgent need for the types of infrastructure covered by the NPS when considering applications for DCOs.

3.5.6 Description of the need for:

- new electricity transmission infrastructure is set out in EN-1 and EN-5
- new offshore/onshore wind generation is set out in EN-1 and EN-3, and
- new nuclear generation is set out in EN-1 and EN-6.

3.5.7 The need for new transmission infrastructure for the Project is described in Chapter 3 of the SOR.

Assessment principles applied by decision maker

3.5.8 Part 4 of EN-1 sets out the general policies that are applied in determining DCO applications relating to new energy infrastructure. Part 2 of EN-5 sets out the assessment principles in the specific context of electricity networks infrastructure.

3.5.9 There are a number of key principles of particular importance for transmission infrastructure projects.

Presumption in Favour of Development

3.5.10 Section 4.1 of EN-1 confirms that the Secretary of State will start with a presumption in favour of granting consent for energy NSIPs. This presumption applies unless any more specific and relevant policies set out in the relevant NPS clearly indicate that consent should be refused. The presumption is also subject to the exceptions set out in Section 104(4)-(8) of the Planning Act 2008.

3.5.11 In assessing any application, the Secretary of State should take account of potential:

- benefits (e.g. the contribution to meeting the need for energy infrastructure, job creation, reduction of geographical disparities, environmental enhancements, and long term or wider benefits), and
- adverse impacts (including on the environment, and including any long-term and cumulative adverse impacts, as well as any measures to avoid, reduce, mitigate or compensate for any adverse impacts, following the mitigation hierarchy).

The critical national priority for low carbon infrastructure

3.5.12 Section 4.2 of EN-1 states that there is a critical national priority (CNP) for the provision of nationally significant low carbon infrastructure. EN-1 confirms that the CNP extends to all power lines in scope of EN-5 (including network reinforcement and upgrade works, and associated infrastructure such as substations), CNP is not limited to infrastructure associated specifically with a particular generation technology.

3.5.13 Paragraph 4.2.7 explains that the CNP policy is relevant during Secretary of State decision making in reference to any residual impacts. Where the required assessment has been provided by an applicant, paragraph 4.2.17 further explains that the CNP policy applies a starting assumption that CNP Infrastructure will meet tests such as:

- where development within a Green Belt requires very special circumstances to justify development,
- where development within or outside a Site of Special Scientific Interest (SSSI) requires the benefits (including need) of the development in the location proposed to clearly outweigh both the likely impact on features of the site that make it a SSSI, and any broader impacts on the national network of SSSIs,
- where development in nationally designated landscapes requires exceptional circumstances to be demonstrated, and
- where substantial harm to or loss of significance to heritage assets should be exceptional or wholly exceptional.

3.5.14 Paragraphs 4.2.18 to 4.2.22 set out the approach to be taken to CNP Infrastructure in the context of a Habitats Regulations Assessment (HRA) or a Marine Conservation Zone Assessment (MCZA):

- Any HRA or MCZA residual impacts will continue to be considered under existing frameworks.
- Where, following Appropriate Assessment or MCZA, CNP Infrastructure has residual adverse impacts on the integrity of sites forming part of the UK national site network, either alone or in combination with other plans or projects, or which significantly risk hindering the achievement of the stated conservation objectives for the MCZ (as relevant) the Secretary of State will consider making a derogation.
- In that consideration, the Secretary of State will start from the position that energy security and decarbonising the power sector to combat climate change:
  - requires a significant number of deliverable locations for CNP Infrastructure and for each location to maximise its capacity, with the fact that there are other

potential plans or projects deliverable in different locations to meet the need for CNP Infrastructure being unlikely to be treated as an alternative solution and the existence of another way of developing the proposed plan or project which results in a significantly lower generation capacity being unlikely to meet the objectives and therefore be treated as an alternative solution, and

- are capable of amounting to imperative reasons of overriding public interest (IROPI) for HRAs, and, for MCZ assessments, the benefit to the public is capable of outweighing the risk of environmental damage, for CNP Infrastructure.
- For HRAs, where an applicant has shown there are no deliverable alternative solutions, and that there are IROPI, compensatory measures must be secured as part of a derogation.
- For MCZs, where an applicant has shown there are no other means of proceeding which would create a substantially lower risk, and the benefit to the public outweighs the risk of damage to the environment, the Secretary of State must be satisfied that measures of equivalent environmental benefit will be undertaken.

Consideration of alternatives

3.5.15 Paragraph 4.3.9 of EN-1 states that the NPS does not contain any general requirement to consider alternatives or to establish whether the proposed project represents the best option from a policy perspective. However, in relation to electricity transmission projects, paragraph 2.9.14 of EN-5 states:

"Where the nature or proposed route of an overhead line will likely result in particularly significant landscape and visual impacts, as would be assessed through landscape, seascape and visual impact assessment, the applicant should demonstrate that they have given due consideration to the costs and benefits of feasible alternatives to the overhead line. This could include – where appropriate – re-routing, underground or subsea cables and the feasibility e.g. in cost, engineering or environmental terms of these."

3.5.16 Paragraph 4.3.9 of EN-1 also makes clear that there will be circumstances where an applicant is specifically required to include information in their application about the main alternatives that were considered. These circumstances may include requirements in relation to compulsory acquisition and habitats sites.

Good design

3.5.17 Section 4.7 of EN-1 stresses the importance of 'good design' for energy infrastructure, explaining that this goes beyond aesthetic considerations as fitness for purpose and sustainability are equally important. It is acknowledged in EN-1 that the nature of much energy infrastructure development will often limit the extent to which it can contribute to the enhancement of the quality of the area. Section 2.4 of EN-5 highlights that the Secretary of State should bear in mind that electricity networks infrastructure must in the first instance be safe and secure, and that the functional design constraints of safety and security may limit an applicant’s ability to influence the aesthetic appearance of that infrastructure.

Climate change adaptation and resilience

3.5.18 Section 4.10 of EN-1 explains how climate change adaptation and resilience should be taken into account, requiring the assessment of the impacts on and from the proposed energy project across a range of climate change scenarios. Section 2.3 of EN-5 expands on this in the specific context of electricity networks infrastructure. This states that DCO applications are required to set out the vulnerabilities / resilience of the proposals to flooding, effects of wind and storms on overhead lines, higher average temperatures leading to increased transmission losses, earth movement or subsidence caused by flooding or drought (for underground cables) and coastal erosion (for the landfall of offshore transmission cables and their associated substations in the inshore and coastal locations respectively).

Networks DCO applications submitted in isolation

3.5.19 Section 2.7 of EN-5 confirms that it can be appropriate for DCO applications for new transmission infrastructure to be submitted separately from applications for the generation that this infrastructure will serve. Section 2.8 of EN-5 explains that, where an application is a reinforcement project in its own right and does not accompany an application for a generating station, or is not underpinned by a "contractually-supported agreement" to provide an as-yet-unconsented generating station with a connection, the Secretary of State should have regard to the need case for new electricity networks infrastructure set out in Section 3.3 of EN-1.

Electricity Act Duties

3.5.20 Paragraphs 2.8.4 and 2.8.5 of EN-5 recognise developers' duties pursuant to section 9 of the Electricity Act to bring forward efficient and economical proposals in terms of network design, as well as the duty to facilitate competition and so provide a connection whenever and wherever one is required.

Adverse Impacts and Potential Benefits

3.5.21 Part 5 of EN-1 covers the impacts that are common across all energy NSIPs and sections 2.9 to 2.15 of EN-5 consider impact in the specific context of electricity networks infrastructure.

3.5.22 Those impacts identified in EN-1 include air quality and emissions, greenhouse gas emissions, biodiversity and geological conservation, civil and military aviation and defence interests, coastal change (to the extent in or proximate to a coastal area), dust, odour, artificial light, smoke, steam and insect infestation, flood risk, historic environment, landscape and visual, land use, noise and vibration, socioeconomic impacts, traffic and transport, resource and waste management and water quality and resources. The extent to which these impacts are relevant to a particular stage of a project or are a relevant differentiator at a particular stage of the options appraisal process, will vary. In particular, some of these impacts are scoped out of this stage of the options appraisal process for the Project.

3.5.23 EN-5 considers specific potential impacts associated with electricity networks, including the following topics: biodiversity and geological conservation, landscape and visual, noise and vibration, electric and magnetic fields and sulphur hexafluoride.

3.5.24 Landscape and Visual impacts are of particular relevance for electricity transmission infrastructure projects. Paragraph 2.9.7 of EN-5 states that the Government does not believe that development of overhead lines is incompatible in principle with the statutory duty under Schedule 9 of the Electricity Act 1989 to have regard to visual and landscape amenity and to reasonably mitigate impacts. While paragraph 2.9.20 of EN-5 states that use of overhead lines as transmission technology should be the strong starting presumption for electricity networks developments, EN-5 recognises that in practice overhead lines can give rise to adverse landscape and visual impacts, dependent upon their type, scale, siting, degree of screening and the nature of the landscape and local environment through which they are routed. It also confirms that the presumption is reversed when crossing part of a nationally designated landscape.

3.5.25 In relation to alternative technologies for electricity transmission projects, paragraph 2.9.22 of EN-5 states in relation to developments crossing a nationally designated landscape that:

"Undergrounding will not be required where it is infeasible in engineering terms, or where the harm that it causes (see section 2.11.4) is not outweighed by its corresponding landscape, visual amenity and natural beauty benefits."

3.5.26 Similarly, paragraph 2.9.24 of EN-5 states in relation to developments that do not cross a nationally designated landscape that:

"Taking account of the fact that the government has not laid down any further rule on the circumstances requiring use of underground or subsea cables, the Secretary of State must weigh the feasibility, cost, and any harm of the undergrounding or subsea option against:

- *the adverse implications of the overhead line proposal;*
- *the cost and feasibility of re-routing overhead lines or mitigation proposals for the relevant line section; and*
- *the cost and feasibility of the reconfiguration, rationalisation, and/or use of underground or subsea cabling of proximate existing or proposed electricity networks infrastructure."*

3.5.27 Paragraph 2.9.16 of EN-5 confirms that the Holford Rules, which are a set of "common-sense" guidelines for routeing new overhead lines should be embodied in applicants' proposals. The Horlock Rules deal in a similar fashion with the siting of new substations and similar infrastructure. Paragraph 2.11.2 goes on to state that the Secretary of State should be satisfied that the development, so far as is reasonably possible, complies with the Holford Rules and Horlock Rules.

3.6 Security and Quality of Supply Standard (SQSS)

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

3.6.2 The NETS SQSS also sets out in "Generation Connection Criteria applicable to the onshore transmission system" that connections to the transmission system must be secured to meet the identified requirements. Where the SQSS applies, the generator(s) are considered part of a "generation group" for assessment against these criteria.

What is a generation group?

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.

3.6.3 Generators apply to NESO for connections to the NETS in Great Britain. If the application is for an onshore generation connection, the applicant will indicate the specific location of the generating station, which will indicate the likely geographical connection to the transmission system. If the application is for an offshore connection or impacts multiple transmission owners, NESO will coordinate the process known as Connection and Infrastructure Options Note (CION) / HND to determine the preferred connection option.

3.6.4 NESO ensures the relevant onshore or offshore transmission owner undertakes generation connection process studies via the relevant process and makes a connection offer to the customer for a connection point and identifies the relevant infrastructure work needed to make the connection. Once this offer is signed the connection is recorded on the TEC Register and forms a contractually binding connection location and timescale with which the transmission owner, such as NGET, is required to connect the generation customer or undertake the works to facilitate their connection.

3.6.5 A connection offer will normally be given in respect of a particular geographical area. Sometimes this leads to a presumption as to the connection point located on the existing transmission network. In other circumstances where there is no or little existing transmission infrastructure, this will require the provision of new infrastructure. The post connection offer assessment process enables further evaluation of the preferred connection option and refinement of the preferred overall transmission solution. This process continues, informed by evolving circumstances and consultation, until an application is submitted for development consent in relation to a transmission project.

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

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

3.6.8 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 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".

4. The need case for reinforcement of the transmission system

4.1 Need for future reinforcement in the Humber and East Coast Regions

4.1.1 As discussed in the previous chapter, UK Government policy requires significant reinforcement of the transmission system to facilitate the connection of renewable energy sources and to transport electricity to where it is used. In particular, the BESS sets targets for the connection of up to 50 GW of offshore wind by 2030 as a key part of a strategy for secure, clean and affordable British energy for the long term.

4.1.2 As described in Section 2.6, NESO through its publications develops a set of possible energy growth scenarios to 2050 and uses these to provide a 10-year view of the future transmission requirements and the capability of Great Britain's National Electricity Transmission System (NETS).

4.1.3 National Grid is responsible for ensuring compliance with the National Electricity Transmission System (NETS) Security and Quality of Supply Standards (SQSS), which sets out the criteria and methodology for planning and operating the system.

4.1.4 Reinforcement of the Humber and East Coast regions is required due to the planned growth in offshore wind in the North Sea and new interconnectors between England and Europe.

4.1.5 The Project was originally recommended by the ESO as part of the Network Options Assessment (NOA) published in July 2022 and subsequently recommended as to proceed as critical enabling and wider works in the Beyond 2030 report.

4.2 The existing transmission network

4.2.1 The transmission system in Scotland and the North and Midlands areas of England 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 fire power stations and nuclear power stations in Scotland and the North and Midlands areas of England. The existing transmission system in Scotland, the North of England and the Midlands is shown in Figure 4.1.

4.2.2 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.

4.2.3 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 South East. The transmission system carries bulk energy from the generators to points on the network where that power is taken onto the distribution networks for onward transmission to homes and businesses across England and Wales. As the country decarbonises, this demand for energy will increase and replace fossil fuel usage.

4.2.4 The existing transmission system in the North of England and the Midlands is shown in Figure 4.1. The geography under consideration in this report is shown in Figure 4.2.

Figure 4.1 – The National Electricity Transmission System in the North, Midlands and East Anglia

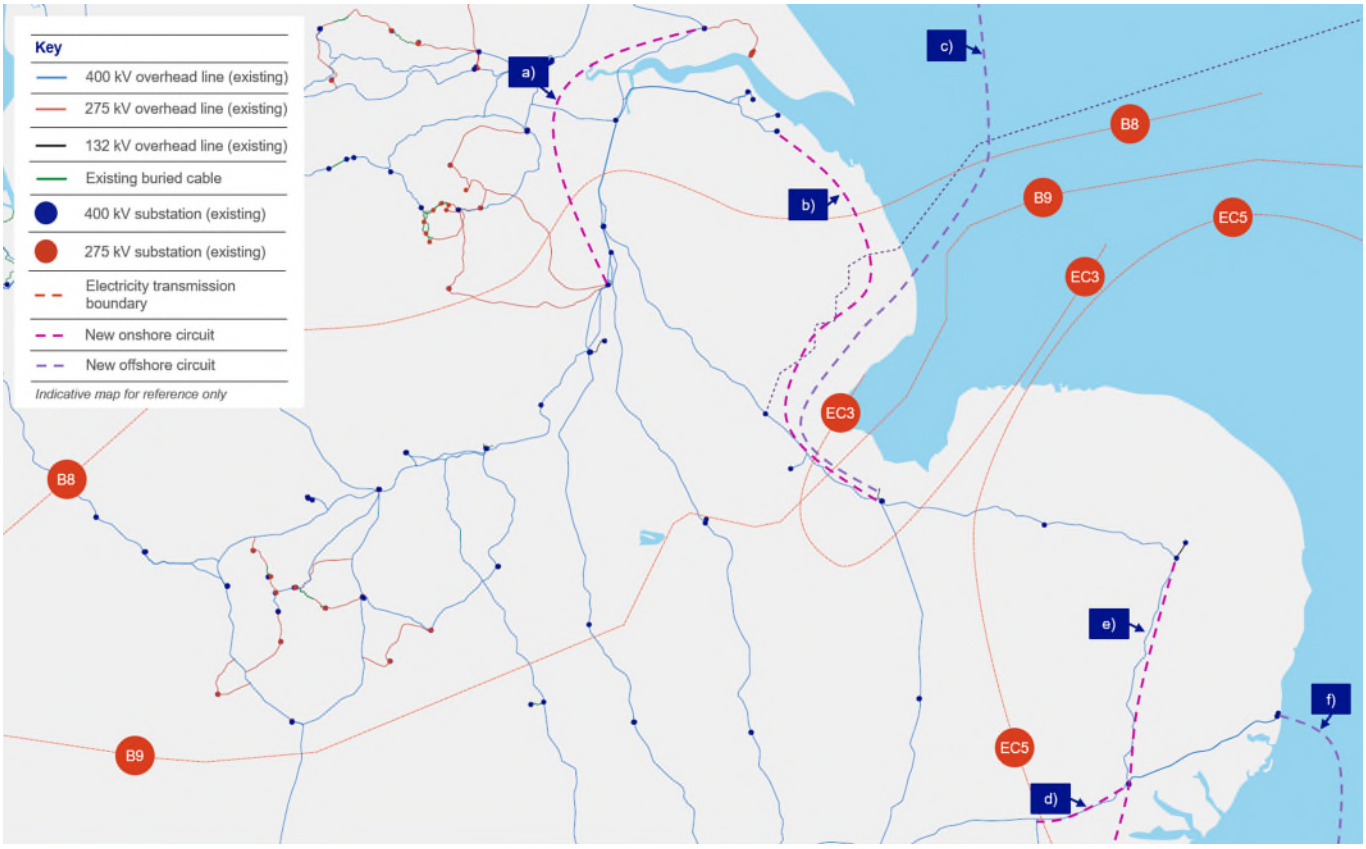
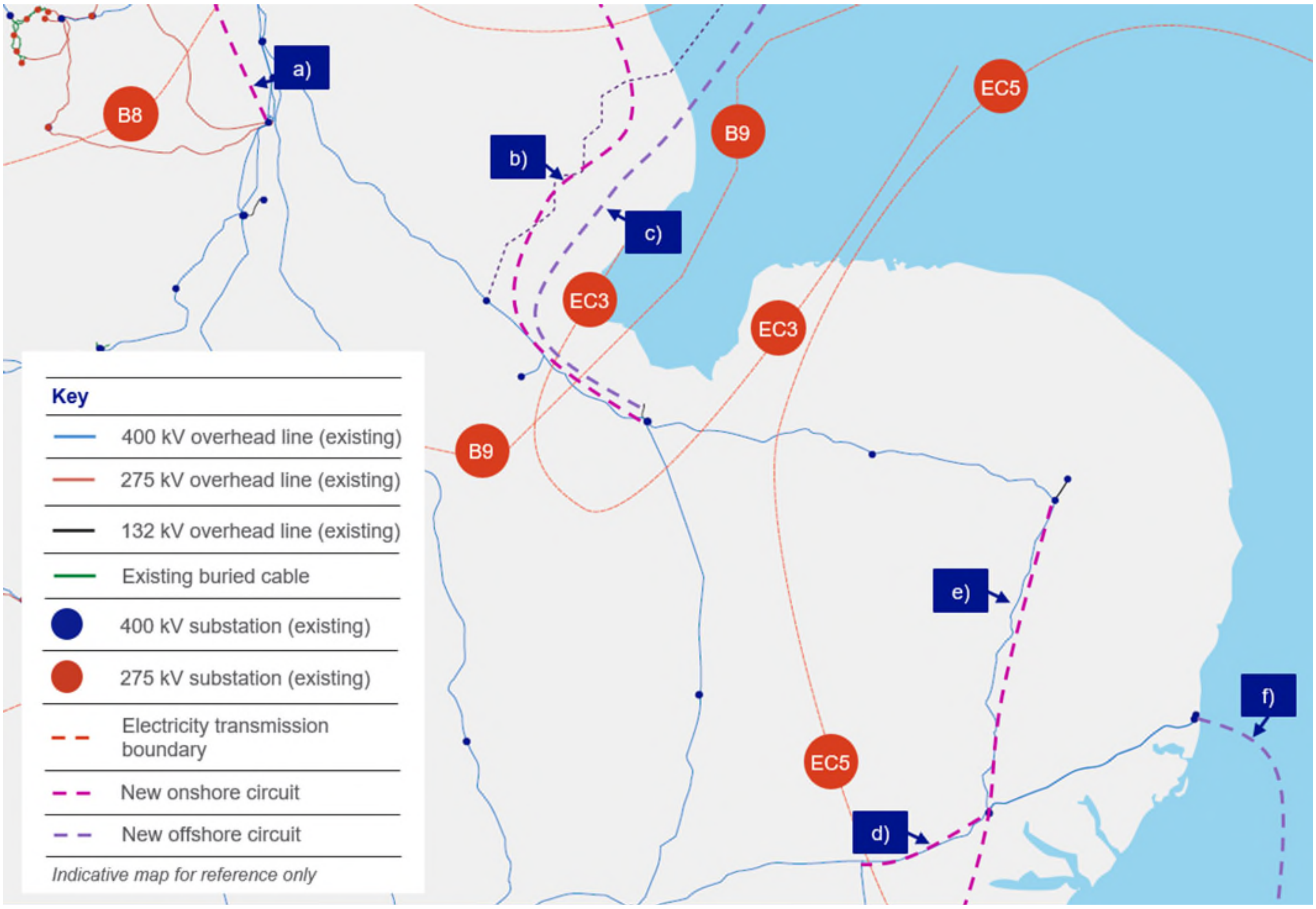


Figure 4.2 – Lincolnshire, East Midlands, East Anglia transmission system



4.2.5 Figures 4.1 and 4.2 show the existing transmission system and the B9, EC3 and EC5 boundary which will be described further below. Both figures also show the following proposed investments:

a) North Humber to High Marnham

b) Grimsby to Walpole

c) Eastern Green Link 3 and 4 (EGL3 and EGL4)

d) Bramford to Twinstead

e) Norwich to Tilbury

f) Sea Link

4.2.6 The proposed new connections b) and c) all cross the B9 boundary along with facilitating generation connections. Connection a) does not cross the B9 boundary but has an impact on power flows in the region. 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 Option Report located on the project website.

4.2.7 The proposed new circuits d), e) and f) all cross the EC5 East Anglia boundary and the need case for Norwich to Tilbury project which takes into account all of the proposed circuit are available in the Strategic Backcheck and Review document on the project website.

4.3 Boundaries

4.3.1 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.

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

4.3.3 The boundary assessments completed on the Economy Planned Transfer already accounts 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.

4.4 B9 Boundary

4.4.1 Boundary B9 is a wider system boundary containing areas with significant volumes of both generation and demand. Power system studies have been undertaken jointly by NGET and NESO to assess the impact of changes in demand and generation on power flows across the boundary and to determine if these impacts require reinforcement to the transmission system.

4.4.2 The boundary B9 as described above have been evaluated using the Economy Planned Transfer assessment, which takes prescribed generation contributions from above and below the boundary, alongside demand in each area to determine the expected flow across the boundary. In this case, the Economy Planned Transfer condition represents the most onerous boundary condition which must be secured by NGET to the requirements set out in the NETS SQSS.

4.4.3 Each of the circuits which B9 boundary has a capacity during the winter ACS period. The summation of the capacity for all of these circuits provides the pre fault capacity. The post fault capacity is defined by the remaining capacity across a boundary following the worst fault "Secured Event" as described above.

4.4.4 Each boundary then will see flows across it based upon the circuit parameters and system conditions, when the natural flow of energy on every circuit will be maximised. This is known as the circuit boundary capability, which is based upon the capability seen following the worst fault "Secured Event".

4.4.5 The following capacities and capabilities are applicable to the boundaries by 2035 should no reinforcement occur. Reinforcements across the boundary would seek to deliver enhanced boundary capacity between 2030 and 2035, delivering sufficient capacity to meet the 2035 capacity requirements set out below. If all reinforcements were not delivered ahead of 2035 for each generation group and boundaries, significant generation projects would be impacted, and system constraints would be incurred for energy seeking to meet the government 2030 goals and beyond. This means any delays would have a significant impact on government ambitions and consumers need for sustainable and affordable energy.

NGET's B9 analysis results

4.4.6 Table 4.1 shows the capacities and capabilities applicable to the B9 system boundary in 2035 without reinforcement of the existing transmission system:

Table 4.1 – Existing transmission system capacities and capabilities

System Boundary	Pre Fault Capacity	Post Fault Capacity	Post Fault Capability
B9	24,411MW	18,033MW	12,900MW

4.4.7 Table 4.2 shows the capacities and capabilities applicable to system boundary B9 by 2035, based upon the ETYS 2024[13] boundary assessment, including the following projects which all cross B9 applied to the existing transmission system capacity:

- Grimsby to Walpole – circa 6.9 GW AC transmission connection
- EGL 3 – 2 GW HVDC connection Scotland to England (connection to Walpole area)
- EGL 4 – 2 GW HVDC connection Scotland to England (connection to Walpole area)

Table 4.2 – Proposed transmission system capacities and capabilities by 2035

System Boundary	Pre Fault Capacity	Post Fault Capacity	Post Fault Capability
B9	35,341MW	28,411MW	19,300MW

4.4.8 Table 4.3 shows how the existing generation groups and boundaries perform in 2035 for the expected planned transfer flows.

[13] ETYS 2024
https://www.neso.energy/publications/electricity-ten-year-statement-etys/etys-documents-and-appendices

Table 4.3 – Proposed B9 boundary performance by 2035 including proposed circuits b) and c)

Generation Group or Boundary Export		Proposed 2035 Post Fault Capability	Proposed 2035 Post Fault Capacity	Capability Deficit (-) / Surplus (+)	Capacity Deficit (-) / Surplus (+)	Secured Event Fault
B9 – 2035 (Boundary)	25,093 MW	19,300 MW	28,411 MW	-5,793 MW	+3,318 MW	Lincolnshire –Walpole 400kV double circuit

4.4.9 Taking account of the increases to B9 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 a:

- capability deficit of -5,793 MW (megawatt); and
- capacity surplus of 3,318 MW

for the B9 system boundary. NGET recognises that the capability deficit needs to be addressed to enable the required system transfers

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

4.4.11 As described in the “Communicating our thermal needs” section set out in the NESO ETYS 24 documentation, the FES boundary graphs for each area display two sets of shaded areas. The 50th Percentile of power flows lies in the 25% and 75% range of the graph. The 90th percentile of power flows lies in the 5% to 95% range of the ETYS graphs. It states that where the capability of the boundary is between these two regions, 75% and 95%, over 20 years, then there may be a need for reinforcement.

4.4.12 NGET uses the average of the 95% percentile number across the five scenarios for boundary analysis. This ensures that for all five scenarios, our need case capacity and capability requirement would lie between the 75% and 95% ranges of annual power flows for all five scenarios and demonstrating the need for reinforcement regardless of which scenario occurs. Against this assessment in all five FES 24 and CP2030 scenarios should there is clearly a shortfall against boundary capability for the B9 boundary that by 2035 will require reinforcement.

4.4.13 From 2035, further increases in boundary requirements are expected and this is reflected in NGET’s existing contractual commitments. To address these needs, 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.

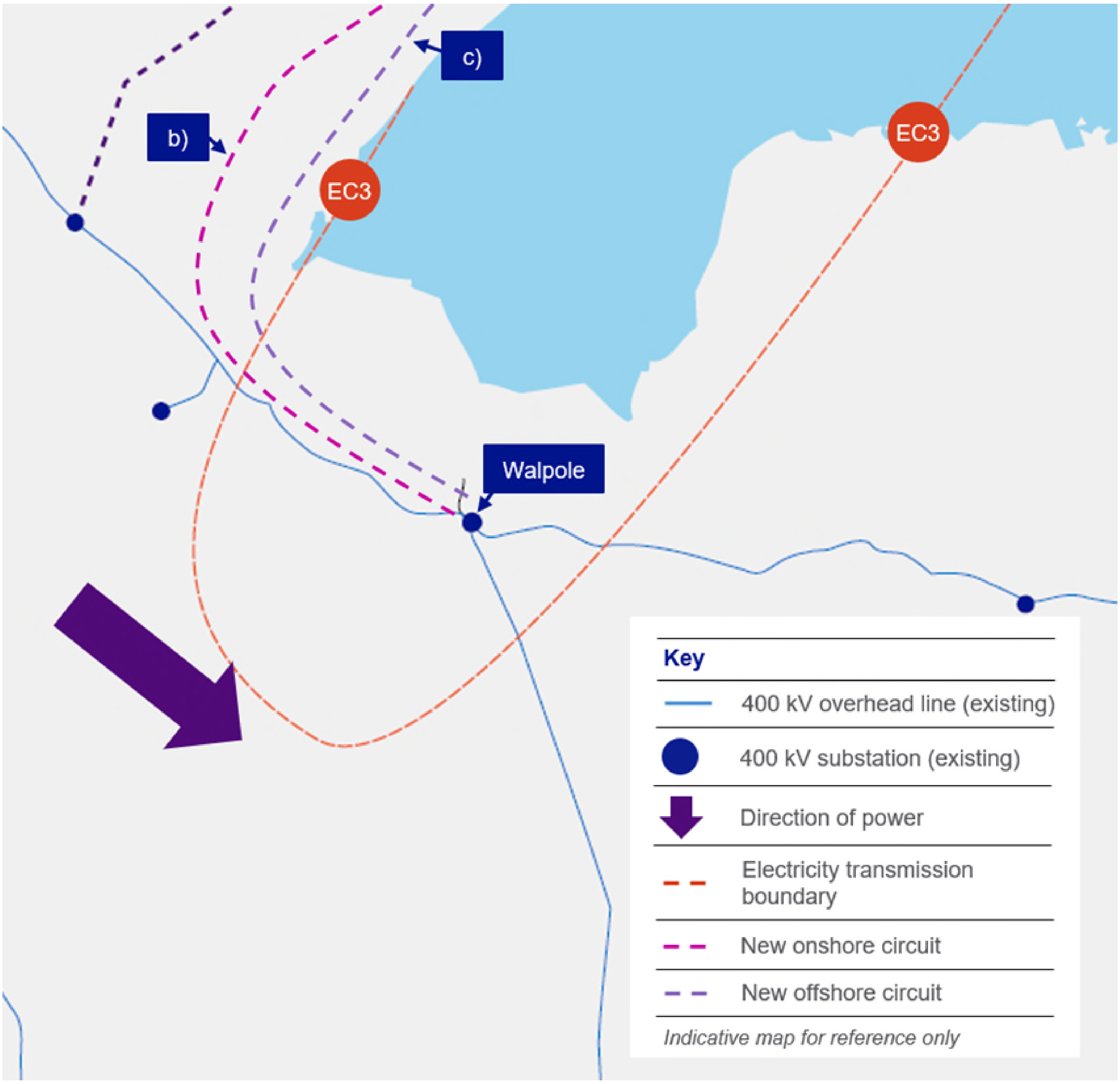
These future requirements would be informed by further SOR and need case assessments. These emerging requirements do not affect the need case set out within this report.

4.4.14 However, through the NOA refresh published in 2022, the ESO signalled the need for reinforcements in the South Yorkshire to North Midlands beyond 2030 as identified in Section 4.1 above. The Project was subsequently recommended to proceed as critical enabling and wider works in the Beyond 2030 report.

4.5 EC3 Boundary

4.5.1 The EC3 boundary is a more localised boundary where specific pinch points on the system occur. Figure 4.3 shows the existing system with the proposed connections b) Grimsby to Walpole and c) EGL3 and EGL4 HVDC connections from Scotland.

Figure 4.3 – EC3 Boundary



4.5.2 As shown in Figure 4.3, the system is formed by the following proposed circuits flowing in from the North.

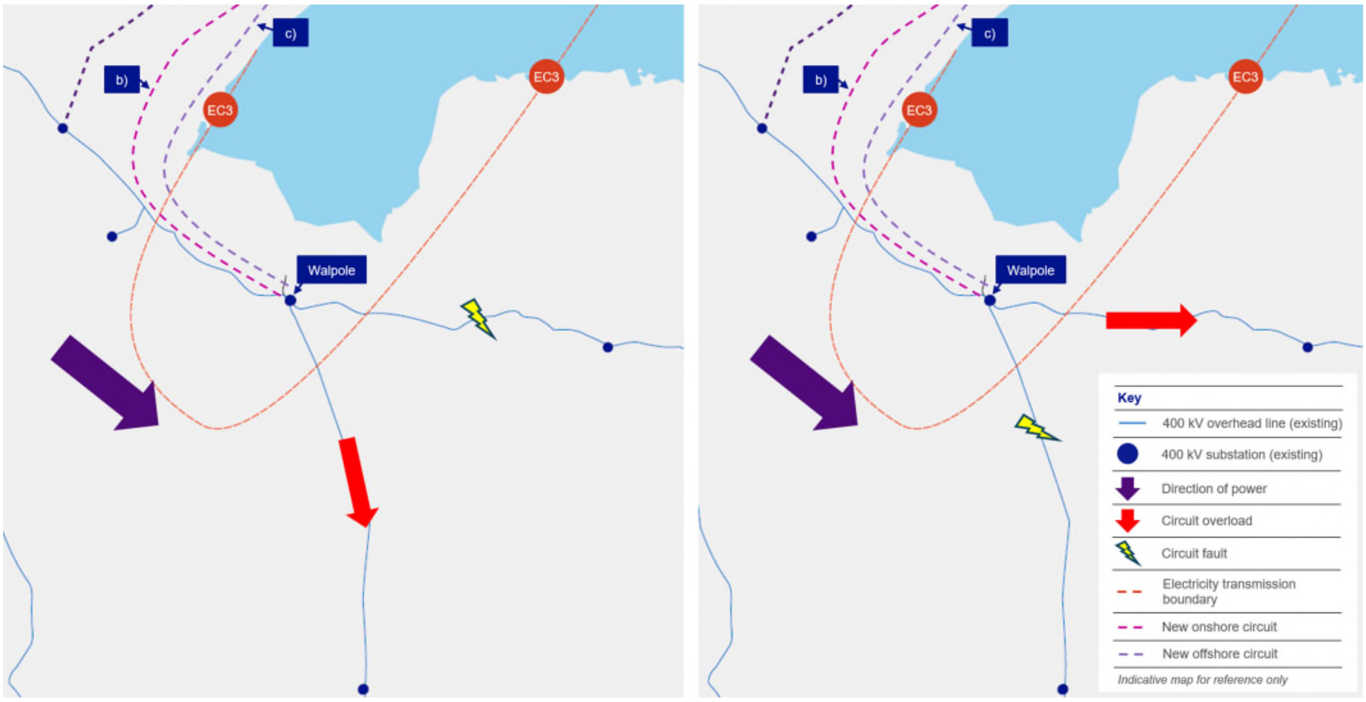
- Bicker Fen – Spalding North – Walpole double circuits
- Grimsby to Walpole double circuits
- EGL3 and EGL4 connections

4.5.3 The following circuits then flow south and east from Walpole.

- Walpole to Burwell Main double circuits
- Walpole to Necton double circuits

4.5.4 The power flow is dominated by a flow created by high generation areas in the north and east coast offshore connections, towards the demand centres in the south and midlands of the country.

Figure 4.4 – EC3 Boundary Faults



4.5.5 As shown in Figure 4.4, when a double circuit fault occurs, where the circuits will switch off the system, much like a circuit tripping in a fuse box, the circuit which did not switch off becomes overloaded far beyond the maximum capacity of a 6,930 MW double circuit. 6,930 MW represents the largest size circuits NGET accommodates on the system, with each circuit carrying 3,465 MW or 5,000 A (Amperes) of current. This is the normal operating rating of the majority of 400 kV equipment on the transmission network. Therefore, as the overloads are above this level NGET requires additional infrastructure to remain compliant with the NETS SQSS. The SQSS requires the system not to be overloaded following a secured event, of which the double circuit faults above are each secured events on the transmission system.

4.5.6 To address the deficit against the highest overloads, an additional operational double circuit with capacity up to 6,930 MW which crosses the EC3 boundary is required following faults.

4.6 EC5 Boundary

4.6.1 The EC5 boundary has been included in the need case for completeness. However, EC5 will see a potential boundary capacity increase from circa 6 GW today, to circa 22 GW following the proposed reinforcements of EC5 with the following reinforcement projects:

d) Bramford to Twinstead

e) Norwich to Tilbury

f) Sea Link.

4.6.2 Some options within this report would impact the EC5 boundary and would therefore contribute to power flows in this area. However, these options would not cause any further detriment to the EC5 boundary.

4.7 Need case conclusion

4.7.1 As described above there are two distinct issues that need to be resolved by system reinforcements:

- Provision of 5,793 MW of boundary capability to the B9 boundary
- Provision of 6,930 MW capacity to the EC3 boundary
- Connect the east to west corridors to alleviate power flow constraints in the east coast

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

5. Options identification and selection process

5.1 Identifying the technically feasible options

5.1.1 Once the need case is established, there is a requirement to consider the many ways in which the Project can be delivered. Before NGET undertakes any further work, a technical compliance filter is applied to make sure that all of the potential strategic options being considered will work on the network, rejecting any that do not meet technical standards or that would not work in practice. There are potentially many ways in which the identified need can be met, so further network modelling is carried out to better understand the issues. This initial identification is based on the network planning information available from NESO at the time of appraisal.

5.2 Potential strategic options

5.2.1 NGET begins with the identification of technically feasible options which individually meet the need case as is set out in Chapter 4 of this SOR. These options cover a wide geographical area and several different technologies which are presented in this document.

5.2.2 A “benefit filter” is then applied to the technically feasible options, allowing focus on those that best meet the obligations to the environment and consumers. It also ensures that any option presented has a comparable benefit over an alternative. The criteria for any potential strategic option to be considered further are the following:

- an environmental benefit;
- a technical system benefit; and
- a socio-economic benefit.

5.2.3 Where the benefits of options are very similar to each other, all options are captured and included for appraisal. This ensures that all possible solutions are assessed regardless of having similar capability.

5.2.4 Table 5.1 lists the potential strategic options and provides an outcome from the benefits filter appraisal for LRN#.

5.2.5 The appraisal of all potential strategic options has led to six options being selected to take forward for detailed appraisal, the details of which are contained within the proceeding sections. These are indicated in Table 5.1 outcome column and Table 5.2 in the following section.

Table 5.1 – Potential strategic options

Potential strategic option	Brief description	Outcome
New Walpole B to Pelham	88 km new 400 kV transmission connection	Discounted - provides minimal reinforcement east to west. See 5.2.10.
New Walpole B to new Pelham	88 km new 400 kV transmission connection	Discounted - provides minimal reinforcement east to west. See 5.2.10.
New Walpole B to Wymondley	100 km new 400 kV transmission connection	Discounted - existing substation extension constraints. See 5.2.12.
New Walpole B to new Wymondley	100 km new 400 kV transmission connection	Take forward for detailed appraisal
New Walpole B to new Wymondley (via new Ryhall)	130 km new 400 kV transmission connection	Discounted - greater overhead line (OHL) route length. See 5.2.9.
New Walpole B to Tilbury	360 km new offshore subsea connection	Take forward for detailed appraisal
New Walpole B to new Pelham (via new Burwell Main)	91 km new 400 kV transmission connection	Discounted - provides minimal reinforcement east to west. See 5.2.10.
New Walpole B to new Wymondley (via Burwell Main)	120 km new 400 kV transmission connection	Take forward for detailed appraisal
New Walpole B to Norwich	90 km new 400 kV transmission connection	Take forward for detailed appraisal
New Weston Marsh to Pelham	101 km new 400 kV transmission connection	Discounted - provides minimal reinforcement east to west. See 5.2.10.
New Weston Marsh to new Pelham	101 km new 400 kV transmission connection	Discounted - provides minimal reinforcement east to west. See 5.2.10.
New Weston Marsh to Wymondley	107 km new 400 kV transmission connection	Discounted - existing substation extension constraints. See 5.2.12.
New Weston Marsh to new Wymondley	107 km new 400 kV transmission connection	Discounted - greater overhead line (OHL) route length. See 5.2.9.
New Weston Marsh to new Wymondley (via new Ryhall)	116 km new 400 kV transmission connection	Discounted - greater overhead line (OHL) route length. See 5.2.9.
New Weston Marsh to Tilbury	365 km new offshore subsea connection	Discounted - longest subsea route. See 5.2.13.

Potential strategic option	Brief description	Outcome
New Weston Marsh to new Pelham (via new Burwell Main)	108 km new 400 kV transmission connection	Discounted - greater overhead line (OHL) route length. See 5.2.9.
New Weston Marsh to new Wymondley (via new Burwell Main)	122 km new 400 kV transmission connection	Discounted - greater overhead line (OHL) route length. See 5.2.9.
New Weston Marsh to Norwich	95 km new 400 kV transmission connection	Discounted - greater overhead line (OHL) route length. See 5.2.9.
Spalding North to New Ryhall	25 km new 400 kV transmission connection	Discounted - existing substation extension constraints. See 5.2.7.
New Weston Marsh to new Ryhall	30 km new 400 kV transmission connection	Component of option to take forward for detailed appraisal. See 5.2.14.
New Walpole B to new Ryhall	45 km new 400 kV transmission connection	Component of option to take forward for detailed appraisal. See 5.2.14.
Eaton Socon to Grendon	30 km new 400 kV transmission connection	Component of option to take forward for detailed appraisal. See 5.2.14.
Eaton Socon to Marston Vale	24 km new 400 kV transmission connection	Discounted – increased Distribution Network Operator (DNO) interactions. See 5.2.15.
New Ryhall to new Market Harborough	30 km new 400 kV transmission connection	Component of option to take forward for detailed appraisal. See 5.2.14.
Eaton Socon to Sundon	34 km new 400 kV transmission connection to Grendon and 40 km reconductoring of existing OHL from Grendon to Sundon	Discounted - greater overhead line (OHL) route length. See 5.2.9.
Eaton Socon to Burwell	43 km new 400 kV transmission connection	Discounted - non-compliance with SQSS
Spalding North to Pelham	N/A	Discounted - existing substation extension constraints. See 5.2.7.
Spalding North to New Pelham	N/A	Discounted - existing substation extension constraints. See 5.2.7.
Spalding North to new Wymondley	N/A	Discounted - existing substation extension constraints. See 5.2.7.
Spalding North to new Wymondley via new Ryhall	N/A	Discounted - existing substation extension constraints. See 5.2.7.

Potential strategic option	Brief description	Outcome
Spalding North to Tilbury	N/A	Discounted - existing substation extension constraints. See 5.2.7.
Spalding North to new Pelham via new Burwell Main	N/A	Discounted - existing substation extension constraints. See 5.2.7.
Spalding North to new Wymondley via new Burwell Main	N/A	Discounted - existing substation extension constraints. See 5.2.7.
Spalding North to Norwich	N/A	Discounted - existing substation extension constraints. See 5.2.7.
Spalding North to Wymondley	N/A	Discounted - existing substation extension constraints. See 5.2.7 & 5.2.12.
Bicker Fen to Pelham	N/A	Discounted - existing substation extension constraints. See 5.2.8.
Bicker Fen to new Pelham	N/A	Discounted - existing substation extension constraints. See 5.2.8.
Bicker Fen to new Wymondley	N/A	Discounted - existing substation extension constraints. See 5.2.8.
Bicker Fen to new Wymondley via new Ryhall	N/A	Discounted - existing substation extension constraints. See 5.2.8.
Bicker Fen to Tilbury	N/A	Discounted - existing substation extension constraints. See 5.2.8.
Bicker Fen to new Pelham via new Burwell Main	N/A	Discounted - existing substation extension constraints. See 5.2.8.
Bicker Fen to new Wymondley via new Burwell Main	N/A	Discounted - existing substation extension constraints. See 5.2.8.
Bicker Fen to Norwich	N/A	Discounted - existing substation extension constraints. See 5.2.8.
Bicker Fen to Wymondley	N/A	Discounted - existing substation extension constraints. See 5.2.8 & 5.2.12.
Bicker Fen to new Ryhall	N/A	Discounted - existing substation extension constraints. See 5.2.8.
Bicker Fen to Eaton Socon	N/A	Discounted - existing substation extension constraints. See 5.2.8.

Potential strategic option	Brief description	Outcome
Eaton Socon to new Weston Marsh	70 km new 400 kV transmission connection	Discounted - greater overhead line (OHL) route length. See 5.2.9.
Eaton Socon to New Walpole B	65 km new 400 kV transmission connection	Discounted - greater overhead line (OHL) route length. See 5.2.9.

5.2.6 Note: Walpole B and Weston Marsh are new substations planned to be constructed under the Grimsby to Walpole project which has been subject to its own full review of strategic options and can be found on the project website[14].

5.2.7 Spalding North substation is not extendable due to waterways located to the east and west of the site. Furthermore, there is a constraint to the north due to the proximity of an existing power station, while land to the south cannot be used as it has been purchased, and planning permission has been obtained for a battery energy storage system plant installation. Consequently, all options which originate at Spalding North 400 kV Substation have been discounted.

5.2.8 Bicker Fen 400 kV Substation is also constrained due to the line entries and the number of offered customer connections. Options with a start point at Bicker Fen Substation were discounted following the findings of a study undertaken as part of Grimsby to Walpole Project. Line entries and the reconfiguration required to connect to the existing Bicker Fen Substation are technically challenging, and this reconfiguration would cost more than the construction of a new substation. Therefore, it is a cheaper engineering solution and technically easier construct and connect to a new substation than Bicker Fen Substation.

5.2.9 Several longlisted options have been discounted due to their greater overhead line (OHL) route lengths between the same locations compared to other options taken forward for appraisal.

5.2.10 The aim of any work is to maximise benefits to the system, such as providing reinforcement from east to west and from north to south. Some options provide minimal reinforcement east to west and therefore have been discounted.

5.2.11 Additionally, the options new Walpole B to Pelham and new Weston Marsh to Pelham have been discounted due to security and resilience factors at the existing Pelham substation.

5.2.12 It is not possible to connect at Wymondley due to capacity being filled by customer connections, and large groundworks on methane pockets would be necessary, discounting new Walpole B to Wymondley. Consequently, all options which originate at Wymondley 400 kV Substation have been discounted. Note that Walpole B to new Wymondley and Walpole B to new Wymondley (via Burwell Main) require the construction of a new substation near the existing Wymondley 400 kV Substation.

5.2.13 New Weston Marsh to Tilbury is the longest subsea route and offers no benefit over Walpole B to Tilbury (subsea) and as such, it has been discounted.

5.2.14 New Weston Marsh to new Ryhall, new Walpole B to new Ryhall, and Eaton Socon to Grendon have been combined to form Strategic Option 3. Furthermore, new Weston

[14] Grimsby to Walpole SOR
https://www.nationalgrid.com/document/154026/download

Marsh to new Ryhall and new Ryhall to new Market Harborough have been combined to form Strategic Option 4 and so have been discounted as standalone options.

5.2.15 Eaton Socon to Marston Vale entails more DNO interactions and offers no benefit over other shortlisted options so has also been discounted.

5.3 Proposed strategic options

5.3.1 Six options that potentially achieve the need case for reinforcement in the Humber and East Coast region and present an environmental benefit; a technical system benefit or a socio-economic benefit; are proposed for detailed appraisal and are outlined in Table 5.2.

5.3.2 Option 3 and Option 4 have been created following an appraisal of the potential options. These options combine multiple potential options; this can be seen through the outcome column in Table 5.1 which states "component of option to take forward for detailed appraisal" for the options utilised to establish Option 3 and Option 4 respectively. Additional reconductoring of existing transmission lines are also included during assessment to ensure compliance with the Project need case.

5.3.3 Undertaking this appraisal ensures stakeholders can see how NGET has made judgments and balanced the relevant factors in accordance with its legal duties.

Table 5.2 – Proposed strategic options for appraisal

Proposed strategic option title	Option description
Option-1 Walpole B to new Wymondley	100 km new 400 kV transmission connection
Option-2 Walpole B to new Wymondley (via Burwell Main)	120 km new 400 kV transmission connection
Option-3 Weston Marsh/Walpole B to new Ryhall and Eaton Socon to Grendon	60 km new 400 kV transmission connection, 40 km reconductoring existing Grendon to Sundon 400 kV connection
Option-4 Weston Marsh to new Market Harborough (via new Ryhall)	60 km new 400 kV transmission connection, 55 km reconductoring new Market Harborough to Grendon 400 kV connections
Option-5 Walpole B to Tilbury	360 km subsea HVDC connection
Option-6 Walpole B to Norwich	90 km new 400 kV transmission connection

5.4 NGET's approach to appraising the proposed strategic options

5.4.1 Each proposed strategic option has been checked for compliance with SQSS and appraised against environmental, socio-economic, technical, and cost considerations. Undertaking this appraisal ensures stakeholders can see how NGET has made judgements and balanced the relevant factors in accordance with its legal duties.

5.4.2 At this stage of the optioneering process, the approach is based on the identification of 'differentiators.' This is where one option clearly provides a benefit over another, which for example may be in the form of a lesser environmental impact. Often, at this stage, due to the limited design detail and broad geographical area being considered, it is not possible to identify differences against all appraisal factors.

5.4.3 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 costs considers 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.
  - Circuit lifetime costs, including circuit capital cost, cost of losses over 40 years and cost of operation over 40 years.

Appraisal assumptions

5.4.4 When considering each strategic option, NGET estimates 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

5.4.5 When considering each strategic option, NGET provides circuit cost information for the following technology options for all offshore based options:

- 400 kV AC Offshore cable
- 525 kV HVDC Offshore cable and converter stations

5.4.6 A full evaluation and costs used can be found in the Appendix E.

5.4.7 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 NGETs 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.

5.4.8 At the initial appraisal stage, NGET 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, NGET makes equivalent assumptions for each option. Final project costs for any solution taken forward following detailed design, consenting and mitigation will be in excess of any high-level appraisal cost. However, all options would incur these increases proportional to 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.

5.4.9 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.

5.4.10 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). Study areas 2 km wide have been utilised for the Project.

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

Summary points

5.4.12 Six options that potentially achieve the need case for reinforcement in the Humber and East Coast region and which potentially present an environmental benefit; a technical system benefit; a capital and lifetime cost benefit, which includes the consideration of initial capital costs and long-term maintenance and operating costs or a socio-economic benefit; were proposed for detailed appraisal.

5.4.13 The details and results of the appraisal follow in Chapter 6 onwards.

6. The results of NGET’s appraisal of strategic options

6.1 Introduction

6.1.1 This chapter presents a summary of the findings of the appraisal process undertaken for each of the six strategic options identified for LRN#. This chapter will discuss the options, looking at each from a technical, environmental, socio-economic, and cost perspective. This chapter concludes with a summary of the appraisal process to show the benefits and disadvantages of each option comparatively in Table 6.14.

6.1.2 At this stage of project development, a 2 km study area has been considered in which the route would be located for each option. Information is obtained to consider the relative environmental or socio-economic impacts of different options within this zone. At subsequent stages of appraisal, an approximate route corridor or potential alignment will be known, and a much greater degree of accuracy can be used. The next stage of development involves identification of a preliminary route corridor and graduated swathe (which shows the areas within the corridor considered more likely for development), as discussed in Section 7.3.

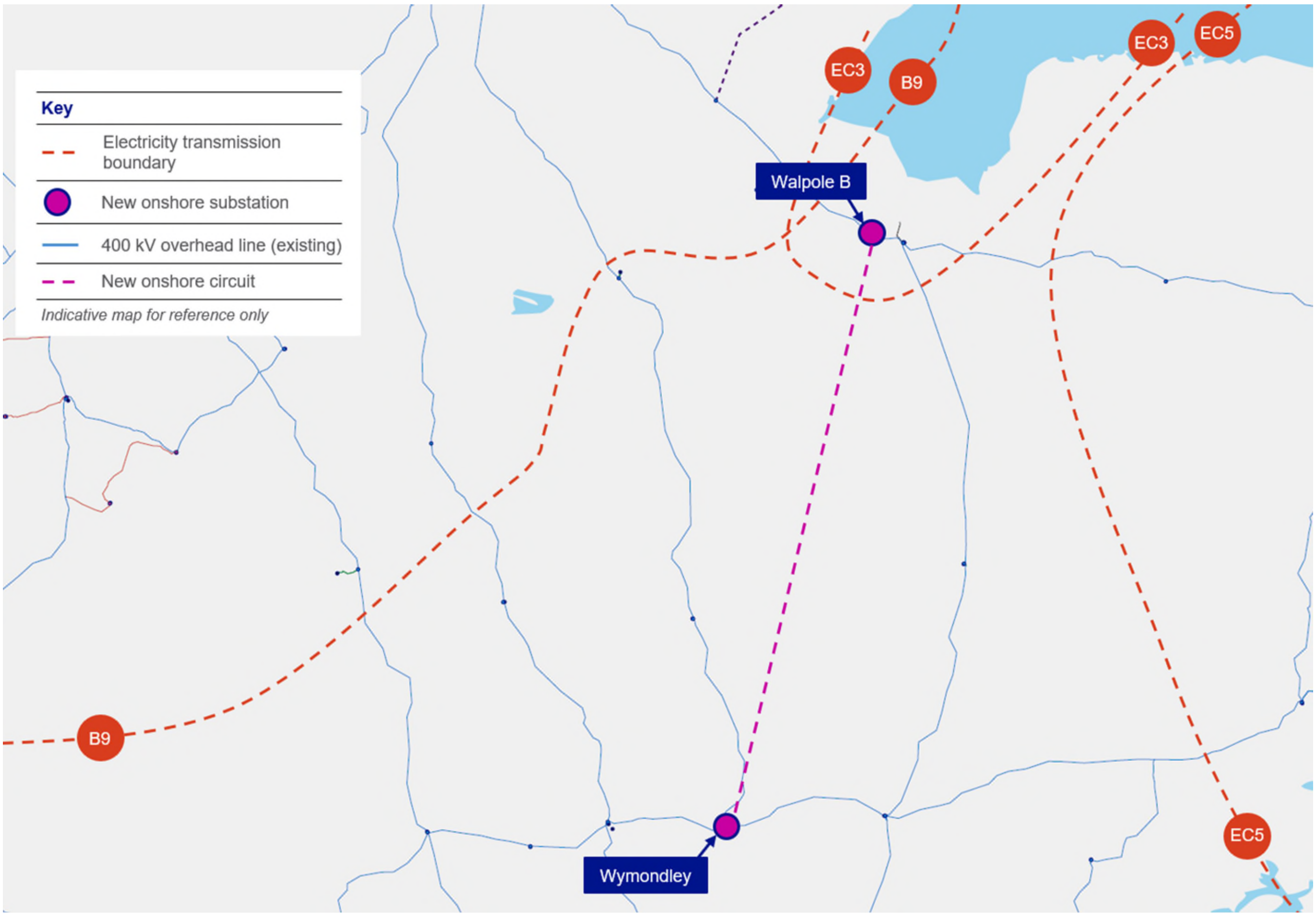
6.2 Appraisal of Option 1 Walpole B to new Wymondley

Description of strategic option 1

6.2.1 Option 1, Walpole B to new Wymondley, proposes the establishment of a new 400 kV transmission connection between a new Walpole B 400 kV Substation and a new Wymondley 400 kV Substation. The proposed route spans approximately 100 km, as depicted in Figure 6.1.

6.2.2 Option 1 will provide additional transmission capability to boundary B9, only facilitating East-West transfer when the circuit reaches new Wymondley and links to the North London busbar. The option presents an additional East to West route helping to relieve constraints across the B9 boundary.

Figure 6.1 – Indicative route for strategic option 1



Summary of the environmental appraisal

Ecology

6.2.3 Option 1 crosses the Nene Washes which is designated as a Special Area of Conservation (SAC), Special Protection Area (SPA), Site of Special Scientific Interest (SSSI), Ramsar and RSPB Important Bird Area. The Option 1 study area also includes a further SSSI, two areas of Ancient Woodland, and passes through/very close to a Veteran Tree.

6.2.4 Within the 2 km study area, there are a further six SSSIs and nineteen areas of Ancient Woodland.

6.2.5 During construction there is the potential for this option to affect Nene Washes, a further SSSI, two areas of Ancient Woodland and possibly a Veteran Tree due to land take. Construction could also affect designations within the 2 km study area through pollution of land and water, and general disturbance as a result of construction works. This is dependent upon the alignment of the final overhead line (OHL) and construction methodologies.

6.2.6 Standard environmental control measures should be implemented which may include undertaking works at the appropriate time of year to avoid impacts on certain species. Such control measures would be outlined in a Construction Environmental Management Plan (CEMP) and/or a Construction Traffic Management Plan (CTMP) and would reduce potential impacts.

6.2.7 OHL (Overhead Line) is the preferred technology for this Strategic Option. Further details on this preference are available below in the technical and cost appraisal sub-sections.

6.2.8 During operation there is potential for the OHL to affect wintering/ breeding bird populations associated with Nene Washes.

6.2.9 However, it is anticipated that impacts on designated sites are likely to be reduced or avoidable through adopting appropriate route corridors and sensitive routeing, thus avoiding, or reducing effects. However, early engagement with Natural England and the Forestry Commission would be required to determine the extent of any impacts and identify appropriate mitigation.

Landscape and Visual

6.2.10 There are no National Parks, National Landscapes, World Heritage Sites, Biospheres, or National Trails located along or within the 2 km study area of Option 1.

6.2.11 Option 1 crosses the settlements of Little Wymondley and St Ives. There is therefore the potential for this option to affect local visual receptors to these two settlements during construction and operation.

6.2.12 Developing appropriate route corridors and undertaking sensitive routeing would ensure that the settlements are either avoided, or that impacts on sensitive visual receptors are reduced. It should be noted that there would however be a permanent above-ground OHL which could result in adverse impacts on the two settlements. Further detailed assessment would need to be undertaken to understand the impacts on local visual receptors.

Historic Environment

6.2.13 Option 1 crosses one Scheduled Monument (Hinxworth Roman fortlet for approximately 0.12 km) and one Registered Park and Garden (Hatley Park for approximately 0.17 km).

6.2.14 There are a number of Scheduled Monuments, Grade I and II* Listed Buildings and a further three Registered Parks and Gardens distributed throughout the 2 km study area.

6.2.15 During construction there is potential for impacts on one Scheduled Monument and one Registered Park and Garden and impacts on the setting of other designated heritage assets (including further Scheduled Monuments, Listed Buildings and Registered Parks and Gardens). Such impacts on setting are also likely to continue into operation of the Project depending on the location of the OHL.

6.2.16 It is assumed that adopting appropriate route corridors and undertaking sensitive routeing would avoid adverse effects on heritage assets. Adopting standard construction control measures within a CEMP and/or CTMP would also reduce impacts.

6.2.17 There does however remain the potential for impacts on the setting of a Scheduled Monument and a Registered Park and Garden. This would require further assessment and early engagement with Historic England.

6.2.18 At this stage, it cannot be confirmed that all effects on the setting of heritage features can be ruled out without more detailed assessment.

Water, Geology and Soils

6.2.19 There are large areas of Flood Zones 2 and 3, and Areas Benefitting from Flood Defences across the study area and, given the extent of this, it is likely that a significant amount of development would be located within the floodplain. Option 1 also crosses a number of rivers/ watercourses and an area of Flood Storage. Within the 2 km study area there are two Geological SSSIs.

6.2.20 During construction there are likely to be pollution risks, together with impacts associated with flood risk due to the extent of Flood Zones 2 and 3, Areas Benefitting from Flood Defences and Flood Storage areas. There is also the potential for construction effects on two Geological SSSIs. Early Engagement with Natural England would assist in identifying impacts and associated mitigation.

6.2.21 Crossings of main rivers and Flood Zones 2 and 3 are likely to be unavoidable. However, developing appropriate route corridors and undertaking sensitive routeing that minimises the number of watercourse crossings and work in Flood Zones would ensure that residual impacts are reduced, or avoided wherever possible. In addition, assuming that standard construction control measures and/or Best Practicable Means would be adhered to within a CEMP, residual pollution risks to watercourses would be reduced.

6.2.22 It is noted that additional consents and/or permits would be required from the Environment Agency along with a Flood Risk Assessment and therefore early engagement is recommended.

Noise

6.2.23 Option 1 crosses the two settlements of Little Wymondley and St Ives. There is therefore potential for this option to affect sensitive receptors during both construction and operation.

6.2.24 During construction, noise effects are likely to be mitigated through standard control measures and Best Practicable Means outlined in a CEMP and consulted upon with the relevant local authority environmental health officer.

6.2.25 It is, however, anticipated that developing appropriate route corridors and adopting sensitive routeing would ensure that operational noise impacts are minimised. This could be through maximising separation distances and building proximity distances where possible between the new OHL and sensitive receptors.

Summary of the socio-economic appraisal

Tourism and recreation

6.2.26 Option 1 crosses two National Cycle Routes (51 and 63) and one area of Countryside and Rights of Way (CRoW) Open Access Land. Within the 2 km study area there are a further sixteen areas of CRoW Open Access Land and one major visitor attraction (The Raptor Foundation).

6.2.27 During construction and operation there is the possibility of disruption to National Cycle Routes and CRoW Open Access Land. However, adopting appropriate route corridors together with an assumption that standard construction control measures would be adhered to within a CEMP and/or CTMP would reduce any impacts. Early engagement with stakeholders from The Raptor Foundation would also determine appropriate mitigation should there be impacts to this visitor attraction following routeing.

Infrastructure

6.2.28 Option 1 crosses nineteen road networks and three rail lines, and there are eight crossings of other National Grid infrastructure (including OHL and gas mains), as of January 2023, National Gas is the owner and operator of Britain's gas transmission network.

6.2.29 During construction there is the potential for disruption to road and rail networks. However, adopting appropriate route corridors which minimise the number of road and rail crossings, and implementing standard control measures outlined in a CEMP and/or CTMP would reduce any impacts on the road and rail networks. Impacts related to crossing other National Grid infrastructure could also be mitigated through appropriate routeing and adopting sensitive construction methods utilising technology types such as undergrounding when crossing other OHLs.

6.2.30 Within the study area there are six passenger airports/Instrument Landing System (ILS) licensed aerodromes, and one other NSIP (East West Rail – Bedford to Cambridge and Western Improvements, which is at the pre-application stage).

6.2.31 During construction and operation there is the potential for impacts to the identified airports/aerodromes however it is anticipated that these can be mitigated through appropriate routeing. There is the potential for cumulative impacts to occur as a result of concurrent NSIPs. However, sensitive routeing that either avoids other NSIPs altogether or adopts careful siting to reduce cumulative impacts would ensure that impacts are minimised.

Summary of the technical appraisal

6.2.32 A technical appraisal has established that a transmission connection between Walpole B and new Wymondley would satisfy the National Electricity Transmission System (NETS) Security and Quality of Supply Standards (SQSS) at Walpole, whilst providing additional transmission capability to boundary B9 as well as capability to the Midlands and southern England boundaries.

6.2.33 Technical analysis of this option is as follows:

- Route connects into a new 400 kV substation starting at Walpole B and terminates at a new 400 kV substation at Wymondley.
- This option will be configured as an AC double circuit overhead line (OHL) and will involve the installation of a new AC 400 kV circuit rated at 6,930 MW.
- For the appraisal of onshore options of significant distance, an OHL would normally be expected to offer the most economic, efficient, and co-ordinated development and would meet NGET's obligations under Section 9 of the Electricity Act.
- Use of OHL is low risk in terms of construction complexity and standard construction and access techniques can be adopted for this option, as well as operation and maintenance. The same applies for the crossing that would be required for the roads and rail lines involved.
- Technology implemented is well established, relatively straight forward to construct, operate and maintain.
- Option 1 does not cross B9, however it helps with increase in capability for the boundary, without providing any future capacity reinforcements. Additionally, the

option only facilitates East-West transfer when the circuit reaches new Wymondley and links to the North London busbar.

6.2.34 It is important to note that there are a number of other National Grid projects which relate to Option 1, including: Walpole B, a new substation to be built by Grimsby to Walpole and also required for LRN#; and new Wymondley, a new substation also likely to be required by two other National Grid projects.

Summary of the cost appraisal

6.2.35 As set out in Chapter 5, NGET undertakes a cost evaluation of the following four technologies for onshore options evaluation:

a) 400 kV alternating current (AC) overhead line

b) 400 kV AC underground cable

c) 400 kV AC Gas Insulated Line (GIL)

d) 525 kV High Voltage Direct Current (HVDC) underground cable and converter stations

6.2.36 Option 1 requires the following transmission works to satisfy the requirements of the SQSS:

- Substation works
  - New Wymondley 400 kV Substation able to accommodate 12 bays
  - Utilisation of two bays at new Walpole B 400 kV Substation to accommodate new circuits
- New circuit requirements:
  - AC connections options use high-capacity double circuits (two 400 kV AC circuits) with a total capacity of up to 6,930 MW; or,
  - HVDC using 525 kV 2,000 MW voltage source links, which would require a convertor station at each end similar in size to a large warehouse. A 6,000 MW connection would require three convertor stations at each end, six overall, this is to come close to matching the AC high-capacity circuits of 6,930 MW.

6.2.37 Table 6.1 sets out the capital costs for Option 1 considering substation works and each technology option.

Table 6.1 – Capital costs for Option 1

Item	Capital cost			
Substation and wider works	£172.0m			
New circuits	**AC OHL**	**AC Cable**	**AC GIL**	**HVDC**
New circuit	£398.0m	£4,290.0m	£4,326.0m	£2,530.1m
Total capital cost	**£570.0m**	**£4,462.0m**	**£4,498.0m**	**£2,702.1m**

6.2.38 Table 6.2 sets out the lifetime cost for the new circuit technology options. The lifetime 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", found in Appendix E.

Table 6.2 – Lifetime cost by technology option

Land based option	AC OHL	AC Cable	AC GIL	HVDC
Capital Cost of new Circuits	£398.0m	£4,290.0m	£4,326.0m	£2,530.1m
NPV of Cost of Losses over 40 years	£280.5m	£206.3m	£130.2m	£471.2m
NPV of Operation & Maintenance costs over 40 years	£5.8m	£19.7m	£5.9m	£172.3m
Lifetime Cost of new Circuits	**£684m**	**£4,516m**	**£4,462m**	**£3,174m**

6.2.39 The table above presents figures and numbers for the following cost terms:

- Capital Cost of new Circuits is a term utilised to demonstrate the initial capital expenditure associated with the implementation of a new circuit.
- Net Present Value (NPV) of Cost of Losses is a term utilised to demonstrate the present-day monetary value of cost of losses while factoring in initial capital investment required for the Project.
- Net Present Value (NPV) of Operation and Maintenance Costs is a term utilised to demonstrate the present-day monetary value of operation and maintenance costs while factoring in initial capital investment required for the Project.
- Lifetime Cost of new Circuits is a term utilised to demonstrate the total capital expenditure associated with the implementation of a new circuit and is calculated by summing the above three cost terms.

6.2.40 Based on the data in the above tables, the following conclusions can be drawn:

- AC OHL has the lowest capital cost of new circuits.
- AC OHL has a reasonable NPV of Cost of Losses over a forty-year projection.
- AC OHL has the lowest NPV of Operation and Maintenance Costs over a forty-year projection.
- AC OHL has the lowest lifetime cost of new circuits.

Summary of the strategic option

6.2.41 From the environmental and technical appraisal considered, alongside capital and circuit lifetime costs, the preferred technology option for Option 1 is a 100 km connection, configured as an AC circuit, between a new Walpole B Substation and a new Wymondley Substation. In light of this analysis, NGET's starting presumption for further development of this option, should it be selected, would be for a majority overhead line connection.

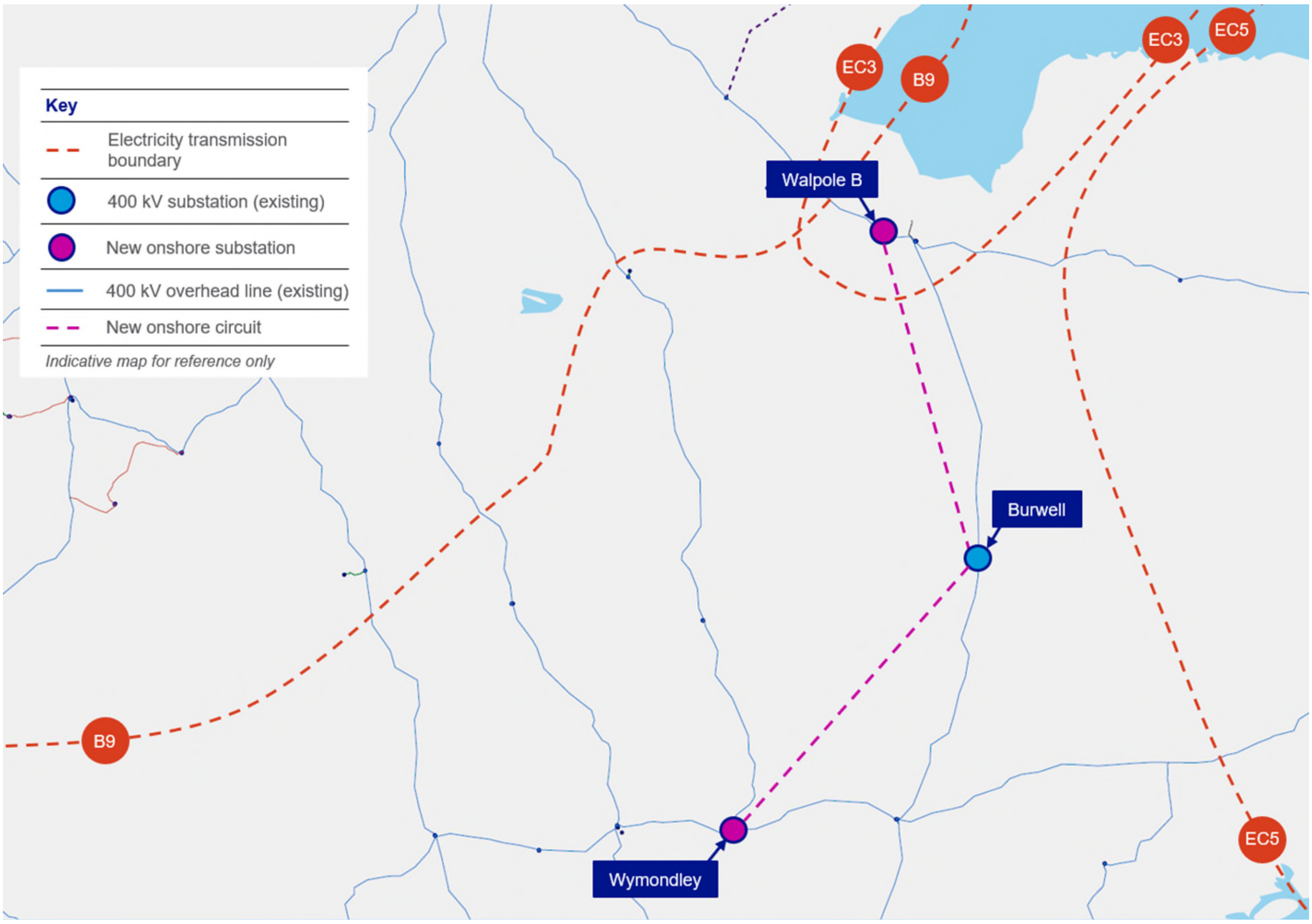
6.3 Appraisal of Option 2 Walpole B to new Wymondley (via Burwell)

Description of strategic option 2

6.3.1 Option 2, Walpole B to new Wymondley (via Burwell), proposes the establishment of a new 400 kV transmission connection between a new Walpole B 400 kV Substation and a new Wymondley 400 kV Substation, via a new Burwell 400 kV Substation. The proposed route spans approximately 120 km, as depicted in Figure 6.2.

6.3.2 Option 2 will provide additional transmission capability to boundary B9, whilst also providing capability to the midlands and southern England boundaries. This option achieves boundary requirements and LRN# drivers and presents a solution to connect to two routes that allow power to flow south.

Figure 6.2 – Indicative route for Strategic Option 2



Summary of the environmental appraisal

Ecology

6.3.3 Option 2 crosses Ouse Washes which is designated as a SAC, SPA, SSSI, Ramsar and RSPB Important Bird Area. Option 2 also crosses a further four SSSIs and two areas of Ancient Woodland.

6.3.4 Within the 2 km study area is Wicken Fen (designated as a SAC, Ramsar, SSSI and National Nature Reserve (NNR)), a further seven SSSIs and forty-nine areas of Ancient Woodland.

6.3.5 Overhead Line (OHL) is the preferred technology for this Strategic Option. Further details on this preference are available below in the technical and cost appraisal sub-sections.

6.3.6 During construction there is the potential for this option to affect Ouse Washes, a further four SSSIs and two areas of Ancient Woodland due to land take. Construction could also affect designations within the 2 km study area through pollution of land and water, and general disturbance as a result of construction works. This is dependent upon the alignment of the final OHL and construction methodologies.

6.3.7 Standard environmental control measures should be implemented which may include undertaking works at the appropriate time of year to avoid impacts on certain species. Such control measures would be outlined in a Construction Environmental Management Plan (CEMP) and/or a Construction Traffic Management Plan (CTMP) and would reduce potential impacts.

6.3.8 During operation there is potential for the OHL to affect wintering/ breeding bird populations associated with Ouse Washes.

6.3.9 However, it is anticipated that impacts on designated sites are likely to be reduced or avoided through adopting appropriate route corridors and sensitive routeing, thus avoiding, or reducing effects. However, early engagement with Natural England and the Forestry Commission would be required to determine the extent of any impacts and identify appropriate mitigation.

Landscape and Visual

6.3.10 There are no National Parks, National Landscapes, World Heritage Sites, Biospheres or National Trails located along or within the 2 km study area of Option 2.

6.3.11 Option 2 crosses the settlements of Clavering, Stevenage and Wicken Bonhunt. There is therefore the potential for this option to affect local visual receptors to these three settlements during construction and operation.

6.3.12 Developing appropriate route corridors and undertaking sensitive routeing would ensure that the settlements are either avoided, or that impacts on sensitive visual receptors are reduced. It should be noted that there would however be a permanent above-ground OHL which could result in adverse impacts on the three settlements. Further detailed assessment would need to be undertaken to understand the impacts on local visual receptors.

Historic Environment

6.3.13 There are three Scheduled Monuments: Clavering Castle, Devil's Ditch, and Fleam Dyke within the 2 km study area for Option 2, however each fall within this area for less than 100 m.

6.3.14 There are a number of further Scheduled Monuments, Grade I and II* Listed Buildings and six Registered Parks and Gardens distributed throughout the 2 km study area.

6.3.15 During construction there is potential for impacts on three Scheduled Monuments and impacts on the setting of other designated heritage assets (including further Scheduled Monuments, Listed Buildings and Registered Parks and Gardens). Such impacts on setting are also likely to continue into operation of the Project depending on the location of the OHL.

6.3.16 It is assumed that adopting appropriate route corridors and undertaking sensitive routeing would avoid or reduce adverse effects on heritage assets. Adopting standard construction control measures within a CEMP and/or CTMP would also reduce impacts.

6.3.17 There does however remain the potential for impacts on the setting of three Scheduled Monuments, depending on the location of the OHL. This would require further assessment and early engagement with Historic England.

6.3.18 At this stage, it cannot be confirmed that all effects on the setting of heritage features can be ruled out without more detailed assessment.

Water, Geology and Soils

6.3.19 There are large areas of Flood Zones 2 and 3, Areas Benefitting from Flood Defences and one area of Flood Storage within the study area. Ely Pits and Meadows Geological SSSI is also located within the 2 km study area. Given the extent of this, it is likely that a large amount of the development would be located within the floodplain.

6.3.20 During construction there are likely to be pollution risks, together with impacts associated with flood risk due to the extent of Flood Zones 2 and 3, Areas Benefitting from Flood Defences and Flood Storage areas. There is also the potential for construction effects on the Geological SSSI due to its proximity. Early Engagement with Natural England would assist in identifying impacts and associated mitigation.

6.3.21 Crossings of watercourses are likely to be unavoidable, with circa twenty-six watercourses and numerous unnamed linear water features identified in the study area. However, developing appropriate route corridors and undertaking sensitive routeing that minimises the number of watercourse crossings and work in Flood Zones would ensure that residual impacts are reduced, or avoided wherever possible. In addition, standard construction control measures and/or Best Practicable Means would be adhered to within a CEMP and would thus reduce residual pollution risks to watercourses.

6.3.22 It is noted that additional consents and/or permits would be required from the Environment Agency along with a Flood Risk Assessment and therefore early engagement is recommended.

Noise

6.3.23 Option 2 crosses the three settlements of Clavering, Stevenage and Wicken Bonhunt. There is therefore potential for this option to affect sensitive receptors during both construction and operation.

6.3.24 During construction, noise effects are likely to be capable of mitigation through standard control measures and Best Practicable Means outlined in a CEMP and consulted upon with the relevant local authority environmental health officer.

6.3.25 It is, however, anticipated that developing appropriate route corridors and adopting sensitive routeing would ensure that operational noise impacts are minimised. This could be through maximising separation distances and building proximity distances where possible between the new OHL and sensitive receptors.

Summary of the socio-economic appraisal

Tourism and Recreation

6.3.26 Option 2 crosses four National Cycle Routes (1, 11, 12 and 51) and two areas of CRoW Open Access Land. This option also crosses Wicken Fen National Trust Inalienable Land for approximately 0.32 km. Within the 2 km study area there are a further sixty-two areas of CRoW Open Access Land.

6.3.27 During construction and operation there is the possibility of disruption to National Cycle Routes and CRoW Open Access Land. However, adopting appropriate route corridors together with an assumption that standard construction control measures would be adhered to within a CEMP and/or CTMP would reduce any impacts.

6.3.28 It is anticipated that developing appropriate route corridors could avoid the National Trust Inalienable Land. However, it is recommended that early engagement with the National Trust take place should this option be pursued as there is the potential for residual impacts to the setting of this land.

Infrastructure

6.3.29 Option 2 crosses fourteen road networks and six rail networks, and there are nine crossings of other National Grid infrastructure (including OHL and gas pipes).

6.3.30 During construction there is the potential for disruption to road and rail networks. However, adopting appropriate route corridors which minimise the number of road and rail crossings, and implementing standard control measures outlined in a CEMP and/or CTMP would reduce any impacts on the road and rail networks. Impacts related to crossing other National Grid infrastructure could also be mitigated through appropriate routeing and adopting sensitive construction methods utilising technology types such as undergrounding when crossing other OHLs.

6.3.31 Cottered Airstrip is located within the 2 km study area. During construction and operation there is the potential for impacts to the airstrip however it is anticipated that these can be mitigated through appropriate routeing.

Summary of the technical appraisal

6.3.32 A technical appraisal has established that a transmission connection between Walpole B and new Wymondley would satisfy the NETS SQSS at Walpole, whilst providing additional transmission capability to boundary B9 as well as to the Midlands and southern England boundaries.

6.3.33 Technical analysis of the option is as follows:

- Route to be connected into three 400 kV substations starting at Walpole B and routing through Burwell Main to finally terminate at a new 400 kV Wymondley Substation.
- Two new substations require construction for this option, one at Wymondley and one at Burwell Main.
- This option will be configured as a double circuit overhead line (OHL) and will involve the installation of a new AC 400 kV circuit rated at 6,930 MW.

- For the appraisal of onshore options of significant distance, an OHL would normally be expected to offer the most economic, efficient, and co-ordinated development and would meet NGET's obligations under Section 9 of the Electricity Act.
- Use of OHL is low risk in terms of construction complexity and standard construction and access techniques can be adopted for this option, as well as operation and maintenance. The same applies for the crossing that would be required for the roads and rail lines involved. Substation build is also low risk, and standard techniques can be applied for this as well.
- Technology implemented is well established, relatively straightforward to construct, operate and maintain. There is a higher consenting risk, however, due to longer OHL to be used and increased size of OHL build.
- Option meets the needs of the system requirements to reinforce the B9 boundary by providing a capability uplift and helping relieve constraints.

6.3.34 It is important to note that there are a number of other National Grid projects which relate to Option 2, including: Walpole B, a new substation to be built by Grimsby to Walpole and also required for LRN#; and new Wymondley, a new substation also likely to be required by two other National Grid projects.

Summary of the cost appraisal

6.3.35 As set out in Chapter 5, NGET undertakes a cost evaluation of the following four technologies for onshore options evaluation:

a) 400 kV alternating current (AC) overhead line

b) 400 kV AC underground cable

c) 400 kV AC gas insulated line (GIL)

d) 525 kV high voltage direct current (HVDC) underground cable and converter stations

6.3.36 Option 2 requires the following transmission works to satisfy the requirements of the SQSS:

- Substation works
  - New Wymondley 400 kV Substation able to accommodate 12 bays
  - New Burwell 400 kV Substation able to accommodate 12 bays
  - Utilisation of 2 bays at new Walpole B 400 kV Substation to accommodate new circuits
- New circuit requirements
  - AC connections options use high-capacity double circuits (two 400 kV AC circuits) with a total capacity of up to 6,930 MW; or
  - HVDC using 525 kV 2,000 MW voltage source links, which would require a convertor station at each end similar in size to a large warehouse. A 6,000 MW connection would require three convertor stations at each end, six overall, this is to come close to matching the AC high-capacity circuits of 6,930 MW.

6.3.37 Table 6.3 sets out the capital costs for Option 2 considering substation works and each technology option.

Table 6.3 – Capital costs for Option 2

Item	Capital Cost			
Substation and Wider Works	£328.0m			
New Circuits	**AC OHL**	**AC Cable**	**AC GIL**	**HVDC**
New Circuit	£477.6m	£5,158.6m	£5,191.2m	£3,517.1m
Total Capital Cost	**£805.6m**	**£5,486.6m**	**£5,519.2m**	**£3,845.1m**

6.3.38 Table 6.4 sets out the lifetime cost for the new circuit technology options, the lifetime 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” found in Appendix E.

Table 6.4 – Lifetime Cost by Technology Option

Land Based Option	AC OHL	AC Cable	AC GIL	HVDC
Capital Cost of new Circuits	£477.6m	£5,158.6m	£5,191.2m	£3,517.1m
NPV of Cost of Losses over 40 years	£336.6m	£251.2m	£156.3m	£706.9m
NPV of Operation & Maintenance costs over 40 years	£7.0m	£24.0m	£7.1m	£258.1m
Lifetime Cost of new Circuits	**£821m**	**£5,434m**	**£5,355m**	**£4,482m**

6.3.39 Based on the data in the above tables, the following conclusions can be drawn:

- AC OHL has the lowest capital cost of new circuits.
- AC OHL has a reasonable NPV of Cost of Losses over a forty-year projection.
- AC OHL has the lowest NPV of Operation and Maintenance Costs over a forty-year projection.
- AC OHL has the lowest lifetime cost of new circuits.

Summary of the strategic option

6.3.40 From the environmental and technical appraisal considered, alongside capital and circuit lifetime costs, the preferred technology option for Option 2 is a 120 km connection, configured as an AC circuit, between a new Walpole B Substation and a new Wymondley Substation via a new Burwell Substation. In light of this analysis, NGET’s starting presumption for further development of this option should it be selected, would be for a majority overhead line connection.

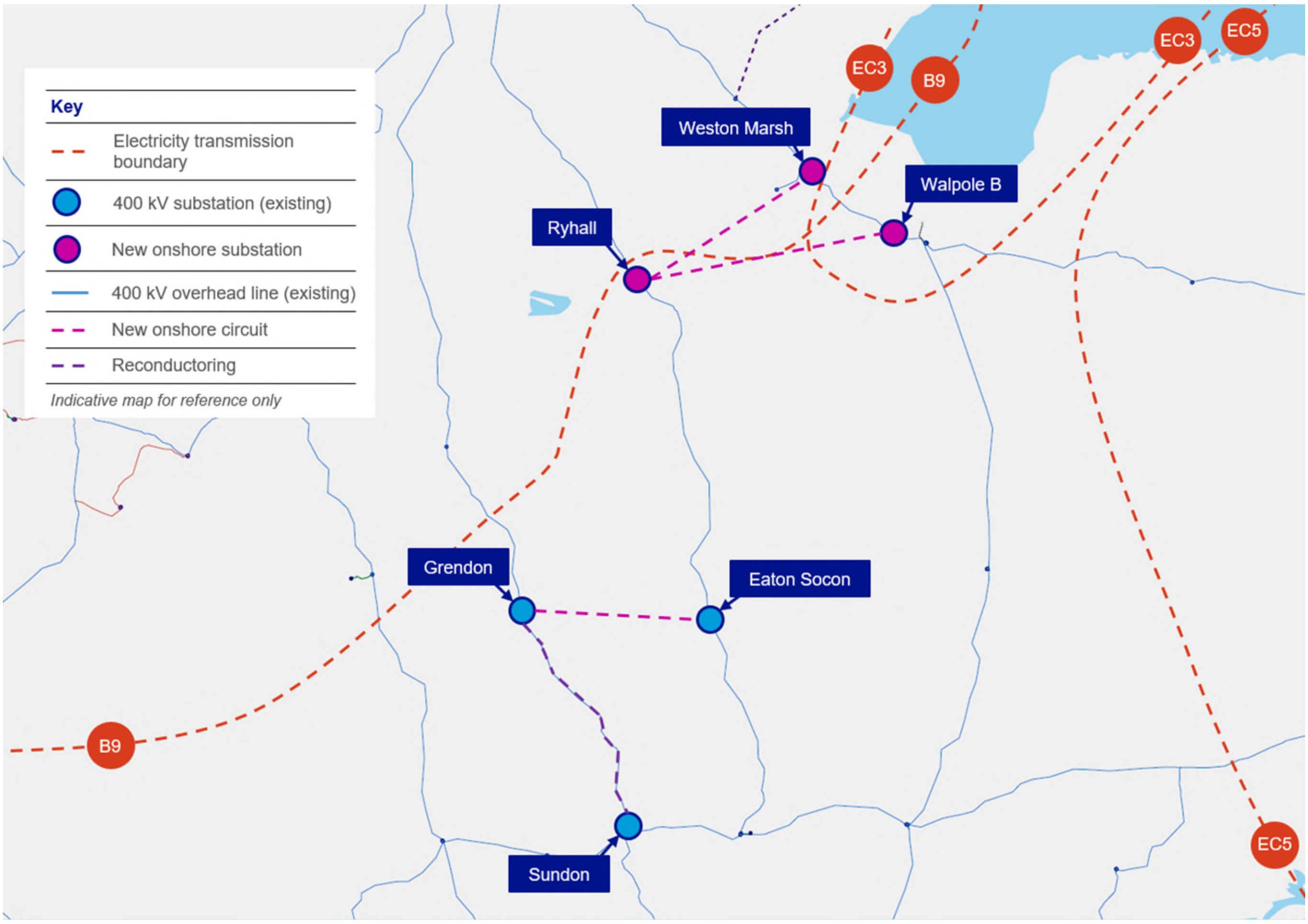
6.4 Appraisal of Option 3 Weston Marsh/Walpole B to new Ryhall and Eaton Socon to Grendon to Sundon

Description of strategic option 3

6.4.1 Option 3, Weston Marsh/Walpole B to new Ryhall and Eaton Socon to Grendon, proposes the establishment of two new 400 kV transmission connections: the first being between either a new Weston Marsh 400 kV or a new Walpole B 400 kV Substation and a new Ryhall 400 kV Substation. The second being between existing Eaton Socon 400 kV Substation and the existing Grendon 400 kV Substation – necessitating the use of two bays at each substation. Option 3 will also require reconductoring of the existing Grendon to Sundon circuit. The proposed route spans approximately 60 km, with an additional 40 km of reconductoring, as depicted in Figure 6.3.

6.4.2 Option 3 will provide additional transmission capacity across boundary B9 if Weston Marsh Substation is the chosen connection location. Regardless, it also provides capability to the midlands and southern England boundaries. This option achieves boundary requirements and LRN# drivers and presents a solution to connect to two routes that allow power to flow south.

Figure 6.3 – Indicative route for strategic Option 3



Summary of the environmental appraisal

Ecology

6.4.3 The Weston Marsh – new Ryhall section of Option 3 crosses Baston Fen SAC and SSSI. Within the 2 km study area there are four areas of Ancient Woodland, Dole Wood SSSI and a number of Veteran Trees.

6.4.4 The Walpole B – new Ryhall section of Option 3 crosses Cross Drain SSSI, and within the 2 km study area there are three areas of Ancient Woodland, Langtoft Gravel Pits SSSI and several Veteran Trees.

6.4.5 The Eaton Socon – Grendon section of Option 3 crosses three areas of Ancient Woodland and passes very close to a Veteran Tree. Within the 2 km study area there are seven SSSIs, a further twenty-three areas of Ancient Woodland and a number of other Veteran/Ancient Trees. The study area also contains the Upper Nene Valley Gravel Pits (designated as SPA, Ramsar and RSPB Important Bird Area).

6.4.6 Overhead Line (OHL) is the preferred technology for this Strategic Option. Further details on this preference are available below in the technical and cost appraisal sub-sections.

6.4.7 During construction, there is the potential for Option 3 to affect Baston Fen SAC and SSSI, three areas of Ancient Woodland and a Veteran Tree. This could be through land-take, pollution of land and water and general disturbance as a result of construction works, depending upon the alignment of the final OHL and construction methodologies.

6.4.8 Standard environmental control measures should be implemented which may include undertaking works at the appropriate time of year to avoid impacts on certain species. Such control measures would be outlined in a Construction Environmental Management Plan (CEMP) and/or a Construction Traffic Management Plan (CTMP) and would reduce potential impacts.

6.4.9 If areas of Ancient Woodland and/or Veteran/Ancient Trees cannot be avoided, then a suitable compensatory package could be developed as part of the application in consultation with the Forestry Commission.

6.4.10 However, it is anticipated that impacts on the designated sites, areas of Ancient Woodland and Veteran/Ancient Trees are likely to be reduced or avoidable through adopting appropriate routeing corridors and sensitive routeing, thus avoiding, or reducing affects. However, early engagement with the Forestry Commission and Natural England would be required to determine the extent of any impacts and identify appropriate mitigation.

Landscape and Visual

6.4.11 There are no National Parks, National Landscapes, World Heritage Sites, Biospheres or National Trails located along or within the 2 km study area of Option 3.

6.4.12 The Weston Marsh – new Ryhall section of Option 3 crosses the settlement of Spalding, the Walpole B – new Ryhall section crosses the settlements of Greatford and Langtoft, and the Eaton Socon – Grendon section crosses the settlement of Thurleigh Airfield Business Park. There is therefore the potential for this option to affect local visual receptors to these four settlements during construction and operation.

6.4.13 Developing appropriate route corridors and undertaking sensitive routeing would ensure that the settlements are either avoided, or that impacts on sensitive visual receptors are reduced. It should be noted that there would however be a permanent above-ground OHL which could result in adverse impacts on the four settlements. Further detailed assessment would need to be undertaken to understand the impacts on local visual receptors.

Historic Environment

6.4.14 Option 3 does not cross any designated heritage assets. However, there are several Scheduled Monuments, Registered Parks and Gardens, and Grade I and II* Listed Buildings distributed throughout the 2 km study areas of each of the sections of this option.

6.4.15 During construction there are no anticipated effects on designated heritage assets. However, there may be impacts on the setting of designated heritage assets (including Scheduled Monuments, Listed Buildings and Registered Parks and Gardens). Such impacts on setting are also likely to continue into operation of the Project depending on the location of the OHL.

6.4.16 It is assumed that adopting appropriate route corridors and undertaking sensitive routeing would avoid or reduce effects on heritage assets. Adopting standard construction control measures within a CEMP and/or CTMP would also reduce impacts. Early engagement with Historic England is recommended.

6.4.17 At this stage, it cannot be confirmed that all effects on the setting of heritage features can be ruled out without more detailed assessment.

Water, Geology and Soils

6.4.18 Within the study area there are large areas of Flood Zones 2 and 3, and a number of rivers/watercourses.

6.4.19 There is one Area Benefitting from Flood Defences within the study areas of both the Weston Marsh – new Ryhall section and Eaton Socon – Grendon section, and three Areas Benefitting from Flood Defences within the study area of the Walpole B – new Ryhall section. There is also one Geological SSSI within the study area of the Eaton Socon – Grendon section of Option 3.

6.4.20 During construction there are likely to be pollution risks to watercourses, together with impacts associated with flood risk due to the extent of Flood Zones 2 and 3 and Areas Benefitting from Flood Defences. There is also the potential for construction effects on the Geological SSSI due to its proximity. Early Engagement with Natural England would assist in identifying impacts and associated mitigation.

6.4.21 Crossings of watercourses are likely to be unavoidable however, developing appropriate route corridors and undertaking sensitive routeing that minimises the number of watercourse crossings and work in Flood Zones would ensure that residual impacts are reduced, or avoided wherever possible. In addition, an assumption that standard construction control measures and/or Best Practicable Means would be adhered to within a CEMP and would thus reduce residual pollution risks to watercourses.

6.4.22 It is noted that additional consents and/or permits would be required from the Environment Agency along with a Flood Risk Assessment and therefore early engagement is recommended.

Noise

6.4.23 Option 3 crosses the settlements of Spalding, Greatford, Langtoft, and Thurleigh Airfield Business Park. There is therefore the potential for this option to affect sensitive receptors during both construction and operation.

6.4.24 During construction, noise effects are likely to be capable of mitigation through standard control measures and Best Practicable Means outlined in a CEMP and consulted upon with the relevant local authority environmental health officer.

6.4.25 It is, however, anticipated that developing appropriate route corridors and adopting sensitive routeing would ensure that operational noise impacts are minimised. This could be through maximising separation distances and building proximity distances where possible between the new OHL and sensitive receptors.

Summary of the socio-economic appraisal

Tourism and Recreation

6.4.26 The Weston Marsh – new Ryhall section of Option 3 does not cross any major visitor attractions, National Trust Inalienable Land, National Cycle Routes, or CRoW Open Access Land, nor is there any located within the 2 km study area.

6.4.27 The Walpole B – new Ryhall section of Option 3 crosses National Cycle Route 12.

6.4.28 The study area for the Eaton Socon – Grendon section of Option 3 includes one major visitor attraction (Santa Pod Raceway) and crosses National Cycle Route 12. Within the 2 km study area there are a further two major visitor attractions (Wyboston Lakes Resort and PalmerSport Racetrack), and four areas of CRoW Open Access Land.

6.4.29 During construction and operation there is the possibility of disruption to National Cycle Routes and CRoW Open Access Land. However, adopting appropriate route corridors together with an assumption that standard construction control measures would be adhered to within a CEMP and/or CTMP would reduce any impacts.

6.4.30 Early engagement with stakeholders from the Santa Pod Raceway would also determine appropriate mitigation should there be impacts to this visitor attraction following routeing.

Infrastructure

6.4.31 The Weston Marsh – new Ryhall section of Option 3 crosses three road networks and two rail networks, and there are five crossings of other National Grid infrastructure (including OHL and gas pipes). Johnson Community Hospital in Spalding, and Northorpe Fen Airstrip are also within the 2 km study area.

6.4.32 The Walpole B – new Ryhall section of Option 3 crosses four road networks and two rail networks, and there are four crossings of other National Grid infrastructure (comprising of gas pipes). There are two passenger airfields located within the 2 km study area (Crowland Airstrip and Fenland Airfield).

6.4.33 The Eaton Socon – Grendon section of Option 3 crosses two road networks and one rail network, and there are five crossings of other National Grid infrastructure (including OHL and gas pipes). Bedford Aerodrome is located within the 2 km study area.

6.4.34 During construction there is the potential for disruption to road and rail networks. However, adopting appropriate route corridors which minimise the number of road and rail crossings, and implementing standard control measures outlined in a CEMP and/or CTMP would reduce any impacts on the road and rail networks. Impacts related to crossing other National Grid infrastructure could also be mitigated through appropriate routeing and adopting sensitive construction methods utilising technology types such as undergrounding when crossing other OHLs.

6.4.35 During construction and operation there is the potential for impacts on the airstrips/aerodromes identified and the Johnson Community Hospital however, it is anticipated that these can be mitigated through appropriate routeing.

6.4.36 Within the study area of Option 3 there are four other NSIPs: Mallard Pass Solar Project (decision stage), East Park Energy (pre-application stage), East West Rail - Bedford to Cambridge and Western Improvements (pre-application stage), and A428 Black Cat to Caxton Gibbet Road Improvement Scheme (under construction, expected completion in 2027). There is the potential for cumulative impacts to occur as a result of concurrent NSIPs however, sensitive routeing that either avoids other NSIPs altogether or adopts careful siting to reduce cumulative impacts would ensure that impacts are minimised.

Summary of the technical appraisal

6.4.37 A technical appraisal has established that a transmission connection between Weston Marsh or Walpole B and new Ryhall, and a connection between Eaton Socon and Grendon would satisfy the NETS SQSS at Weston Marsh, Walpole B and Eaton Socon, whilst providing additional transmission capacity across boundary B9 (if Weston Marsh is chosen) and capability to the Midlands and Southern England boundaries.

6.4.38 Technical analysis of the option is as follows (considering three most likely connections):

- Route connects into a new 400 kV substation starting at Weston Marsh/Walpole B and terminating at a new Ryhall Substation. Option also includes a new circuit between Eaton Socon and Grendon as well as reconductoring of existing OHL between Grendon and Sundon.
- The new transmission connections proposed as part of Option 3 will be configured as double circuit overhead lines (OHLs) and will involve the installation of two new AC 400 kV circuits, one 30 km circuit (Weston Marsh/Walpole B to new Ryhall) and one 30 km circuit (Eaton Socon to Grendon). The collective length of the circuits totals approximately 60 km with a power rating of 6,930 MW. The reconductoring effort for overhead lines (OHL) encompasses the entire 40 km length of the Grendon to Sundon circuit.
- For the appraisal of onshore options of significant distance, an OHL would normally be expected to offer the most economic, efficient, and co-ordinated development and would meet NGET’s obligations under Section 9 of the Electricity Act.
- Use of OHL is low risk in terms of construction complexity, and standard construction and access techniques can be adopted for this option, as well as operation and maintenance. The same applies for the crossing that would be required for the roads and rail lines involved. For this option, OHL build is not as large, meaning that the consenting risk involved is also lower.
- Technology implemented is well established, relatively straightforward to construct, operate and maintain.

- Option 3 meets the needs of the system requirements to reinforce the B9 boundary and to help relieve boundary constraints. The option also employs greater power flow flexibility by supplying an additional route to allow power coming into the East Coast of England to cross over to the west and flow south to demand. This way, the option provides support under more scenarios and provides further system benefit, as parts of the solution remain under fault conditions.
- In terms of future upgrades, the option has the capability to extend the east flows by going further west from Grendon, if required in the future.

6.4.39 It is important to note that there are several other National Grid projects which relate to Option 3: including new substation at Weston Marsh and a new substation at Walpole B, both to be built by Grimsby to Walpole and required for LRN#. Other infrastructure related to this option includes: a new substation at Ryhall and substation extension at both Eaton Socon Substation and Grendon Substation, to be built by this project. Further analysis of this planned infrastructure is required and may result in rationalisation of this option.

Summary of the cost appraisal

6.4.40 As set out in Chapter 5, NGET undertakes a cost evaluation of the following four technologies for onshore options evaluation:

a) 400 kV alternating current (AC) overhead line

b) 400 kV AC underground cable

c) 400 kV AC gas insulated line (GIL)

d) 525 kV high voltage direct current (HVDC) underground cable and converter stations

6.4.41 Option 3 requires the following transmission works to satisfy the requirements of the SQSS:

- Substation works
  - Utilisation of 2 bays at a new Weston Marsh/Walpole B 400 kV Substation to accommodate new circuits.
  - Extension to Eaton Socon 400 kV Substation by 2 bays to accommodate new circuits.
  - New Ryhall 400 kV Substation able to accommodate 12 bays.
  - Extension to Grendon 400 kV Substation by 2 bays to accommodate new circuits.
- New circuit requirements
  - AC connections options use high-capacity double circuits (two 400 kV AC circuits) with a total capacity of up to 6,930 MW; or,
  - HVDC using 525 kV 2,000 MW voltage source links, which would require a convertor station at each end similar in size to a large warehouse. A 6,000 MW connection would require three convertor stations at each end, six overall, this is to come close to matching the AC high-capacity circuits of 6,930 MW.
  - Reconductoring of existing Grendon to Sundon Circuit.

6.4.42 Table 6.5 sets out the capital costs for Option 3 considering substation works and each technology option.

Table 6.5 – Capital costs for Option 3

Item	Capital Cost			
Substation and Wider Works	£397.0m			
New Circuits	**AC OHL**	**AC Cable**	**AC GIL**	**HVDC**
New Circuit	£238.8m	£2,552.7m	£2,595.6m	£3,762.5m
Total Capital Cost	**£635.8m**	**£2,949.7m**	**£2,992.6m**	**£4,159.5m**

6.4.43 Table 6.6 sets out the lifetime cost for the new circuit technology options, the lifetime 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" found in Appendix E.

Table 6.6 – Lifetime cost by technology option

Land Based Option	AC OHL	AC Cable	AC GIL	HVDC
Capital Cost of new Circuits	£238.8m	£2,552.7m	£2,595.6m	£3,762.5m
NPV of Cost of Losses over 40 years	£168.3m	£116.4m	£78.1m	£942.5m
NPV of Operation & Maintenance costs over 40 years	£3.5m	£11.2m	£3.5m	£343.2m
Lifetime Cost of new Circuits	**£411m**	**£2,680m**	**£2,677m**	**£5,048m**

6.4.44 Based on the data in the above tables, the following conclusions can be drawn:

- AC OHL has the lowest capital cost of new circuits.
- AC OHL has a reasonable NPV of Cost of Losses over a forty-year projection.
- AC OHL has the lowest NPV of Operation and Maintenance Costs over a forty-year projection.
- AC OHL has the lowest lifetime cost of new circuits.

Summary of the strategic option

6.4.45 From the environmental and technical appraisal considered, alongside capital and circuit lifetime costs, the preferred technology option for Option 3 is the utilisation of two transmission connections, configured as AC circuits: the first between a new Weston Marsh/Walpole B Substation and a new Ryhall Substation, the second between existing Eaton Socon Substation and the existing Grendon Substation. In light of this analysis, NGET's starting presumption for further development of this option should it be selected, would be for majority overhead line connections.

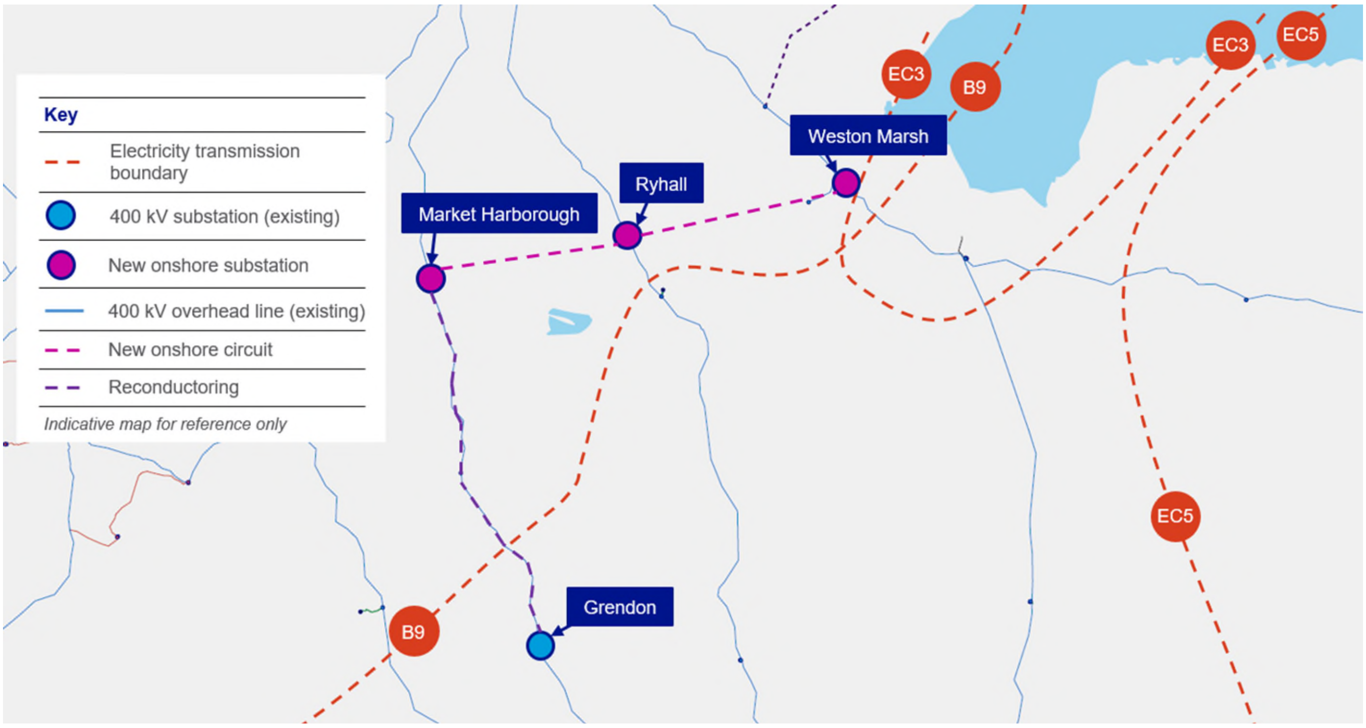
6.5 Appraisal of Option 4 Weston Marsh to new Market Harborough (via new Ryhall)

Description of strategic option 4

6.5.1 Option 4, Weston Marsh to new Market Harborough (via new Ryhall), proposes the establishment of a new 400 kV transmission connection between a new Weston Marsh 400 kV Substation and a new Market Harborough 400 kV Substation. This connection will be facilitated by routeing via a new 400 kV substation at Ryhall. Option 4 additionally proposes the reconductoring of the Market Harborough to Grendon connection. The proposed route for the new connection spans approximately 60 km, with circa 55 km of reconductoring also to be implemented, as depicted in Figure 6.4.

6.5.2 Option 4 will provide additional transmission capability to boundary B9 while increasing system flexibility due to facilitating two circuits out of Weston Marsh and Ryhall. Moreover, the option mitigates overloading of the Ryhall-Eaton Socon circuit, under fault conditions, hence helping to relieve constraints on the boundary.

Figure 6.4 – Indicative route for strategic option 4



6.5.3 The existing 400 kV transmission connection between Grendon and Sundon requires reconductoring however, this is proposed to be completed in advance of LRN# as part of the SGRE Project.

6.5.4 “Hot Wiring”, where the operating temperature of the existing conductors is increased to increase capacity, is also proposed on the existing 400 kV transmission connection between Cottam Substation and proposed new Market Harborough Substation. This is a separate project and can be carried out regardless of LRN# however, coordination will be required should this option proceed as it occurs on the same north-south OHL transmission connections as those for the Project.

Summary of the environmental appraisal

6.5.5 It should be noted that the environmental and socio-economic appraisals are solely of new installations, therefore have not been carried out for the reconductoring scope at this stage.

Ecology

6.5.6 The option crosses three areas of Ancient Woodland. Within the 2 km study area there is one SAC (Grimsthorpe), seven SSSIs and nine further areas of Ancient Woodland.

6.5.7 During construction, there is potential for this option to affect the areas of Ancient Woodland, and to affect designated sites. This could be through pollution of land and water and general disturbance as a result of construction works, depending upon the alignment of the final OHL and construction methodologies.

6.5.8 Standard environmental control measures should be implemented which may include undertaking works at the appropriate time of year to avoid impacts on certain species. Such control measures would be outlined in a CEMP and/or a CTMP and would reduce potential impacts.

6.5.9 If areas of Ancient Woodland cannot be avoided, then a suitable compensatory package could be developed as part of the application in consultation with the Forestry Commission.

6.5.10 However, it is anticipated that impacts on areas of Ancient Woodland and designated sites are likely to be reduced or avoidable through adopting appropriate route corridors and sensitive routeing, thus avoiding, or reducing effects. Early engagement with the Forestry Commission would be required to determine the extent of any impacts and identify appropriate mitigation.

Landscape and Visual

6.5.11 There are no National Parks, National Landscapes, World Heritage Sites, Biospheres or National Trails within the 2 km study area of this option.

6.5.12 The option passes through the settlement of Edenham. There is therefore the potential for this option to affect local visual receptors to this settlement during construction and operation.

6.5.13 Developing appropriate route corridors and undertaking sensitive routeing would ensure that the settlements are either avoided, or that impacts on sensitive visual receptors are reduced. It should be noted that there would however be a permanent above-ground OHL which could result in adverse impacts on the settlement. Further detailed assessment would need to be undertaken to understand the impacts on local visual receptors.

Historic Environment

6.5.14 The option crosses one Registered Park and Garden at Grimsthorpe Castle. There are seven Scheduled Monuments and several Grade I and Grade II* Listed Buildings within the 2 km study area.

6.5.15 During construction there is potential for impacts on the Registered Park and Garden, and impacts on the setting of other designated heritage assets (including Scheduled

Monuments and Listed Buildings). Such impacts on setting are also likely to continue into operation of the Project depending on the location of the OHL.

6.5.16 It is assumed that adopting appropriate route corridors and undertaking sensitive routeing would avoid adverse effects on heritage assets. Adopting standard construction control measures within a CEMP and/or CTMP would also reduce impacts.

6.5.17 There does however remain the potential for impacts on the setting of the Registered Park and Garden, depending on the location of the OHL. This would require further assessment and early engagement with Historic England.

6.5.18 At this stage, it cannot be confirmed that all effects on the setting of heritage features can be ruled out without more detailed assessment.

Water, Geology and Soils

6.5.19 There are large areas of Flood Zones 2 and 3 covering the option, and the option would require a number of river/watercourse crossings, namely the River Great Ouse and the River Cam.

6.5.20 During construction there are likely to be pollution risks, together with impacts associated with flood risk due to the extent of Flood Zones 2 and 3. Crossings of watercourses are likely to be unavoidable however, developing appropriate route corridors and undertaking sensitive routeing that minimises the number of watercourse crossings and work in Flood Zones would ensure that residual impacts are reduced, or avoided wherever possible. In addition, an assumption that standard construction control measures and/or Best Practicable Means would be adhered to within a CEMP and would thus reduce residual pollution risks to watercourses.

6.5.21 It is noted that additional consents and/or permits would be required from the Environment Agency along with a Flood Risk Assessment and therefore early engagement is recommended.

Noise

6.5.22 The option passes through the settlement of Edenham and there is therefore the potential for this option to affect sensitive receptors during both construction and operation.

6.5.23 During construction, noise effects are likely to be capable of mitigation through standard control measures and Best Practicable Means outlined in a CEMP and consulted upon with the relevant local authority environmental health officer.

6.5.24 It is, however, anticipated that developing appropriate route corridors and adopting sensitive routeing would ensure that operational noise impacts are minimised. This could be through maximising separation distances and building proximity distances where possible between the new OHL and sensitive receptors.

Summary of the socio-economic appraisal

Tourism and Recreation

6.5.25 The option crosses three areas of CRoW Open Access Land. Within the 2 km study area there are a further two areas of CRoW Open Access Land and one major visitor attraction (Grimsthorpe Castle).

6.5.26 During construction and operation there is the possibility of disruption to CRoW Open Access Land. However, adopting appropriate route corridors together with an assumption that standard construction control measures would be adhered to within a CEMP and/or CTMP would reduce any impacts.

6.5.27 Early engagement with stakeholders from Grimsthorpe Castle would also determine appropriate mitigation should there be impacts to this visitor attraction following routeing.

Infrastructure

6.5.28 The option crosses six road networks, three rail networks, and there are four crossings of other National Grid infrastructure (including OHL and pipelines). Kendrew Barracks military site and Black Spring Farm Airstrip are also located within the 2 km study area.

6.5.29 During construction there is the potential for disruption to road and rail networks. However, adopting appropriate route corridors which minimise the number of road and rail crossings, and implementing standard control measures outlined in a CEMP and/or CTMP would reduce any impacts on the road and rail networks. Impacts related to crossing other National Grid infrastructure could also be mitigated through appropriate routeing and adopting sensitive construction methods utilising technology types such as undergrounding when crossings other OHLs.

6.5.30 During construction and operation there is the potential for impacts to the airstrip and military site identified. Adopting route corridors to minimise or avoid land take at the airstrip and military site will be required, and siting will have to take into consideration any aircraft movements/ testing operations. Early engagement with the MoD will be required as this option is taken forward.

Summary of the technical appraisal

6.5.31 A technical appraisal has established that a transmission connection between Weston Marsh and Market Harborough, via Ryhall, would satisfy the National Electricity Transmission System (NETS) Security and Quality of Supply Standards (SQSS) at Weston Marsh, whilst providing additional transmission capacity across boundary B9 and capability to the Midlands and southern England boundaries.

6.5.32 Technical analysis of this option is as follows:

- Route connects into a new 400 kV substation starting at Weston Marsh and terminates at a new 400 kV substation at Market Harborough after routeing through a new 400 kV substation at Ryhall.
- This option will be configured as an AC double circuit overhead line (OHL) and will involve the installation of a new AC 400 kV circuit rated at 6,930 MW.
- For the appraisal of onshore options of significant distance, an OHL would normally be expected to offer the most economic, efficient, and co-ordinated development and would meet NGET’s obligations under Section 9 of the Electricity Act.
- Use of OHL is low risk in terms of construction complexity and standard construction and access techniques can be adopted for this option, as well as operation and maintenance. The same applies for the crossing that would be required for the roads and rail lines involved.

- Technology implemented is well established, relatively straightforward to construct, operate and maintain. Multiple interfaces to manage and mitigate asset crossings to be considered.
- This option provides extra uplift in comparison to other options, while increasing system flexibility, due to the implementation of two circuits out of Weston Marsh and Ryhall and mitigating the overloading of the Ryhall-Eaton Socon circuit, under fault conditions.
- This option proposes an increased OHL reconductoring length.

Summary of the cost appraisal

6.5.33 As set out in Chapter 5, NGET undertakes a cost evaluation of the following four technologies for onshore options evaluation:

a) 400 kV Alternating Current (AC) overhead line

b) 400 kV AC underground cable

c) 400 kV AC Gas Insulated Line (GIL)

d) 525 kV High Voltage Direct Current (HVDC) underground cable and converter stations

6.5.34 Option 4 requires the following transmission works to satisfy the requirements of the SQSS:

- Substation works
  - Utilisation of 2 bays at a new Weston Marsh 400 kV Substation to accommodate new circuits.
  - New Ryhall 400 kV Substation able to accommodate 12 bays.
  - New Market Harborough 400 kV Substation able to accommodate 12 bays.
- Wider works
  - 55 km reconductoring between new Market Harborough Substation and Grendon Substation.
- New circuit requirements
  - AC connections options use high-capacity double circuits (two 400 kV AC circuits) with a total capacity of up to 6,930 MW; or,
  - HVDC using 525 kV 2,000 MW voltage source links, which would require a convertor station at each end similar in size to a large warehouse. A 6,000 MW connection would require three convertor stations at each end, six overall, this is to come close to matching the AC high-capacity circuits of 6,930 MW.

6.5.35 Table 6.7 sets out the capital costs for Option 4 considering substation works and each technology option.

Table 6.7 – Capital costs for Option 4

Item	Capital Cost			
Substation and Wider Works	£359.0 m			
New Circuits	**AC OHL**	**AC Cable**	**AC GIL**	**HVDC**
New Circuit	£238.8m	£2,552.7m	£2,595.6m	£2,159.3m
Total Capital Cost	**£597.8m**	**£2,911.7m**	**£2,954.6m**	**£2,518.3m**

6.5.36 Table 6.8 sets out the lifetime cost for the new circuit technology options, the lifetime 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", found in the Appendix E.

Table 6.8 – Lifetime cost by technology option

Land Based Option	AC OHL	AC Cable	AC GIL	HVDC
Capital Cost of new Circuits	£238.8m	£2,552.7m	£2,595.6m	£2,159.3m
NPV of Cost of Losses over 40 years	£168.3m	£116.4m	£78.1m	£471.2m
NPV of Operation & Maintenance costs over 40 years	£3.5m	£11.2m	£3.5m	£171.9m
Lifetime Cost of new Circuits	**£411m**	**£2,680m**	**£2,677m**	**£2,802m**

6.5.37 The table above presents figures and numbers for the following cost terms, with definitions provided in the bullet points below.

- Capital Cost of new Circuits is a term utilised to demonstrate the initial capital expenditure associated with the implementation of a new circuit.
- Net Present Value (NPV) of Cost of Losses is a term utilised to demonstrate the present-day monetary value of cost of losses while factoring in initial capital investment required for the Project.
- Net Present Value (NPV) of Operation and Maintenance Costs is a term utilised to demonstrate the present-day monetary value of operation and maintenance costs while factoring in initial capital investment required for the Project.
- Lifetime Cost of new Circuits is a term utilised to demonstrate the total capital expenditure associated with the implementation of a new circuit and is calculated by summing the above three cost terms.

6.5.38 Based on the data in the above tables, the following conclusions can be drawn:

- AC OHL has the lowest capital cost of new circuits.
- AC OHL has a reasonable NPV of Cost of Losses over a forty-year projection.
- AC OHL has the lowest NPV of Operation and Maintenance Costs over a forty-year projection.

- AC OHL has the lowest lifetime cost of new circuits.

Summary of the strategic option

6.5.39 From the environmental and technical appraisal considered, alongside capital and circuit lifetime costs, the preferred technology option for Option 4 is a 60 km connection, configured as an AC circuit, between a new Weston Marsh Substation and a new Market Harborough Substation, via a new Ryhall Substation. This connection will be implemented alongside 55 km of reconductoring of the Market Harborough to Grendon circuit. Considering this analysis, NGETs starting presumption for further development of this option, would be for a majority overhead line connection.

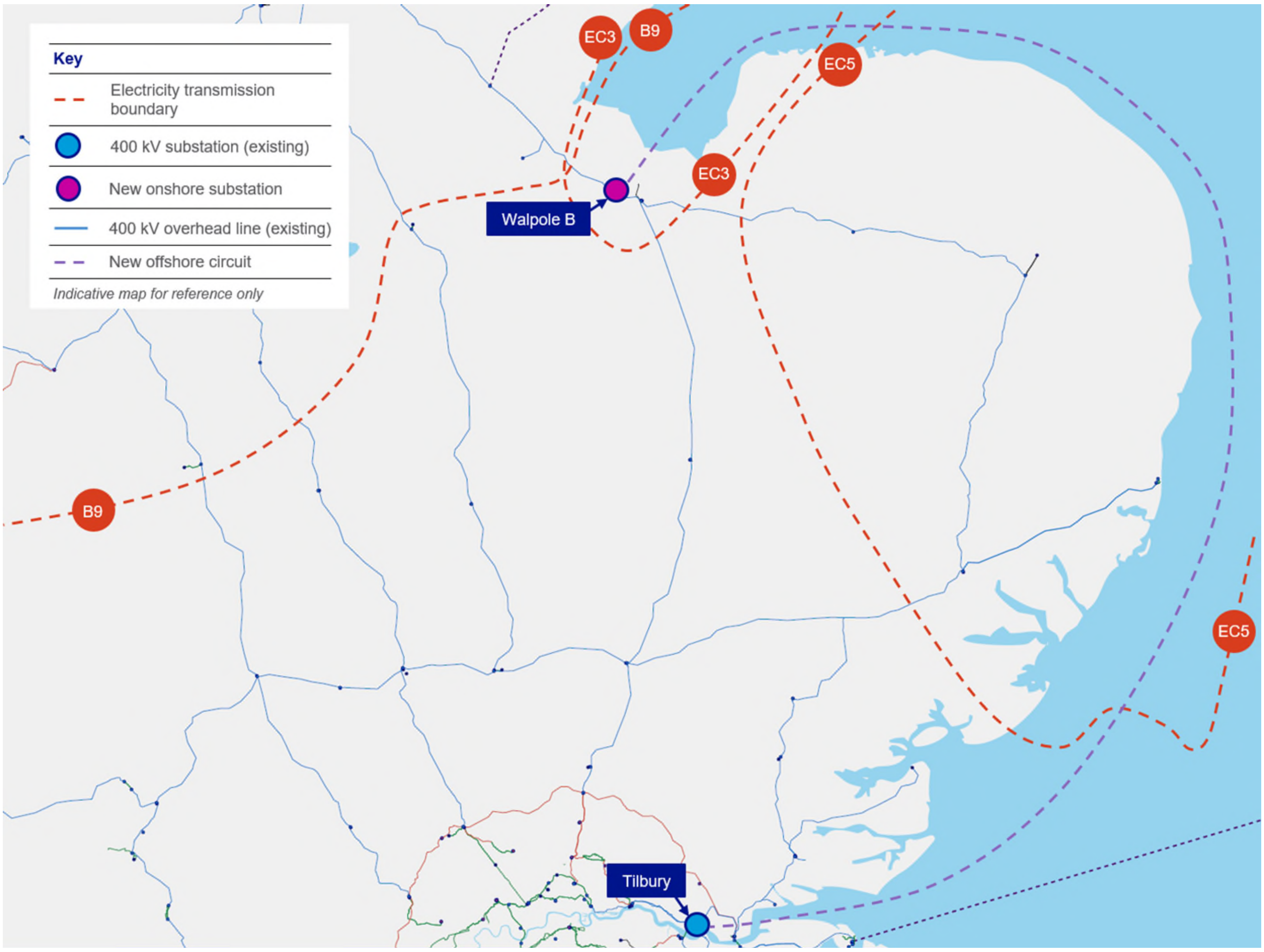
6.6 Appraisal of Option 5 Walpole B to Tilbury (subsea)

Description of strategic option 5

6.6.1 Option 5, Walpole B to Tilbury (subsea), proposes the establishment of a new Subsea HVDC connection between a new Walpole B 400 kV Substation and the existing Tilbury 400 kV Substation – necessitating the construction of two new bays at Tilbury Substation. The proposed subsea connection will span 360 km and be rated at 6,000 MW, as depicted in Figure 6.5.

6.6.2 Option 5 will provide additional transmission capability to boundary B9, whilst also providing capability to the midlands and southern England boundaries as well as an additional east to west route. This helps to relieve constraints across the B9 boundary.

Figure 6.5 – Indicative route for strategic option 5 (subsea)



Summary of the environmental appraisal

Ecology

6.6.3 Option 5 crosses four SACs, seven SPAs, five Ramsar sites, eight SSSIs, five RSPB Important Bird Areas, and passes close to a number of Veteran Trees. Within the study area, there are a further five SACs, four SPAs, four Ramsar sites, fifteen SSSIs, eighteen areas of Ancient Woodland, four RSPB Important Bird Areas, and several Veteran Trees.

6.6.4 It is anticipated that many of the designations identified would be unavoidable. Although adopting appropriate route corridors would reduce impacts on some designations, adverse impacts are still expected following mitigation on designated sites that are unavoidable.

Landscape and Visual

6.6.5 There are no National Parks, National Landscapes, World Heritage Sites or Biospheres that are located along or within the 2 km study area. Option 5 does however cross one National Trail (Peddar’s Way and Norfolk Coast Path), and thirty settlements.

6.6.6 For the onshore elements of this Strategic Option, Overhead Line (OHL) is the preferred technology. Further details on this preference are available below in the technical and cost appraisal sub-sections on pages 81 and 82.

6.6.7 It is anticipated that adopting appropriate route corridors and sensitive routeing would avoid or reduce impacts to the National Trail and ensure that the settlements are avoided or that impacts on sensitive visual receptors are reduced. It should be noted that there would however be a permanent above-ground OHL which could result in adverse impacts on some settlements. Further detailed assessment would need to be undertaken to understand the impacts on local visual receptors, given the high number of settlements in the study area.

Historic Environment

6.6.8 Option 5 crosses six Scheduled Monuments, one Listed Building and one Registered Park and Garden (Crown Point for approximately 1.07 km). There are a number of other Scheduled Monuments, Grade I and II* Listed Buildings and Registered Parks and Gardens within the 2 km study area.

6.6.9 During construction there is potential for impacts on six Scheduled Monuments, one Listed Building and a Registered Park and Garden, and impacts on the setting of other designated heritage assets (including further Scheduled Monuments, Listed Buildings and Registered Parks and Gardens). Such impacts on setting are also likely to continue into operation of the Project depending on the location of the OHL.

6.6.10 It is assumed that adopting appropriate route corridors and undertaking sensitive routeing would avoid adverse effects on heritage assets. Adopting standard construction control measures within a CEMP and/or CTMP would also reduce impacts.

6.6.11 There does however remain the potential for impacts on the setting of the Scheduled Monuments, Listed Building and Registered Park and Garden, depending on the location of the OHL. This would require further assessment and early engagement with Historic England.

6.6.12 At this stage, it cannot be confirmed that all effects on the setting of heritage features can be ruled out without more detailed assessment.

Water, Geology and Soils

6.6.13 There are large areas of Flood Zones 2 and 3 covering Option 5, and areas of Reduction in Risk of Flooding from Rivers and Seas covering the study area. Within the 2 km study area there is also one Flood Storage Area, and eight Geological SSSIs.

6.6.14 During construction there are likely to be pollution risks, together with impacts associated with flood risk due to the extent of Flood Zones 2 and 3 and the areas of Reduction in Risk of Flooding from Rivers and Seas. There is also the potential for impacts on the eight Geological SSSIs during construction due to their proximity, depending on location of the final OHL. Early engagement with Natural England would assist in identifying impacts and associated mitigation.

6.6.15 Crossings of watercourses are likely to be unavoidable however, developing appropriate route corridors and undertaking sensitive routeing that minimises the number of watercourse crossings and work in Flood Zones would ensure that residual impacts are reduced, or avoided wherever possible. In addition, standard construction control measures and/or Best Practicable Means would be adhered to within a CEMP and would thus reduce residual pollution risks to watercourses.

6.6.16 It is noted that additional consents and/or permits would be required from the Environment Agency along with a Flood Risk Assessment and therefore early engagement is recommended.

Noise

6.6.17 The study area for Option 5 includes thirty settlements and there is therefore the potential for this option to affect multiple sensitive receptors during both construction and operation.

6.6.18 During construction, noise effects are likely to be capable of mitigation through standard control measures and Best Practicable Means outlined in a CEMP and consulted upon with the relevant local authority environmental health officer.

6.6.19 It is, however, anticipated that developing appropriate route corridors and adopting sensitive routeing would ensure that operational noise impacts are minimised. This could be through maximising separation distances and building proximity distances where possible between the new OHL and sensitive receptors.

Summary of the socio-economic appraisal

Tourism and Recreation

6.6.20 Option 5 crosses the three major visitor attractions of Great Yarmouth Beach, Coalhouse Fort and the Thames Estuary nature reserves. Option 5 also crosses three National Cycle Routes (1, 13 and 16), and two areas of CRoW Open Access Land.

6.6.21 Within the 2 km study area there are a further three major visitor attractions and twenty areas of CRoW Open Access Land.

6.6.22 During construction and operation there is the possibility of disruption to National Cycle Routes and CRoW Open Access Land. However, adopting appropriate route corridors together with an assumption that standard construction control measures would be adhered to within a CEMP and/or CTMP would reduce any impacts.

6.6.23 During construction there is the potential for impacts on visitors of the three nature reserves due to general disturbance as a result of construction works. There is also potential for impacts to the setting of these visitor attractions. However, it is assumed that sensitive routeing would avoid or reduce impacts. Early engagement with stakeholders from the three major visitor attractions would also determine appropriate mitigation should there be anticipated impacts to this visitor attraction following routeing.

Infrastructure

6.6.24 Option 5 crosses seven road networks and six rail networks, and there are nine crossings of other National Grid infrastructure (including OHL and gas mains).

6.6.25 During construction there is the potential for disruption to road and rail networks. However, adopting appropriate route corridors which minimise the number of road and rail crossings, and implementing standard control measures outlined in a CEMP and/or CTMP would reduce any impacts on the road and rail networks. Impacts related to crossing other National Grid infrastructure could also be mitigated through appropriate routeing and adopting sensitive construction methods utilising technology types such as undergrounding when crossing other OHLs.

6.6.26 There is one military facility located withing the study area of Option 5: QinetiQ MoD training area. Adopting route corridors to minimise or avoid land take at the military facility will be required, and siting will have to take into consideration any aircraft movements/testing operations. Early engagement with the MoD will be required should this option be taken forward.

6.6.27 Option 5 crosses two NSIPs: A47-A11 Thickthorn Junction (post-decision stage), and Norwich to Tilbury (pre-application stage). There is the potential for cumulative impacts to occur as a result of concurrent NSIPs however, sensitive routeing that either avoids other NSIPs altogether or adopts careful siting to reduce cumulative impacts would ensure that impacts are minimised.

Summary of the technical appraisal

6.6.28 A technical appraisal has established that a subsea transmission connection between Walpole B and Tilbury would satisfy the NETS SQSS at Walpole, whilst providing additional transmission capability to boundary B9 and capability to the Midlands and southern England boundaries.

6.6.29 Technical analysis of the option is as follows:

- Route connects into a new 400 kV substation starting at Walpole B and terminates at the existing 400 kV Tilbury Substation. A connection between the new Walpole B Substation and the existing Norwich 400 kV Substation would also be required for this option.
- For the appraisal of subsea options of significant distance, an HVDC option would normally be expected to offer the most economic, efficient, and co-ordinated development and would meet NGET’s obligations under Section 9 of the Electricity Act.
- Offshore cable installation, compared to onshore, offers the delivery advantage of having the ability to carry significant lengths of cable on a large vessel for deployment. This way, cable laying campaigns of up to 100 km carried by a single vessel can be utilised, whereas land cables would need to be deployed in drum lengths of around 1 km for delivery to site. Technology implemented is well established, however constructability risk is increased, and maintenance is more challenging, considering its offshore location.
- This option meets the needs of the system requirements to reinforce the B9 boundary.

6.6.30 It is important to note that there is a National Grid project which relates to Option 5: Walpole B which is a new substation to be built by Grimsby to Walpole and which is also required for LRN#.

Summary of the cost appraisal

6.6.31 As set out in Chapter 5, NGET undertakes a cost evaluation of the following two technologies for subsea options evaluation:

a) 400 kV alternating current (AC) subsea cable

b) 525 kV HVDC subsea cable and converter stations

6.6.32 Option 5 requires the following transmission works to satisfy the requirements of the SQSS:

- Substation Works
  - Utilisation of two bays at new Walpole B 400 kV Substation to accommodate new circuits.
  - Extension to Tilbury 400 kV Substation by two bays to accommodate new circuits.
- New circuit requirements
  - AC subsea connections circuit options use high-capacity double circuits (two 400 kV AC circuits) with a total capacity of up to 6,930 MW; or
  - HVDC connection options use 525 kV 2,000 MW voltage source links, which would require a convertor 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), this is to come close to matching the AC high-capacity circuits of 6,930 MW.

6.6.33 Table 6.9 sets out the capital costs for Option 5 considering substation works and each technology option.

Table 6.9 – Capital costs for Option 5

Item	Capital Cost	
Substation and Wider Works	£32.0m	
New Circuits	**Subsea AC Cable**	**Subsea HVDC**
New Circuit	£15,582.3m	£4,940.3m
Total Capital Cost	**£15,614.3m**	**£4,972.3m**

6.6.34 Table 6.10 sets out the lifetime cost for the new circuit technology options, the lifetime 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” found in Appendix E.

Table 6.10 – Lifetime cost by subsea technology option

Land Based Option	AC Subsea Cable	Subsea HVDC
Capital Cost of new Circuits	£15,582.3m	£4,940.3m
NPV of Cost of Losses over 40 years	£790.6m	£471.2m
NPV of Operation & Maintenance costs over 40 years	£74.9m	£174.5m
Lifetime Cost of new Circuits	**£16,448m**	**£5,586m**

6.6.35 Based on the data in the above tables, the following conclusions can be drawn:

- Subsea HVDC has the highest capital cost of new circuits.
- Subsea HVDC has the lowest NPV of Cost of Losses over a forty-year projection.
- Subsea HVDC has a reasonable NPV of Operations & Maintenance costs over a forty-year projection.
- Subsea HVDC has the lowest lifetime cost of new circuits.

Summary of the strategic option

6.6.36 From the environmental and technical appraisal considered, alongside capital and circuit lifetime costs, the preferred technology option for Option 5 is a 360 km connection, configured as an HVDC subsea circuit, between a new Walpole B Substation and an existing Tilbury Substation. In light of this analysis, NGET's starting presumption for further development of this option should it be selected, would be for a majority HVDC subsea connection.

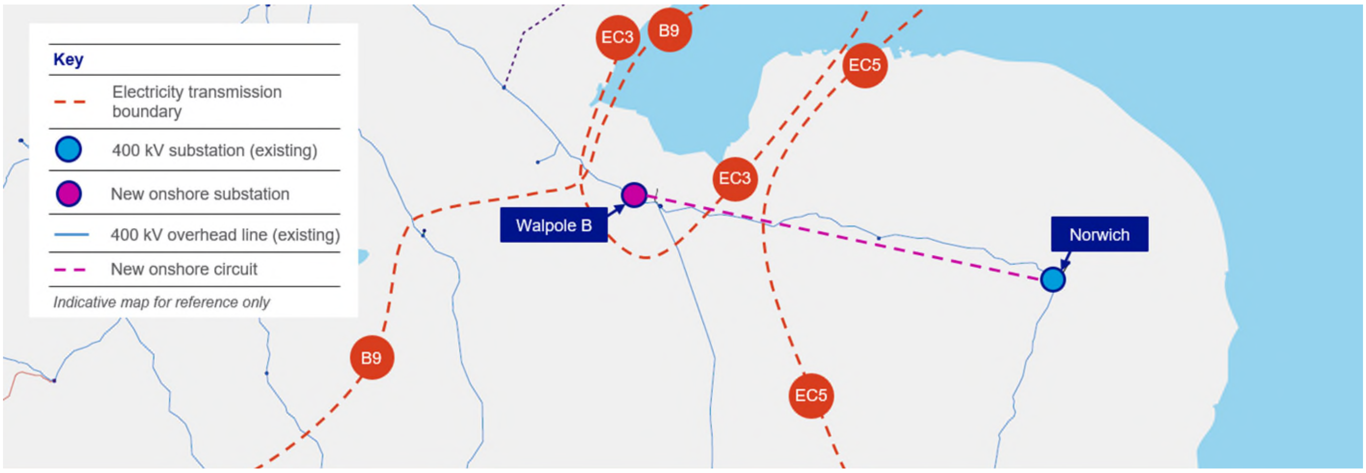
6.7 Appraisal of Option 6 Walpole B to Norwich

Description of strategic option 6

6.7.1 Option 6, Walpole B to Norwich, proposes a new 400 kV transmission connection between a new Walpole B 400 kV Substation and the existing Norwich 400 kV Substation – necessitating the construction of two new bays at Norwich Substation. The proposed route spans approximately 90 km, as depicted in Figure 6.6.

6.7.2 Option 6 will provide additional transmission capability to boundary B9, whilst also providing capability to the midlands and southern England boundaries. This helps to relieve constraints across the B9 boundary.

Figure 6.6 – Indicative route for strategic option 6



Summary of the environmental appraisal

Ecology

6.7.3 Option 6 crosses one SSSI (River Nar, for approximately 0.11 km) and passes through/very close to a number of Veteran/Ancient Trees. Within the study area there are a further ten SSSIs, nine areas of Ancient Woodland, four SACs and further Veteran Trees.

6.7.4 Overhead Line (OHL) is the preferred technology for this Strategic Option. Further details on this preference are available below in the technical and cost appraisal sub-sections.

6.7.5 During construction, there is the potential for Option 6 to affect the SSSI and Veteran Trees and affect the other designated sites. This could be through land-take, pollution of land and water, and general disturbance as a result of construction works, depending upon the alignment of the final OHL and construction methodologies.

6.7.6 Standard environmental control measures should be implemented which may include undertaking works at the appropriate time of year to avoid impacts on certain species. Such control measures would be outlined in a CEMP and/or a CTMP and would reduce potential impacts.

6.7.7 If Veteran Trees cannot be avoided, then a re-planting scheme could be developed as part of the application in consultation with the Forestry Commission, and which would include a monitoring and management plan.

6.7.8 However, it is anticipated that the impacts on SSSI and Veteran Trees are likely to be reduced or avoidable through adopting appropriate routeing corridors and sensitive routeing, thus avoiding, or reducing affects. However, early engagement with the Forestry Commission and Natural England would be required to determine the extent of any impacts and identify appropriate mitigation.

Landscape and Visual

6.7.9 There are no National Parks, National Landscapes, World Heritage Sites or Biospheres located along or within the 2 km study area. Option 6 does however cross one National Trail (Peddar’s Way and Norfolk Coast Path), and the two settlements of Dereham and West Winch).

6.7.10 It is anticipated that adopting appropriate route corridors and sensitive routeing would avoid or reduce impacts to the National Trail and ensure that the settlements are avoided or that impacts on sensitive visual receptors are reduced. It should be noted that there would however be a permanent above-ground OHL which could result in adverse impacts on the settlements. Further detailed assessment would need to be undertaken to understand the impacts on local visual receptors.

Historic Environment

6.7.11 Option 6 crosses one Scheduled Monument, West Acre Priory for less than 100 m. There are a number of other Scheduled Monuments, Grade I and II* Listed Buildings and three Registered Parks and Gardens within the 2 km study area.

6.7.12 During construction there is potential for impacts on the Scheduled Monument and impacts on the setting of other designated heritage assets (including further Scheduled Monuments, Listed Buildings and Registered Parks and Gardens). Such impacts on setting are also likely to continue into operation of the Project depending on the location of the OHL.

6.7.13 It is assumed that adopting appropriate route corridors and undertaking sensitive routeing would reduce or avoid adverse effects on heritage assets. Adopting standard construction control measures within a CEMP and/or CTMP would also reduce impacts.

6.7.14 There does however remain the potential for impacts on the setting of the West Acre Priory Scheduled Monument, depending on the location of the OHL. This would require further assessment and early engagement with Historic England.

6.7.15 At this stage, it cannot be confirmed that all effects on the setting of heritage features can be ruled out without more detailed assessment.

Water, Geology and Soils

6.7.16 There are large areas of Flood Zones 2 and 3 covering Option 6, and areas of Reduction in Risk of Flooding from Rivers and Seas covering the study area. Within the study area there are also five Geological SSSIs and one Flood Storage Area.

6.7.17 During construction there are likely to be pollution risks, together with impacts associated with flood risk due to the extent of Flood Zones 2 and 3 and the areas of Reduction in Risk of Flooding from Rivers and Seas. There is also the potential for construction effects on the five Geological SSSIs and the Flood Storage Area due to their proximity, depending on location of the final OHL. Early engagement with Natural England would assist in identifying impacts and associated mitigation.

6.7.18 Crossings of watercourses are likely to be unavoidable however, developing appropriate route corridors and undertaking sensitive routeing that minimises the number of watercourse crossings and work in Flood Zones would ensure that residual impacts are reduced, or avoided wherever possible. In addition, an assumption that standard construction control measures and/or Best Practicable Means would be adhered to within a CEMP and would thus reduce residual pollution risks to watercourses.

6.7.19 It is noted that additional consents and/or permits would be required from the Environment Agency along with a Flood Risk Assessment and therefore early engagement is recommended.

Noise

6.7.20 There are two settlements of Dereham and West Winch within the study area for Option 6. There is therefore the potential for this option to affect sensitive receptors during both construction and operation.

6.7.21 During construction, noise effects are likely to be capable of mitigation through standard control measures and Best Practicable Means outlined in a CEMP and consulted upon with the relevant local authority environmental health officer.

6.7.22 It is, however, anticipated that developing appropriate route corridors and adopting sensitive routeing would ensure that operational noise impacts are minimised. This could be through maximising separation distances and building proximity distances where possible between the new OHL and sensitive receptors.

Summary of the socio-economic appraisal

Tourism and Recreation

6.7.23 Option 6 crosses two National Cycle Routes (1 and 13), and two areas of CRoW Open Access Land. Within the 2 km study area there are three major visitor attractions and a further 20 areas of CRoW Open Access Land.

6.7.24 During construction and operation there is the possibility of disruption to National Cycle Routes and CRoW Open Access Land. However, adopting appropriate route corridors together with an assumption that standard construction control measures would be adhered to within a CEMP and/or CTMP would reduce any impacts.

Infrastructure

6.7.25 Option 6 crosses five road networks and three rail networks, and there are five crossings of other National Grid infrastructure (including OHL and gas mains).

6.7.26 During construction there is the potential for disruption to road and rail networks. However, adopting appropriate route corridors which minimise the number of road and rail crossings, and implementing standard control measures outlined in a CEMP and/or CTMP would reduce any impacts on the road and rail networks. Impacts related to crossing other National Grid infrastructure could also be mitigated through appropriate routeing and adopting sensitive construction methods utilising technology types such as undergrounding when crossing other OHLs.

6.7.27 Option 6 crosses two NSIPs: A47-A11 Thickthorn Junction (post-decision stage), and Norwich to Tilbury (pre-application stage). There is the potential for cumulative impacts to occur as a result of concurrent NSIPs however, sensitive routeing that either avoids other NSIPs altogether or adopts careful siting to reduce cumulative impacts would ensure that impacts are minimised.

Summary of the technical appraisal

6.7.28 A technical appraisal has established that a transmission connection between Walpole B and Norwich would satisfy the NETS SQSS at Walpole, whilst providing additional transmission capability to boundary B9 and capability to the Midlands and southern England boundaries.

6.7.29 Technical analysis of the option is as follows:

- Route connects into a new 400 kV substation at Walpole B and terminates at the existing 400 kV Norwich Substation.
- The proposed transmission connection will be configured as a double circuit overhead line (OHL) and will involve the installation of a new AC 400 kV circuit rated at 6,930 MW.
- For the appraisal of onshore options of significant distance, an OHL would normally be expected to offer the most economic, efficient, and co-ordinated development and would meet NGET’s obligations under Section 9 of the Electricity Act.
- Use of OHL is low risk in terms of construction complexity, and standard construction and access techniques can be adopted for this option, as well as operation and maintenance. The same applies for the crossing that would be required for the roads and rail lines involved.
- Technology implemented is well established, relatively straightforward to construct, operate and maintain.
- Option meets the needs of the system requirements to reinforce the B9 boundary. Option does not provide flexibility with regards to power flow from East to West, however it provides a boundary uplift to B9.

6.7.30 It is important to note that there is a National Grid project which relates to Option 6: Walpole B which is a new substation to be built by Grimsby to Walpole and which is also required for LRN#.

Summary of the cost appraisal

6.7.31 As set out in Chapter 5, NGET undertakes a cost evaluation of the following four technologies for onshore options evaluation:

a) 400 kV alternating current (AC) overhead line

b) 400 kV AC underground cable

c) 400 kV AC gas insulated line (GIL)

d) 525 kV high voltage direct current (HVDC) underground cable and converter stations:

6.7.32 Option 6 requires the following transmission works to satisfy the requirements of the SQSS:

- Substation works
  - Utilisation of two bays at new Walpole B 400 kV Substation to accommodate new circuits.
  - Extension to Norwich 400 kV Substation by two bays to accommodate new circuits.
- New circuit requirements
  - AC connections options use high-capacity double circuits (two 400 kV AC circuits) with a total capacity of up to 6,930 MW; or,
  - HVDC using 525 kV 2,000 MW voltage source links, which would require a convertor station at each end similar in size to a large warehouse. A 6,000 MW connection would require three convertor stations at each end, six overall, this is to come close to matching the AC high-capacity circuits of 6,930 MW.

6.7.33 Table 6.11 sets out the capital costs for Option 6 considering substation works and each technology option.

Table 6.11 – Capital cost for Option 6

Item	Capital Cost			
Substation and Wider Works	£36.0m			
New Circuits	**AC OHL**	**AC Cable**	**AC GIL**	**HVDC**
New Circuit	£358.2m	£3,873.6m	£3,893.4m	£3,239.0m
Total Capital Cost	**£394.2m**	**£3,909.6m**	**£3,929.4m**	**£3,275.0m**

6.7.34 Table 6.12 sets out the lifetime cost for the new circuit technology options, the lifetime 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" found in Appendix E.

Table 6.12 – Lifetime cost by technology option

Land Based Option	AC OHL	AC Cable	AC GIL	HVDC
Capital Cost of new Circuits	£358.2m	£3,873.6m	£3,893.4m	£3,239.0m
NPV of Cost of Losses over 40 years	£252.5m	£188.4m	£117.2m	£706.9m
NPV of Operation & Maintenance costs over 40 years	£5.3m	£18.2m	£5.3m	£257.8m
Lifetime Cost of new Circuits	**£616m**	**£4,080m**	**£4,016m**	**£4,204m**

6.7.35 Based on the data in the above tables, the following conclusions can be drawn:

- AC OHL has the lowest capital cost of new circuits.
- AC OHL has a reasonable NPV of Cost of Losses over a forty-year projection.
- AC OHL has the lowest NPV of Operation and Maintenance Costs over a forty-year projection.
- AC OHL has the lowest lifetime cost of new circuits.

Summary of the strategic option

6.7.36 From the environmental and technical appraisal considered, alongside capital and circuit lifetime costs, the preferred technology option for Option 6 is a 90 km connection, configured as an AC circuit, between a new Walpole B Substation and an existing Norwich Substation. In light of this analysis, NGET's starting presumption for further development of this option should it be selected, would be for a majority overhead line connection.

6.8 Comparison of the appraisal of the strategic options

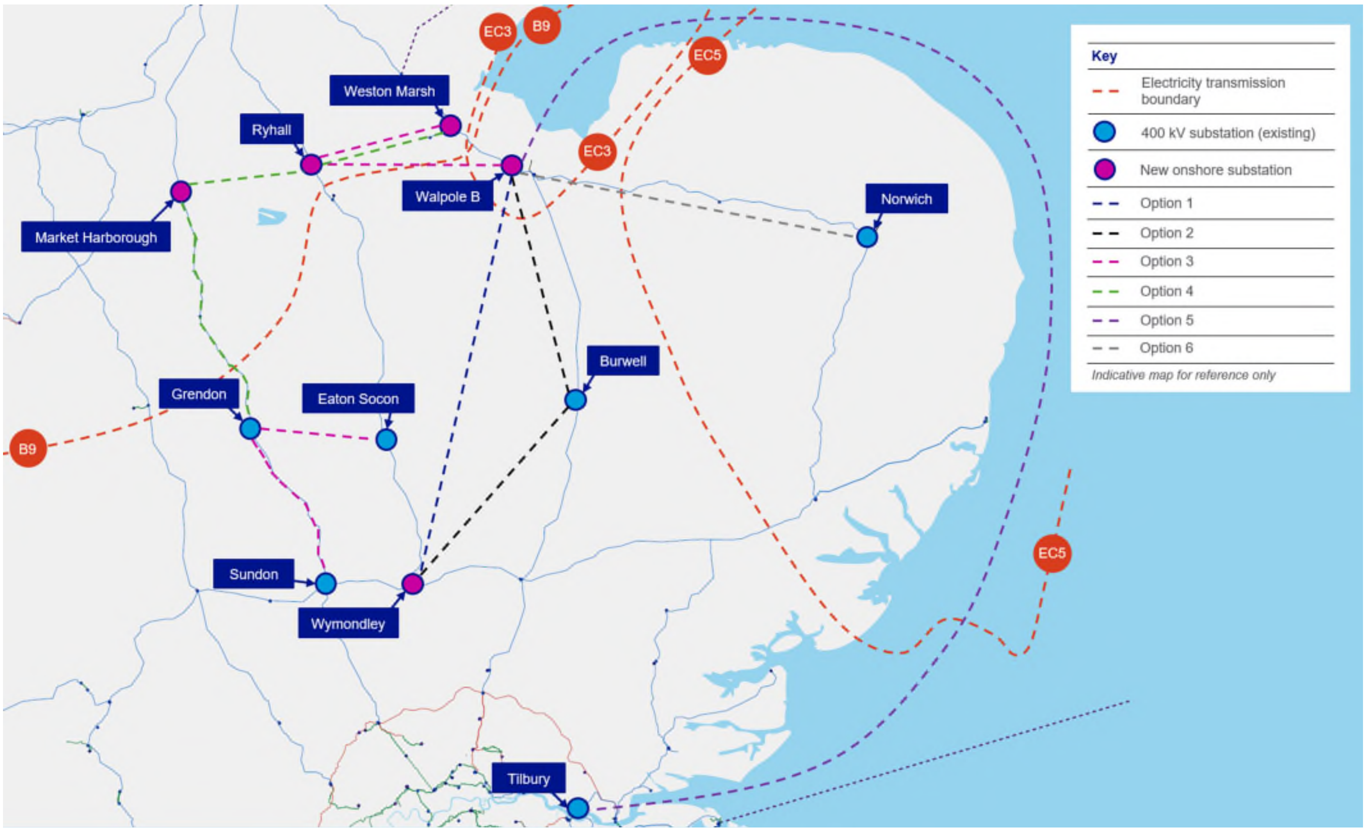
Overview

6.8.1 For the strategic options appraised in section 6.2, this subsequent review considers the following comparative points:

- Technical benefit and associated technical considerations
- Capital and lifetime costs of options
- Environmental and socio-economic constraints

6.8.2 Figure 6.7 shows the indicative location overview of all strategic options.

Figure 6.7 – Indicative overview of all strategic options



Environmental considerations

Ecology

6.8.3 Options 1, 2 and 5 cross several areas designated as a Special Area of Conservation (SAC), Special Protection Area (SPA), Site of Special Scientific Interest (SSSI), Ramsar and RSPB Important Bird Area, and Ancient Woodlands.

6.8.4 Option 1 may also affect a native tree due to land take during construction and there is NNR within 2 km study area for Option 2.

6.8.5 For Option 3, 4 and 6, there are no SPAs, Ramsar sites, RSPB Important Bird Areas or NNRs within the 2 km study area. However, Option 3 crosses one SAC, Option 4 crosses three areas of Ancient Woodland, Option 3 and 6 both cross one SSSI, and all three have several Ancient Woodland and SSSIs within their 2 km study areas. Furthermore, Option 3 and 6 have Veteran Trees within their 2 km study areas and Option 4 has one SAC within the 2 km study area.

6.8.6 All options could affect designations within the 2 km study area through pollution of land and water, and general disturbance as a result of construction works. This is dependent upon the alignment of the final OHL and construction methodologies.

Landscape and Visual

6.8.7 There are no National Parks, National Landscapes, World Heritage Sites or Biospheres that are located within the 2 km study area for all options.

6.8.8 Option 4 crosses one settlement, Option 1 and 6 cross two settlements, Option 2 crosses three settlements, Option 3 crosses four settlements, Option 5 crosses one

National Trail and 30 settlements. There is therefore the potential for all options to affect local visual receptors to settlements during construction and operation.

6.8.9 Developing appropriate route corridors and undertaking sensitive routeing would ensure that the settlements are either avoided, or that impacts on sensitive visual receptors are reduced. It should be noted that there would however be a permanent above-ground OHL which is likely to result in adverse impacts on the settlements. Further detailed assessment would need to be undertaken to understand the impacts on local visual receptors.

Historic Environment

6.8.10 Option 1 crosses one Scheduled Monument for approximately 0.12 km and one Registered Park and Garden for approximately 0.17 km. Option 2 crosses three Scheduled Monuments totalling 0.14 km. Option 4 crosses one Registered Park and Garden for approximately 2.53 km. Option 5 crosses six Scheduled Monuments totalling at 0.53 km, one Listed Building, and one Registered Park and Garden for approximately 1.07 km. Option 6 crosses one Scheduled Monument for less than 100 m.

6.8.11 Option 3 is the only option that does not cross any designated heritage assets.

6.8.12 However, Options 3, 5 and 6, have several Registered Parks and Gardens and Options 3, 4, 5 and 6, also have several Scheduled Monuments and Grade I and II* Listed Buildings within their 2 km study areas.

Water, Geology and Soils

6.8.13 All options have large areas of Flood Zones 2 and 3 within their study areas, however, Options 1 and 2 will have significant amount of development within floodplains.

6.8.14 Options 1, 2 and 3 have Areas Benefitting from Flood Defences in their study areas.

6.8.15 Options 1, 3 and 4 cross several rivers/watercourses and Options 1 and 2, 5 and 6 also cross areas of flood storage.

6.8.16 Options 3 has a single geological SSSI within its study area, Option 2 has two geological SSSIs, and options 5 and 6 have eight and five geological SSSIs, respectively.

6.8.17 Options 5 and 6 also have areas of Reduction in Risk of Flooding from Rivers and Seas in their study areas.

Noise

6.8.18 Option 4 crosses one settlement, Options 1 and 6 cross two settlements, Option 2 crosses three settlements, Option 3 crosses four settlements, however, Option 5 crosses 30 settlements.

Socio-economic considerations

Tourism and Recreation

6.8.19 Option 1 crosses two National Cycle Routes and one area of Countryside and Rights of Way (CRoW) Open Access Land. Within the 2 km study area there are a further 16 areas of CRoW Open Access Land and one major visitor attraction.

6.8.20 Option 2 crosses four National Cycle Routes, two areas of CRoW Open Access Land, and one Inalienable Land for approximately 0.32 km. Within the 2 km study area there are a further 62 areas of CRoW Open Access Land.

6.8.21 Option 3 crosses one National Cycle Route and one major visitor attraction. Within the 2 km study area of Option 3 there are a further two major visitor attractions, and four areas of CRoW Open Access Land.

6.8.22 Option 4 crosses three areas of CRoW Open Access Land. Within the 2 km study area there are a further two areas of CRoW Open Access Land and one major visitor attraction.

6.8.23 Option 5 crosses three major visitor attractions, three National Cycle Routes, and two areas of CRoW Open Access Land. Within the 2 km study area there are a further three major visitor attractions and twenty areas of CRoW Open Access Land.

6.8.24 Option 6 crosses two National Cycle Routes, and two areas of CRoW Open Access Land. Within the 2 km study area there are three major visitor attractions and a further twenty areas of CRoW Open Access Land.

Infrastructure

6.8.25 Option 1 crosses 19 road networks and three rail lines, and there are eight crossings of other National Grid infrastructure. Within the study area there are six passenger airports/ILS licensed aerodromes, and one other NSIP (East West Rail - Bedford to Cambridge and Western Improvements, which is at the pre-application stage).

6.8.26 Option 2 crosses fourteen road networks and six rail networks, and there are nine crossings of other National Grid infrastructure. Cottered Airstrip is located within the 2 km study area.

6.8.27 The Weston Marsh route of option 3 crosses five road networks and three rail networks, there are ten crossings of other National Grid infrastructure, and a hospital. There is also one airstrip within the 2 km study area.

6.8.28 The Walpole B route of Option 3 crosses four road networks and two rail networks, and there are four crossings of other National Grid infrastructure. There are also two passenger airfields within the 2 km study area.

6.8.29 The Eaton Socon – Grendon route of Option 3 crosses two road networks and one rail network, and there are five crossings of other National Grid infrastructure. There is also one aerodrome within the 2 km study area.

6.8.30 Option 4 crosses six road networks and three rail networks, and there are four crossings of other National Grid infrastructure. There is one military site and one airstrip within the 2 km study area.

6.8.31 Option 5 crosses seven road networks and six rail networks, and there are nine crossings of other National Grid infrastructure. Furthermore, this option also crosses a military training facility and two NSIPs.

6.8.32 Option 6 crosses five road networks and three rail networks, and there are five crossings of other National Grid infrastructure. Furthermore, this option also crosses two NSIPs.

6.8.33 It is important to also consider that these options have substations that are related to other National Grid projects.

6.8.34 Options 5 and 6 involve the construction of bays at the new Walpole B Substation which, as previously, is to be constructed by Grimsby to Walpole.

6.8.35 Option 1 and 2 involve the construction of a new substation at Wymondley plus bays at the new Walpole B Substation.

6.8.36 Option 3 involves the construction of a new substation at Ryhall, as well as substation extensions at both Eaton Socon and Grendon plus bays at either the new Weston Marsh or Walpole B substations.

6.8.37 Option 4 involves the construction of a new substation at both Ryhall and Eaton Socon, as well as bays at both new Weston Marsh and Grendon substations.

Technical considerations

6.8.38 From the six potential options considered, five of them implement onshore technologies in the form of new OHL and reconductoring of existing lines, whereas one option employs an offshore solution in the form of a High Voltage Direct Current (HVDC) system comprising both onshore cable and offshore subsea cable plus onshore converter stations at each end. There is generally extensive experience with regards to the operation of overhead lines (OHL) and underground (UG) cables, but limited experience of Gas Insulated Lines (GIL), onshore HVDC systems and 400 kV AC subsea cable for the connection distances considered. There is however more operational experience of offshore HVDC systems.

6.8.39 From the six options considered; all options satisfy the critical requirement for being compliant with NGET SQSS.

6.8.40 Each option has been assessed as to whether it can meet the identified boundary reinforcement requirement and additional inherent system benefits.

6.8.41 All options provide a B9 boundary uplift, with minimal differential between them.

6.8.42 In terms of power flow, Option 4 (Weston Marsh to new Market Harborough, via new Ryhall) supplies the greatest system flexibility compared to the rest of the options, due to the proposal to implement two circuits out of new Weston Marsh and new Ryhall and mitigates the overloading of the Ryhall-Eaton Socon circuit under fault conditions and is therefore, the most beneficial option in terms of power flow flexibility.

6.8.43 Considering existing and proposed new infrastructure that would be required for these options, Option 2 (Walpole B to new Wymondley, via Burwell) is characterised by an increased OHL build (largest compared to the other onshore options) due to the longer distances needed to be covered (120 km). The option also requires two new substations, one at Wymondley and one at Burwell to facilitate this connection. Option 4 also requires two new substations at Ryhall and Market Harborough, however, less OHL is needed at only 60 km, compared to the 120 km needed for Option 2.

6.8.44 Expanding on the need of substation infrastructure, Option 2 and Option 4 require the most substation-related construction with two new substations, as mentioned, as well as two new bays at new Walpole B (for Option 2) or new Weston Marsh (for Option 4). Increased infrastructure works lead to higher capital costs and increased constructability risks for the Project.

6.8.45 To summarise the technical comparison of the options, the technologies implemented are all adequately established and do not add any uncertainty or risk when implementing them onto the Project (both for OHL, UG (Underground) cables and

HVDC subsea cables). Another pertinent technical point for comparison is power flow flexibility, for which Option 4 provides the greatest east-west power flow flexibility. Considering infrastructure and OHL/cable installation works, all options require substation works, with Option 5 having the highest capital cost, due to the option being offshore. Offshore construction would also raise more constructability risks when compared with the onshore options.

6.8.46 The technical appraisal comparison has added substantial weight in favour of Options 1, 3 and 4. More specifically, Option 1 offers the second lowest capital cost due to a decreased OHL build compared to some of the other options. Options 3 and 4 require the lowest amount of OHL, as 60 km of new OHL are needed. Additionally, both Options require lines to be reconductored, Option 3 requiring 40 km and Option 4 requiring 55 km. Option 4 is also characterised by greater power flow flexibility across east-west and whilst providing uplift to the B9 boundary.

Cost considerations

6.8.47 Table 6.13 sets out an overview of the capital and lifetime cost impacts of each strategic option. This table provides a comparison of strategic options based on the most economical technology choice for each option (i.e., AC OHL for onshore options, HVDC for the offshore option).

Table 6.13 – Capital and lifetime cost impact

Options	Onshore Options					Offshore Option
	1. Walpole B to new Wymondley	2. Walpole B to new Wymondley via Burwell	3. Weston Marsh/Walpole B to new Ryhall & Eaton Socon to Grendon	4. Weston Marsh to new Market Harborough, via new Ryhall	6. Walpole B to Norwich	5. Walpole B to Tilbury (subsea)
Technology Capacity Distance	Overhead line 6,930 MW 100 km	Overhead line 6,930 MW 120 km	Overhead line 6,930 MW 60 km	Overhead line 6,930 MW 60 km	Overhead line 6,930 MW 90 km	HVDC Subsea 6,000 MW 360 km
Total capital cost including non-circuit works	£570.0m	£805.6m	£635.8m	£597.8m	£394.2m	£4,972.3m
New Circuits Only 40-year lifetime NPV cost	£684.0m	£821.0m	£411.0m	£411.0m	£616.0m	£5,586.0m

6.8.48 All of the options considered in the table above meet the technical appraisal requirements of the need case and are compliant with the NETS SQSS.

6.8.49 Option 6, Walpole B to Norwich, has the lowest capital cost at £394.2m and the second lowest lifetime cost at £616.0m. This option is not capable of providing east to west power flow. When assessing this option from a cost perspective, the low capital cost is beneficial, however the inability to provide east to west power flow is a notable disadvantage when considering the potential selection of this option.

6.8.50 Option 2, Walpole B to new Wymondley via Burwell, has the highest capital cost of all onshore options at £805.6m (the second highest overall) and the highest lifetime cost of all onshore options at £821.0m (the second highest overall). Despite this option having the highest capital and lifetime costs of the onshore options, it does not provide any significant benefit to justify these costs above the other strategic options. Therefore, potential selection of this strategic option from a cost perspective is not feasible.

6.8.51 Option 5, Walpole B to Tilbury (subsea) has the highest capital cost of all options at £4,972.3m and the highest lifetime cost of all options at £5,586.0m. The high capital and lifetime costs associated with Option 5 are not justified with any significant benefits. Therefore, potential selection of this offshore option from a cost perspective is not feasible.

6.8.52 Option 1, Walpole B to new Wymondley, has the second lowest capital cost at £570.0m but the third highest lifetime cost at £648.0m. Option 1 does not cross B9, however it provides an increase in capability but does not provide future capacity. Option 1 also provides less flexibility as all benefit provided by this option is lost under fault conditions. Moreover, east to west power flow is only provided by this option when the circuit reaches new Wymondley and links to the North London Busbar. Therefore, given the relatively low capital cost (relative to the other options) as well as the technical benefits provided by this option, potential selection of this option from a cost perspective is feasible.

6.8.53 Option 3 (Weston Marsh/Walpole B to new Ryhall and Eaton Socon to Grendon) and Option 4 (Weston Marsh to new Market Harborough, via new Ryhall) are identical from a lifetime cost perspective, however Option 4 has a lower capital cost at £597.8m where Option 3 has a capital cost of £635.8m. Both options would cross boundary B9 (if Weston Marsh is chosen for Option 3) and therefore add capacity as well as capability to the boundary. Both options also provide a significant flexibility as components of this solution remain operational under fault conditions providing further system benefit. Moreover, east to west power flow is facilitated further north on the network than the North London busbar, providing support under more scenarios. Finally, both options provide flexibility to extend the east to west power flows in the future by going further west from Grendon in the future if ever required. Therefore, given that both options present the lowest lifetime cost and significant technical benefit, potential selection of either option from a cost perspective is highly feasible. The selection of the final option is still subject to technical, environmental and socio-economic considerations.

6.9 Summary of the strategic options appraisal

Table 6.14 – Overview of strategic options assessment

	Considerations / Appraisals			
Option	Environmental	Socio-economic	Technical	Cost
1. Walpole B to new Wymondley	It is expected that potential environmental impacts can largely be avoided or mitigated and are capable of resolution – particularly for the landscape and visual topic. However, more detailed assessments are required for potential impacts on the specified ecological sites as it is not known if the designations can be avoided. In addition, this option crosses large swathes of unavoidable Flood Zone 2 and 3 and an area of Flood Storage. Although impacts are predicted to be capable of resolution, detailed assessment would be required, a Flood Risk Assessment prepared, and several consents obtained from the Environment Agency. Impacts on the historic environment cannot be ruled out owing to this option crossing one Scheduled Monument and one Registered Park and Garden.	This option crosses a number of A roads, three major rail links, two National Cycle Routes, one area of Countryside and Rights of Way (CRoW) Open Access Land and National Grid infrastructure. Additionally, within the 2 km study area there is one major visitor attraction, 16 areas of CRoW Open Access Land, six airports/aerodromes and major utilities/installations. There is one NSIP within 5 km of this option but there are no National Trust Inalienable Land or military assets within 2 km. However, the potential impact on the specified infrastructure is thought to be capable of resolution.	This option meets the needs of the system requirements to reinforce the B9 boundary. Route connects into two new 400 kV substations, starting at Walpole B and terminating at new Wymondley. Option to be configured as an AC double circuit overhead lines (OHL) with a new AC 400 kV circuit rated at 6,930 MW. Technology implemented is well established and straightforward to construct, operate and maintain.	Cost appraisal undertaken for four technologies for this option: AC OHL, AC Cable, AC Gas Insulated Lines (GIL)and High Voltage Direct Current (HVDC). Option 1 requires the construction of a new Wymondley 400 kV Substation able to accommodate 12 bays and utilisation of two bays at new Walpole B 400 kV Substation to accommodate new circuits. Option 1 requires the construction of a new AC high-capacity double circuit connection (two 400 kV AC circuits) with a total capacity of up to 6,930 MW. Alternatively, a HVDC connection rated at 6,000 MW with three converters stations at each end, six overall, utilising 525 kV 2,000 MW voltage source links could be constructed if deemed the most cost-effective solution. The capital cost of substation and wider works for this option is £172.0m. The capital cost for the most economical circuit technology choice for this

Considerations / Appraisals				
Option	Environmental	Socio-economic	Technical	Cost
				option, AC OHL, is £398.0m. Thus, the total capital cost of the most economical solution for this option is £570.0m. The Net Present Value (NPV) of Cost of Losses over 40 years for this option (AC OHL) is £280.5m. Furthermore, the NPV of Operation & Maintenance costs over 40 years for this option (AC OHL) is £5.8m. Therefore, the lifetime cost of a new AC OHL circuit for this option is £684m, which includes the capital cost of £398.0m.
2. Walpole B to new Wymondley (via Burwell)	It is expected that potential environmental impacts can largely be avoided or mitigated and are capable of resolution – particularly for the landscape and visual topic. However, more detailed assessments are required for potential impacts on the specified ecological sites as it is not known if the designations can be avoided. In addition, the strategic option crosses large swathes of unavoidable Flood Zone 2 and 3 and an area of Flood Storage. Although impacts are predicted to be capable of resolution detailed assessment would be required, a Flood Risk Assessment prepared, and several consents obtained from the Environment Agency.	This option crosses several A roads, two motorways, six major rail links, National Grid infrastructure, National Trust Land, four National Cycle Routes and two areas of Countryside Right of Way (CRoW) Open Access Land. Additionally, within the 2 km study area is Cottered Airstrip and a further 62 areas of CRoW Open Access Land. There are no major visitor attractions or further National Trust Inalienable Land within 2 km of this Option, and there are no NSIPs within 5 km. However, the potential impact on the specified infrastructure is thought to be capable of resolution.	This option meets the needs of the system requirements to reinforce the B9 boundary. Route connects into two new 400 kV substations, starting at Walpole B and terminating at new Wymondley, routing through a new 400 kV substation at Burwell. Option to be configured as an AC double circuit OHL with a new AC 400 kV circuit rated at 6,930 MW. Technology implemented is well established and straightforward to construct, operate and maintain.	Cost appraisal undertaken for four technologies for this option: AC OHL, AC Cable, AC GIL and HVDC. Option 2 requires the construction of a new Wymondley 400 kV Substation able to accommodate 12 bays and utilisation of two bays at new Walpole B 400 kV Substation to accommodate new circuits. Furthermore, this option requires the construction of a new Burwell 400 kV Substation able to accommodate 12 bays. Option 2 requires the construction of a new AC high-capacity double circuit connection (two 400 kV AC circuits) with a total capacity of up to 6,930 MW. Alternatively, a HVDC

Considerations / Appraisals				
Option	**Environmental**	**Socio-economic**	**Technical**	**Cost**
	Impacts on the historic environment cannot be ruled out owing to this option's crossing of three Scheduled Monuments.			connection rated at 6,000 MW with three converters stations at each end, six overall, utilising 525 kV 2,000 MW voltage source links could be constructed if deemed the most cost-effective solution. The capital cost of substation and wider works for this option is £328.0m. The capital cost for the most economical circuit technology choice for this option, AC OHL, is £477.6m. Thus, the total capital cost of the most economical solution for this option is £805.6m. The NPV of Cost of Losses over 40 years for this option (AC OHL) is £333.6m. Furthermore, the NPV of Operation & Maintenance costs over 40 years for this option (AC OHL) is £7.0m. Therefore, the lifetime cost of a new AC OHL circuit for this option is £821m which includes the capital cost of £477.6m.
3. Weston Marsh/Walpole B to new Ryhall and Eaton Socon to Grendon	It is expected that potential environmental impacts can largely be avoided or mitigated and are capable of resolution – particularly for the landscape and visual and historic environment topics. However, more detailed assessments are required for potential impacts on the specified ecological sites as it is not known if the designations can be avoided.	Western Marsh option – This option crosses several A roads, two major rail links and National Grid Infrastructure. Additionally, within the 2 km study area is Northorpe Fen Airstrip, but there is no National Trust Inalienable Land, Countryside Right of Way Open Access Land or military assets. There is one NSIP within 5 km of this option.	This option meets the needs of the system requirements to reinforce the B9 boundary. Option also employs greater power flow flexibility by supplying an additional route to allow power coming into the East Coast of England to cross over to the west and flow south to demand. Route connects into a new 400 kV substation starting at Weston Marsh/Walpole B and	Cost appraisal undertaken for four technologies for this option: AC OHL, AC Cable, AC GIL and HVDC. Option 3 requires the construction of a new Eaton Socon 400 kV Substation able to accommodate 12 bays and utilisation of two bays at new Walpole B/new Weston Marsh 400 kV Substation to accommodate new circuits. Furthermore, this option

Considerations / Appraisals				
Option	Environmental	Socio-economic	Technical	Cost
	In addition, the strategic option crosses swathes of unavoidable Flood Zone 2 and 3. Although impacts are predicted to be capable of resolution, detailed assessment would be required, a Flood Risk Assessment prepared, and several consents obtained from the Environment Agency. Impacts on the historic environment cannot be ruled out owing to the potential impact to a Scheduled Monument, Listed Buildings and Registered Park and Gardens.	As the alignment of the overhead line (OHL) is not yet known, it is assumed impacts would require further assessment. However, the potential impact on the specified infrastructure is thought to be capable of resolution. Walpole B Option – This option crosses several A roads, two major rail links, a National Cycle Route and National Grid infrastructure. Additionally, within the 2 km study area are two Passenger airfields (Crowland airstrip and Fenland Airfield). There are no Major Visitor Attractions, National Trust Inalienable Land, Countryside Right of Way (CroW) Open Access Land or military assets along this Option nor within 2 km, but there is one NSIP within 5 km. As the alignment of the overhead line (OHL) is not yet known, it is assumed impacts would require further assessment. However, the potential impact on the specified infrastructure is thought to be capable of resolution.	terminating at a new 400 kV substation at Ryhall. Option to be configured as double circuit OHL with two new AC 400 kV circuits to be installed with a collective length of 60 km and rating of 6,930 MW. A reconductoring of 40 km of existing OHL would also take place. Technology implemented is well established and straightforward to construct, operate and maintain.	requires the construction of a new Ryhall 400 kV Substation able to accommodate 12 bays as well as an extension to Grendon 400 kV Substation by 2 bays to accommodate new circuits. Option 3 requires the construction of a new AC high-capacity double circuit connection (two 400 kV AC circuits) with a total capacity of up to 6,930 MW. Alternatively, a HVDC connection rated at 6,000 MW with three converters stations at each end, six overall, utilising 525 kV 2,000 MW voltage source links could be constructed if deemed the most cost-effective solution. The capital cost of substation and wider works for this option is £397.0m. The capital cost for the most economical circuit technology choice for this option, AC OHL, is £238.8m. Thus, the total capital cost of the most economical solution for this option is £635.8m. The NPV of Cost of Losses over 40 years for this option (AC OHL) is £168.3m. Furthermore, the NPV of Operation & Maintenance costs over 40 years for this option (AC OHL) is £3.5m. Therefore, the lifetime cost of a new AC OHL circuit for this option is

Considerations / Appraisals				
Option	Environmental	Socio-economic	Technical	Cost
				£411m which includes the capital cost of £238.8m.
4. Weston Marsh to new Market Harborough (via new Ryhall)	It is expected that potential environmental impacts can largely be avoided or mitigated and are capable of resolution – particularly for the landscape and visual and historic environment topics. However, more detailed assessments are required for potential impacts on the specified ecological sites as it is not known if the designations can be avoided. In addition, the strategic option crosses swathes of unavoidable Flood Zone 2 and 3. Although impacts are predicted to be capable of resolution, detailed assessment would be required, a Flood Risk Assessment prepared, and several consents obtained from the Environment Agency. Impacts on the historic environment cannot be ruled out owing to the potential impact to a Scheduled Monument, Listed Buildings and Registered Park and Gardens.	This option crosses several A roads, two major rail links and National Grid infrastructure. Additionally, within the 2 km study area is Northorpe Fen Airstrip, but there is no National Trust Inalienable Land, Countryside Right of Way Open Access Land or military assets..There is one NSIP within 5 km of this Option. As the alignment of the overhead line (OHL) is not yet known, it is assumed impacts would require further assessment. However, the potential impact on the specified infrastructure is thought to be capable of resolution.	This option meets the needs of the system requirements to reinforce the B9 boundary. Option also employs greater power flow flexibility by supplying an additional route to allow power coming into the East Coast of England to cross over to the West and flow South to demand. Route connects into a new 400 kV substation starting at Weston Marsh and terminating at a new 400 kV substation at Market Harborough via new Ryhall. Option to be configured as double circuit OHL with two new AC 400 kV circuits to be installed with a collective length of 60 km and rating of 6,930 MW. A reconductoring of 40 km of existing OHL would also take place. Technology implemented is well established and straightforward to construct, operate and maintain.	Cost appraisal undertaken for four technologies for this option: AC OHL, AC Cable, AC GIL and HVDC. Option 4 requires the construction of a new Market Harborough 400 kV Substation able to accommodate 12 bays and utilisation of 2 new bays at Weston Marsh 400 kV Substation. Furthermore, this option requires the construction of a new Ryhall 400 kV Substation able to accommodate 12 bays. Option 4 requires the construction of a new AC high-capacity double circuit connection (two 400 kV AC circuits) with a total capacity of up to 6,930 MW. Alternatively, a HVDC connection rated at 6,000 MW with three converters stations at each end, six overall, utilising 525 kV 2,000 MW voltage source links could be constructed if deemed the most cost-effective solution. The capital cost of substation and wider works for this option is £359.0m. The capital cost for the most economical circuit technology choice for this option, AC OHL, is £238.8m. Thus, the total capital cost of

Considerations / Appraisals				
Option	Environmental	Socio-economic	Technical	Cost
				the most economical solution for this option is £597.8m. The MPV of Cost of Losses over 40 years for this option (AC OHL) is £168.3m. Furthermore, the NPV of Operation & Maintenance costs over 40 years for this option (AC OHL) is £3.5m. Therefore, the lifetime cost of the new AC OHL circuit for this option is £411m which includes the capital cost of £238.8m.
5. Walpole B to Tilbury (subsea)	Impacts are anticipated to various SACs, SPAs, Ramsars, RSPB Important Bird Areas and SSSIs. Due to the extent of these designations along this Option and the fact that some of these are anticipated to be unavoidable, adverse impacts after mitigation are predicted. Undertaking sensitive routeing and adopting appropriate route corridors is required to avoid / reduce the potential environmental impacts from this option, particularly for the landscape and visual topic where effects are predicted on numerous settlements. Impacts on designated ecological sites would require more detailed assessment and consultation with Natural England as some designations may be unavoidable. Engagement with Historic England would also be required	This option crosses three Major Visitor Attractions, National Trust Limited Access Land, several A roads, six major rail links, three National Cycle Routes, one military area, three areas of Countryside and Rights of Way (CRoW) Open Access Land, National Grid Infrastructure and two Nationally Significant Infrastructure Projects. Additionally, within the 2 km study area there are a further three major visitor attractions, and 14 additional NSIPs within 5 km. There are no areas of National Trust land or airports/aerodromes within 2 km of this option. It is assumed that Major Attractions, National Trust Limited Access Land, roads, rail, National Cycle Routes, Military areas, CRoW Open Land, existing National Grid infrastructure, NSIPs and other	This option meets the needs of the system requirements to reinforce the B9 boundary. Route connects into a new 400 kV substation starting at Walpole B and terminating at the existing 400 kV Tilbury substation, after routing through the existing 400 kV Norwich substation. Option to be configured as a 360 km HVDC subsea connection. Technology implemented for this option is well known, however constructability risk is increased, and maintenance is more challenging compared to onshore options.	Cost appraisal undertaken for 2 technologies for this offshore option: AC subsea cable and HVDC subsea cable. Option 5 requires the utilisation of two bays at new Walpole B 400 kV Substation to accommodate new circuits as well as an extension to Tilbury 400 kV Substation by 2 bays to accommodate new circuits. Option 5 requires the construction of a new AC high-capacity double circuit subsea connection (two 400 kV AC circuits) with a total capacity of up to 6,930 MW. Alternatively, a HVDC connection rated at 6,000 MW with three converters stations at each end, six overall, utilising 525 kV 2,000 MW voltage source links could be constructed if deemed the most cost-effective solution.

Considerations / Appraisals				
Option	Environmental	Socio-economic	Technical	Cost
	if Scheduled Monuments are unavoidable. In addition, this option crosses large swathes of unavoidable Flood Zone 2 and 3, several watercourses and a Flood Storage Area. Although impacts are predicted to be capable of resolution, detailed assessments would be required, a Flood Risk Assessment prepared, and a number of consents / permits obtained from the Environment Agency.	National Grid projects could be avoided through appropriate route corridors, sensitive routeing and careful planning/siting. However, there may be residual impacts to setting and to operations of the Military facility. As the alignment of the OHL is not yet known it is assumed impacts would require further assessment.		The capital cost of substation and wider works for this option is £32.0m. The capital cost for the most economical circuit technology choice for this option, Subsea HVDC, is £4,940.3m. Thus, the total capital cost of the most economical solution for this option is £4,972.3m. The NPV of Cost of Losses over 40 years for this option (HVDC) is £471.2m. Furthermore, the NPV of Operation & Maintenance costs over 40 years for this option (AC OHL) is £174.5m. Therefore, the lifetime cost of a new AC OHL circuit for this option is £5,586m, which includes the capital cost of £4,940.3m.
6. Walpole B to Norwich	Impacts are anticipated to various SACs, SPAs, Ramsars, RSPB Important Bird Areas and SSSIs. Due to the extent of these designations along this option and the fact that some of these are anticipated to be unavoidable, adverse impacts after mitigation are predicted. Undertaking sensitive routeing and adopting appropriate route corridors is required to avoid / reduce the potential environmental impacts from this option particularly for the landscape and visual topic where only effects are predicted on numerous settlements.	This option crosses a number of A roads, three major rail links, two National Cycle Routes, two areas of Countryside and Rights of Way (CRoW) Open Access Land, National Grid Infrastructure and two Nationally Significant Infrastructure Projects. There are four additional NSIPs within 5 km of this option, but there are no areas of National Trust land, Military facilities, or airports/aerodromes within 2 km. It is assumed that National Trust Limited Access Land could be avoided through appropriate route corridors and	This option meets the needs of the system requirements to reinforce the B9 boundary, however it does not provide power flow flexibility from east to west. Route connects into a new 400 kV substation at Walpole B and terminates at the existing 400 kV Norwich substation. Option to be configured as a double circuit OHL with a new AC 400 kV circuit rated at 6,930 MW. Technology implemented is well established and straightforward to construct, operate and maintain.	Cost appraisal undertaken for 4 technologies for this option: AC OHL, AC Cable, AC GIL and HVDC. Option 6 requires the utilisation of two bays at new Walpole B 400 kV Substation to accommodate new circuits as well as an extension to Norwich 400 kV Substation by 2 bays to accommodate new circuits. Option 6 requires the construction of a new AC high-capacity double circuit connection (two 400 kV AC circuits) with a total capacity of up to 6,930 MW. Alternatively, a HVDC

Considerations / Appraisals				
Option	Environmental	Socio-economic	Technical	Cost
	Impacts on designated ecological sites would require more detailed assessment and consultation with Natural England as some designations may be unavoidable. Engagement with Historic England would also be required if Scheduled Monuments are unavoidable. In addition, the strategic option crosses large swathes of unavoidable Flood Zone 2 and 3, a number of watercourses and a Flood Storage Area- although impacts are predicted to be capable of resolution detailed assessment would be required, a Flood Risk Assessment prepared, and a number of consents / permits obtained from the Environment Agency.	sensitive routeing. However, there may be residual impacts to setting. As the alignment of the overhead line (OHL) is not yet known it is assumed impacts would require further assessment. However, the potential impact on the specified infrastructure is thought to be capable of resolution.		connection rated at 6,000 MW with three converters stations at each end, six overall, utilising 525 kV 2,000 MW voltage source links could be constructed if deemed the most cost-effective solution. The capital cost of substation and wider works for this option is £36.0m. The capital cost for the most economical circuit technology choice for this option, AC OHL, is £358.2m. Thus, the total capital cost of the most economical solution for this option is £394.2m. The NPV of Cost of Losses over 40 years for this option (AC OHL) is £252.5m. Furthermore, the NPV of Operation & Maintenance costs over 40 years for this option (AC OHL) is £5.3m. Therefore, the lifetime cost of a new AC OHL circuit for this option is £616m, which includes the capital cost of £358.2m.

7. Conclusions and next steps

7.1 Overview of identifying the strategic options

7.1.1 This SOR presents the findings of NGET's options appraisal process and is intended to provide a clear justification and evidence for NGET's decision making of a preferred strategic option. This report demonstrates that NGET have used the need case to consider the ways in which the Project could be delivered by generating a number of potential strategic options. Technical feasibility considerations have been applied to make sure that all of the potential strategic options considered would work on the network, rejecting any that would not meet technical standards or would not work in practice. The number of options was then reduced to the proposed strategic options list by applying the benefits filter to make sure that the proposed strategic options taken forward for detailed appraisal have some benefit over other similar options. The report concludes with the identification of a preferred strategic option, which will be taken forward for consideration of an emerging preferred corridor and the selection of a preliminary route.

7.1.2 This Strategic Options Report (SOR) will be available for the purpose of the non-statutory consultation, drawn upon when engaging with stakeholders and submitted with the Development Consent Order (DCO) application.

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

7.1.4 This SOR has considered options to meet the need case set out in Chapter 4. A requirement has been identified for transmission circuit reinforcements that contribute to National Electricity Transmission System (NETS) Security and Quality of Supply Standard (SQSS) compliance.

7.1.5 NGET has considered the information which is available at this stage of the process and have outlined how data has been gathered and evaluated for each option. In addition, NGET has also considered its duties under the Electricity Act 1989 to develop efficient, co-ordinated and economical solutions, their 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 and emerging National Policy Statements, with particular alignment with policies EN-5 and EN-1, regarding the development of LRN#.

7.1.6 Other ongoing NGET projects within the area of Humber and East Coast regions have also been considered as part of the LRN# need case. There are several projects that interact with LRN# within the project area namely:

a) North Humber to High Marnham

b) Grimsby to Walpole

c) Eastern Green Link 3 and 4 (EGL3 and EGL4)

d) Bramford to Twinstead

e) Norwich to Tilbury

f) Sea Link

7.1.7 EGL3, EGL4 and Grimsby to Walpole are anticipated to have the greatest interaction with LRN# due to their geographic locations.

7.1.8 LRN# has to comply with the aforementioned projects, as part of the need case presented in Chapter 4. All the above projects have information published on their respective project websites.

7.2 The case for the selection of the strategic option

7.2.1 Taking all of this into account, to meet the need to uplift boundaries B9 and EC3 and provide the required capacity for the Humber and East Coast generation groups, NGET's proposal at the current stage is to take forward Option 4, Weston Marsh to new Market Harborough (via new Ryhall), which proposes the establishment of a new 400 kV transmission connection between a new Weston Marsh 400 kV Substation and a new Market Harborough 400 kV Substation. This connection will be facilitated by routeing via a new 400 kV substation at Ryhall. Option 4 additionally proposes the reconductoring of the Market Harborough to Grendon connection. The proposed route for the new connection spans approximately 60 km, with circa 55 km of reconductoring also to be implemented.

7.2.2 NGET will continue to review the work, including any notable changes in circumstances, and will carefully consider all responses and feedback when the project moves to the consultation stage. With regard to the selection of Option 4 as the final preferred option, reference can be made to the appraisal factors presented in section 6. Additionally, the selection of Option 4 as the preferred option can be justified following a conclusive review of the comparison points presented in the subsequent sections.

Environmental factors

7.2.3 With regards to the environmental factors, the overview of the option is as follows:

- In terms of Ecology: Option 4 crosses three areas of ancient woodland, and within its 2 km study area there is one SAC, seven SSSIs and nine further areas of ancient woodland.
- In terms of Landscape and Visual: Option 4 crosses only one settlement, limiting the effect on local visual receptors during construction and operation.
- In terms of Historic Environment: Option 4 crosses one Registered Park and Garden, and there are also seven Scheduled Monuments and a number of Grade I and Grade II* Listed Buildings within the 2 km study area.
- In terms of Water, Geology and Soils: Option 4 has a large area in Flood Zones 2 and 3, and the option would require a number of river/watercourse crossings – namely the River Great Ouse and the River Cam. However, developing appropriate route corridors and undertaking sensitive routeing that minimises the number of watercourse crossings and work in Flood Zones would ensure that residual impacts are reduced, or avoided wherever possible.

- In terms of Noise: Option 4 has the potential to affect sensitive receptors of settlements during both construction and operation as it passes through one settlement.

Socio-economic factors

7.2.4 With regards to the socio-economic factors, the overview of the option is as follows:

- In terms of Tourism and Recreation: Option 4 crosses three areas of CRoW Open Access Land. Within the 2 km study area there are a further two areas of CRoW Open Access Land and one major visitor attraction (Grimsthorpe Castle).
- In terms of Infrastructure: Option 4 crosses six road networks, three rail networks and there are four crossings of other National Grid infrastructure (including OHL and pipelines). Moreover, there is also Kendrew Barracks military site, and Black Spring Farm Airstrip located within the 2 km study area.

Technical factors

7.2.5 To summarise, from a technical benefit standpoint, Option 4 provides uplift to the B9 boundary. The option provides increased system flexibility due to the proposal to implement two circuits out of new Weston Marsh and new Ryhall and mitigates the overloading of the Ryhall-Eaton Socon circuit under fault conditions. In terms of the technology solution implemented, OHL technology is well established and does not add uncertainty or constructability risk to the Project. However, the length of the OHL to be reconductored between Market Harborough and Grendon is increased when compared with Option 3.

7.2.6 The interim preference of Option 4 resolves the need case summarised below and as set out in chapter 4.

7.2.7 Option 4 meets the need to increase capacity across the B9 boundary and to provide the required capacity for the Humber and East Coast generation groups.

Cost factors

7.2.8 The overview of the capital and lifetime cost impacts of Option 4, as set out in section 6, is summarised below:

- Option 4 – Weston Marsh to Market Harborough, via new Ryhall: Capital cost of £597.8m and a lifetime circuit cost of £411.0m

7.2.9 Overall, Option 4 provides a satisfactory capital cost while maintaining the second lowest lifetime circuit cost, adding significant weight to the option in terms of the cost factor.

7.3 Next steps

7.3.1 LRN# will now be taken forward to the next stage of development. This involves identification of a preliminary route corridor and graduated swathe, which would indicate a more specific location for the development. This will be consulted on at non-statutory consultation to seek feedback from consultees and to help shape the further development of the project.

7.3.2 Further information regarding the Project and its development can be located on the project website[15].

[15] Western March to East Leicestershire project website https://nationalgrid.com/the-great-grid-upgrade/weston-marsh-to-east-leicestershire

Appendices

Appendix A Glossary of Terms and Acronyms

Acronym / Term	Definition
AC	Alternating Current
AC Cable	AC Underground Cable
ACS	Average Cold Spell
ASTI	Accelerated Strategic Transmission Investment
Availability Factor	The time a generator is able to produce electricity over a period of time divided by that period of time
BESS	British Energy Security Strategy
BRAG	Black Red Amber Green
CBA	Cost Benefit Analysis
CCC	Committee on Climate Change
CEMP	Construction Environmental Management Plan
CION	Connection and Infrastructure Options Note
CNP	Critical National Priority
Conductor	Used to transport power
Constraint costs	payments made to constrain generation, to manage power flows where forecast power flows would exceed to capability of the electricity transmission system
CRoW	Countryside Right of Way
CSC	Current Source Converter
CSNP	Centralised Strategic Network Plan
CTMP	Construction Traffic Management Plan
CP30	Clean Power 2030
DC	Direct Current
DCO	Development Consent Order issued under the Planning Act 2008
DESNZ	Department for Energy Security and Net Zero, the ministerial department with primary responsibility for energy.
DNO	Distribution Network Operator
Double circuit	Two transmission circuits each consisting of three conductors (one for each phase of the

	three phase circuits) carried on two sides of a single pylon
Economy Planned Transfer Assessment	Modelling approach for the Economy Planned Transfer Assessment is set out in NETS SQSS Appendix F
Electricity Act	The Electricity Act 1989
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
ESO	Electricity System Operator The previous operator of the National Electricity Transmission System.
ETYS	Electricity Ten Year Statement sets out the Electricity System Operator's view of future transmission requirements and where the capability of the transmission network might need to be addressed over the next decade.
FES	Future Energy Scenarios represent different credible scenarios for the transition to a cleaner greener energy future by 2050.
GHG	Greenhouse gases
GIL	Gas Insulated Lines
HND	Holistic Network Design The HND issued by the ESO in July 2022, sets out a single integrated transmission network design that supports the large-scale delivery of electricity generated from offshore wind by 2030.
HND FUE	The further development of the HND, which was published by the ESO in 2024, in a report titled 'Beyond 2030'.
HVAC	High Voltage Alternating Current
HVDC	High Voltage Direct Current
IET, PB/CCI Report	An independent report endorsed by the Institution of Engineering and Technology by Parsons Brinckerhoff in association with Cable Consulting International
ILS	Instrument Landing System
Insulators	Used to safely connect conductors to pylons
IPC	Infrastructure Planning Commission
LRN#	NESO project code for Weston Marsh to East Leicestershire (the project)

MCZA	Marine Conservation Zone Assessment
NGET	National Grid Electricity Transmission plc
Net zero	UK Government's commitment to reduce greenhouse gas emissions to net zero by 2050 as per the Climate Change Act 2008 (2050 Target Amendment) Order 2019. Net zero means any emissions that cannot be avoided would be balanced by schemes to offset an equivalent amount of greenhouse gases from the atmosphere.
NESO	National Energy System Operator Operator of National Electricity Transmission System.
NETS SQSS	National Electricity Transmission System Security and Quality of Supply Standard
NOA	Network Options Assessment
NPR	Network Planning Review
NPS	National Policy Statements
NPV	Net Present Value
NSIP	Nationally Significant Infrastructure Project
Ofgem	The Office of Gas and Electricity Markets
OHL	Overhead Line
Planned transfer	The amount of power which will flow out of a region at ACS peak. The Planned Transfers for a region of the NETS is calculated using the modelling approach set out in the NET SQSS.
(the) Policy	National Grid's Stakeholder, Community and Amenity Policy
Pylons	Used to support conductors
RIBA	Royal Institute of British Architects
RSPB	Royal Society for the Protection of Birds
SAC	Special Areas for Conservation
SF_6	Sulphur Hexafluoride (gas used to provide electrical insulation)
SGT	SuperGrid Transformer
SOR	Strategic Options Report
Span length	Distance between adjacent pylons
SPA	Special Protection Areas
SP Energy Networks	SP Transmission plc is a wholly owned subsidiary of ScottishPower (SP) Energy Networks responsible for the transmission of electricity in central and southern Scotland.

SQSS	Security and Quality of Supply Standard. This sets out the criteria and methodology for planning and operating the transmission system.
SSEN	Scottish and Southern Electricity Networks (SSEN) Transmission is the trading name for Scottish Hydro Electric Transmission responsible for the electricity transmission network in the north of Scotland
SSSI	Sites of Special Scientific Interest
STC	System Operator – Transmission Owner Code
Strategic options appraisal	A robust and transparent process used to compare options and to assess the positive and negative effects they may have across a wide range of criteria including environmental, socioeconomic, technical and cost factors.
Study area	A defined geographic area used for the purpose of strategic option appraisal
Substation	Transmission substations are found where electricity enters the power grid to convert generator outputs to a level that suits its means of transmission
TEC	Transmission Entry Capacity
The Authority	Gas and Electricity Markets Authority, the governing body of Ofgem
TO	Transmission Owner
Tpylon	Monopole pylon design developed by National Grid
Transmission Licence	Licence granted under Section 6(1)(b) of the Electricity Act
UG	Underground
volt (V)	The electrical unit of potential difference 1 kilovolt (kV) = 1,000volts
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 B 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 Great Britain and its offshore waters, as a prohibited activity, which cannot be carried out without permission by a transmission licence granted under Section 6(1)(b) of the Electricity Act (a 'Transmission Licence').

1.1.2 National Grid Electricity Transmission 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 NGET 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, coordinated 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

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).

1.3.2 Condition B16: Electricity Network Innovation Strategy

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

1.3.3 Condition D2: Obligation to provide transmission services

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

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

1.3.4 Condition D3: Transmission system security standard and quality of service

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

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

1.3.5 Condition D17: Whole Electricity System Obligations

Transmission owners are required to coordinate and cooperate 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 C 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, 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, Government consulted[16] on proposed updates to the NPS suite including EN-1 and EN-5. The proposed updates include clear linkages of EN-1 with policy -objectives- in respect of -net-zero[17].

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.

1.2 Demonstrating the need for a project

1.2.1 Part 3 of EN-1 sets out Government policy on the need for new nationally significant energy infrastructure projects. Paragraph 3.1 confirms that the UK needs all of the types of energy infrastructure covered by the NPS to achieve energy security and to

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[16] BEIS Consultation, Planning for new infrastructure: review of energy National Policy Statements, September 2021
https://www.gov.uk/government/consultations/planning-for-new-energy-infrastructure-review-of-energy-national-policy-statements

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

dramatically reduce greenhouse gas emissions. It states that "substantial weight" should be given to the contribution which projects would make towards satisfying each need.

1.2.2 Description of the need for:

- new electricity transmission infrastructure is set out in EN-1 and EN-5
- new offshore/onshore wind generation is set out in EN-1 and EN-3, and
- new nuclear generation is set out in EN-1 and EN-6.

1.2.3 The need for new transmission infrastructure for this project is described in chapter 4 of this Report.

1.3 Assessment principles applied by decision maker

1.3.1 Part 4 of EN-1 sets out the general policies that are applied in determining DCO applications relating to new energy infrastructure. Paragraphs 2.32.5 of EN-5 set out the general assessment principles in the specific context of electricity networks infrastructure.

1.3.2 Principles of particular importance for transmission infrastructure projects include:

1.3.3 Presumption in Favour of Development

- Section 4.1 of EN-1 requires the Infrastructure Planning Commission (‘IPC’) to start with a presumption in favour of granting consent for energy NSIPs. This presumption applies unless any more specific and relevant policies set out in the relevant NPS clearly indicate that consent should be refused. The presumption is also subject to the exceptions set out in Section 104(2) of the Planning Act 2008.
- In assessing any application, the IPC should take account of potential:
  - benefits (e.g. the contribution to meeting the need for energy infrastructure, job creation and long-term wider benefits), and
  - adverse impacts (e.g. long term and cumulative impacts but taking into account proposed mitigation measures.

1.3.4 Consideration of Alternatives

- Section 4.4 of EN-1 states that, from a planning policy perspective alone, there is no general requirement to consider alternatives or to establish whether the proposed project represents the best option. However, in relation to electricity transmission projects, paragraph 2.8.4 of EN-5 states that, "wherever the nature or proposed route of an overhead line proposal makes it likely that its visual impact will be particularly significant, the applicant should have given appropriate consideration to the potential costs and benefits of other feasible means of connection or reinforcement, including underground and subsea cables where appropriate."
- Section 4.4 of EN-1 also makes clear that there will be circumstances where an applicant is specifically required to- include information in their application about the

main alternatives that were considered. These circumstances may include requirements under the Habitats Directive and the Birds Directive[18]

1.3.5 Adverse Impacts and Potential Benefits

- Part 5 of EN-1 covers the impacts that are common across all energy NSIPs and sections 2.6-2.9 of EN-5 consider impact in the specific context of electricity networks infrastructure.
- Those impacts identified in EN-1 include air quality and emissions, biodiversity and geological conservation, civil and military aviation and defence interests, coastal change (to the extent in or proximate to a coastal area), dust, odour, artificial light, smoke, steam and insect infestation, flood risk, historic environment, landscape and visual, land use, noise and vibration, socioeconomic effects, traffic and transport, waste management and water quality and resources. The extent to which these impacts are relevant to a particular stage of a project, or are a relevant differentiator at a particular stage of the options appraisal process, will vary. In particular, some of these impacts are scoped out of this stage of the options appraisal process for this project. EN-5 considers specific potential impacts of electricity networks on biodiversity and geological conservation, landscape and visual, noise and vibration, and electric and magnetic fields.
- Potential impacts of particular importance for electricity transmission infrastructure projects include:

1.3.6 Good Design

- Section 4.5 of EN-1 stresses the importance of 'good design' for energy infrastructure, explaining that this goes beyond aesthetic considerations as fitness for purpose and sustainability are equally important. It is acknowledged in EN-1 that the nature of much energy infrastructure development will often limit the extent to which it can contribute to the enhancement of the quality of the area. Section 2.5 of EN-5 identifies a particular need for the applicant to demonstrate the principles of good design were applied in the proposed approach to mitigating the potential adverse impacts which can be associated with overhead lines.

1.3.7 Climate Change

- Section 4.8 of EN-1 explains how the effects of climate change should be taken into account and section 2.4 of EN-5 expands on this in the specific context of electricity networks infrastructure. DCO applications are required to set out the vulnerabilities / resilience of the proposals to flooding, effects of wind on overhead lines, higher average temperatures leading to increased transmission losses and earth movement or subsidence caused by flooding or drought (for underground cables).

1.3.8 Networks DCO Applications Submitted in Isolation

- Section 2.3 of EN-5 confirms that it can be appropriate for DCO applications for new transmission infrastructure to be submitted separately from applications for the generation that this infrastructure will serve. EN-5 explains that the need for the transmission project can be assessed on the basis of both contracted and reasonably anticipated generation.

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[18] Council Directive 92/43/EEC of 21 May 1992 on the conservation of natural habitats and of wild fauna and flora; Council Directive 2009/147/EC on the conservation of wild birds.

1.3.9 Electricity Act Duties

- Paragraph 2.3.5 of EN-5 recognises developers' duties pursuant to section 9 of the Electricity Act to bring forward efficient and economical proposals in terms of network design, taking into account current and reasonably anticipated future generation demand, and its duty to facilitate competition and so provide a connection whenever and wherever one is required.

1.3.10 Adverse Impacts and Potential Benefits

- Part 5 of EN-1 covers the impacts that are common across all energy NSIPs and sections 2.6-2.9 of EN-5 consider impact in the specific context of electricity networks infrastructure.
- Those impacts identified in EN-1 include air quality and emissions, biodiversity and geological conservation, civil and military aviation and defence interests, coastal change (to the extent in or proximate to a coastal area), dust, odour, artificial light, smoke, steam and insect infestation, flood risk, historic environment, landscape and visual, land use, noise and vibration, socioeconomic effects, traffic and transport, waste management and water quality and resources. The extent to which these impacts are relevant to a particular stage of a project, or are a relevant differentiator at a particular stage of the options appraisal process, will vary. In particular, some of these impacts are scoped out of this stage of the options appraisal process for this project. EN-5 considers specific potential impacts of electricity networks on biodiversity and geological conservation, landscape and visual, noise and vibration, and electric and magnetic fields.
- Potential impacts of particular importance for electricity transmission infrastructure projects include:
  - Landscape and Visual

    Paragraph 2.8.2 of EN-5 states that the Government does not believe that development of overhead lines is generally incompatible in principle with the developer statutory duty under section 9 of the Electricity Act 1989 to have regard to amenity and to mitigate impacts. However, EN-5 recognises that in practice overhead lines can give rise to adverse landscape and visual impacts, dependent upon their scale, siting, degree of screening and the nature of the landscape and local environment through which they are routed.

    In relation to alternative technologies for electricity transmission projects, paragraph 2.8.9 of EN-5 states that, "each project should be assessed individually on the basis of its specific circumstances and taking account of the fact that Government has not laid down any general rule about when an overhead line should be considered unacceptable. The IPC should, however, only refuse consent for overhead line proposals in favour of an underground or subsea line if it is satisfied that the benefits from the non-overhead line alternative will clearly outweigh any extra economic, social and environmental impacts and the technical difficulties are surmountable." Paragraph 2.8.7 of EN-5 endorses the Holford Rules which are a set of "common sense" guidelines for routeing new overhead lines.

Appendix D Technology overview

1.1 Introduction

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 E.

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.

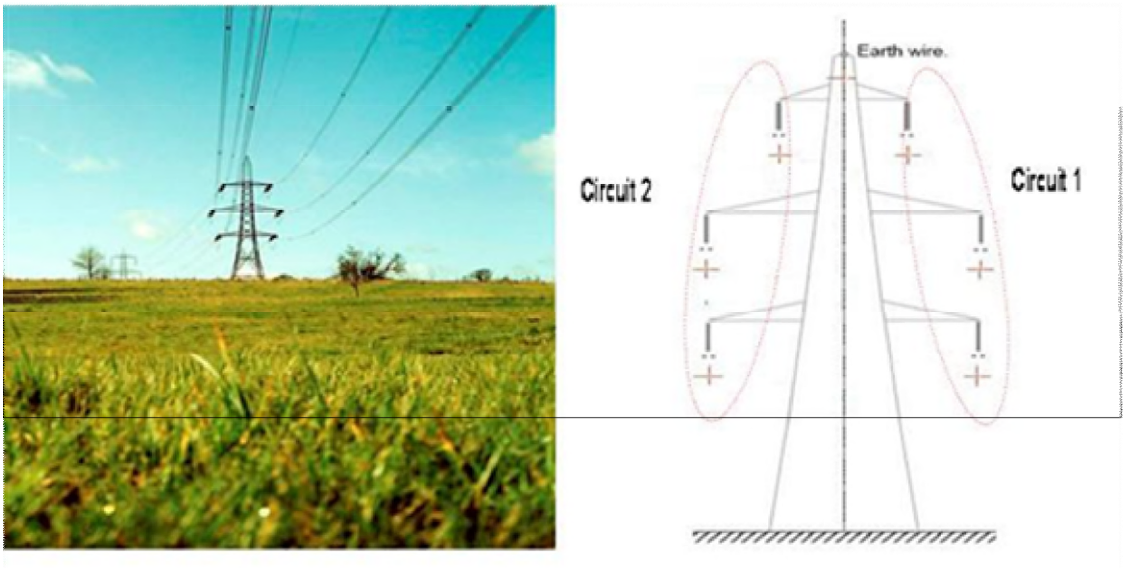
1.2 Overhead lines

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 D.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 D.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.

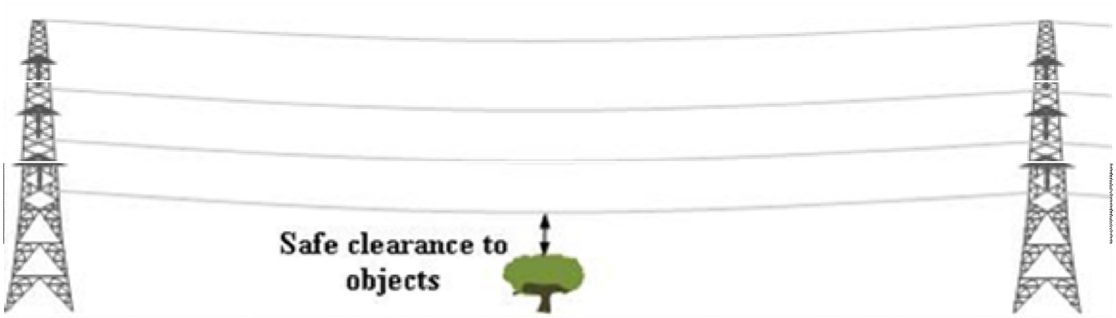
1.2.5 With the conclusion of the Royal Institute of British Architects (RIBA) pylon design competition[19] and other recent work with manufacturers to develop alternative pylon designs, National Grid is now able to consider a broader range of pylon types, including steel lattice and monopole designs. 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 D.2, below, shows an image on the monopole design called the T pylon- that was developed by National Grid.

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

Figure D.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 D.3.

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

Figure D.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 D.5 shows two examples of cable sealing end compounds.

Figure D.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 3550 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.

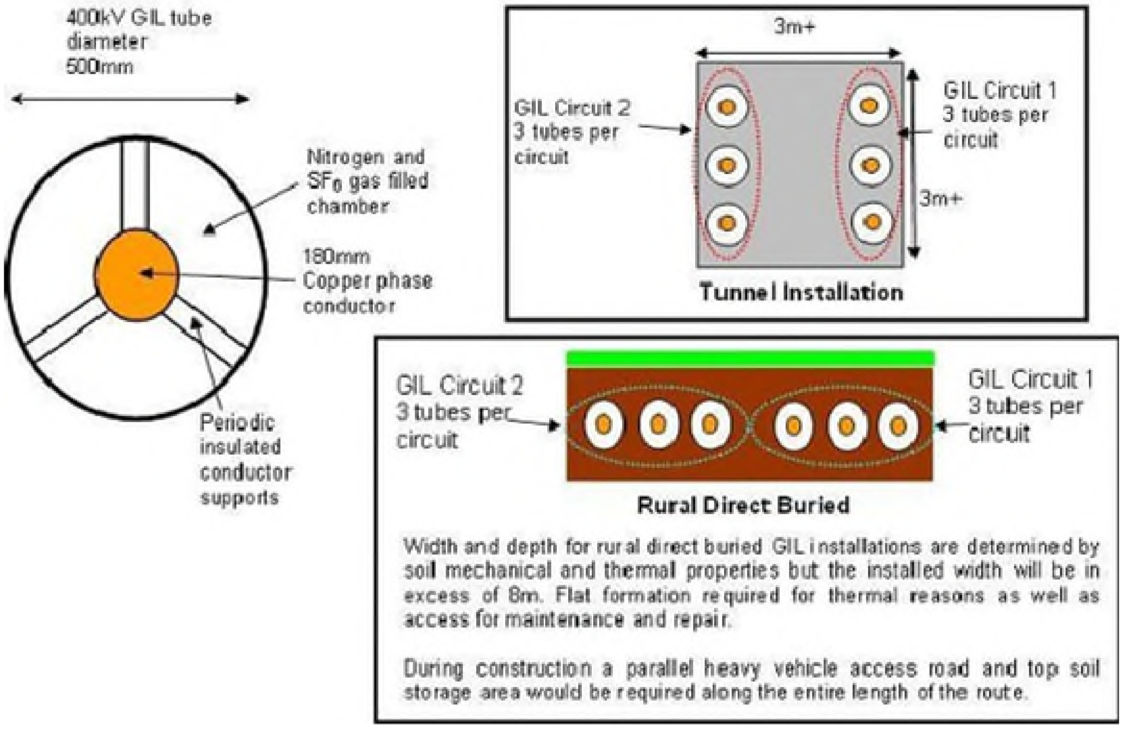
1.3.13 Asset replacement is generally expected at the end of design life. However, National Grid's asset replacement decisions (that are made at the end of design life) will also take account of actual asset condition and may lead to actual life being longer than the design life.

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 D.6 below.

Figure D.6 – Key components of GIL



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 reenergised immediately after a fault (similar to overhead lines) whereas a cable requires investigations prior to reenergisation. If the fault was a transient fault it will remain energised and if the fault was permanent the circuit will automatically and safely deenergise again.

1.4.7 There are environmental concerns with GIL as the SF_6[20] 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;
- designing the GIL tube to withstand an internal fault; and

[20] 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

- 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 SF_6 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[21]. 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.…

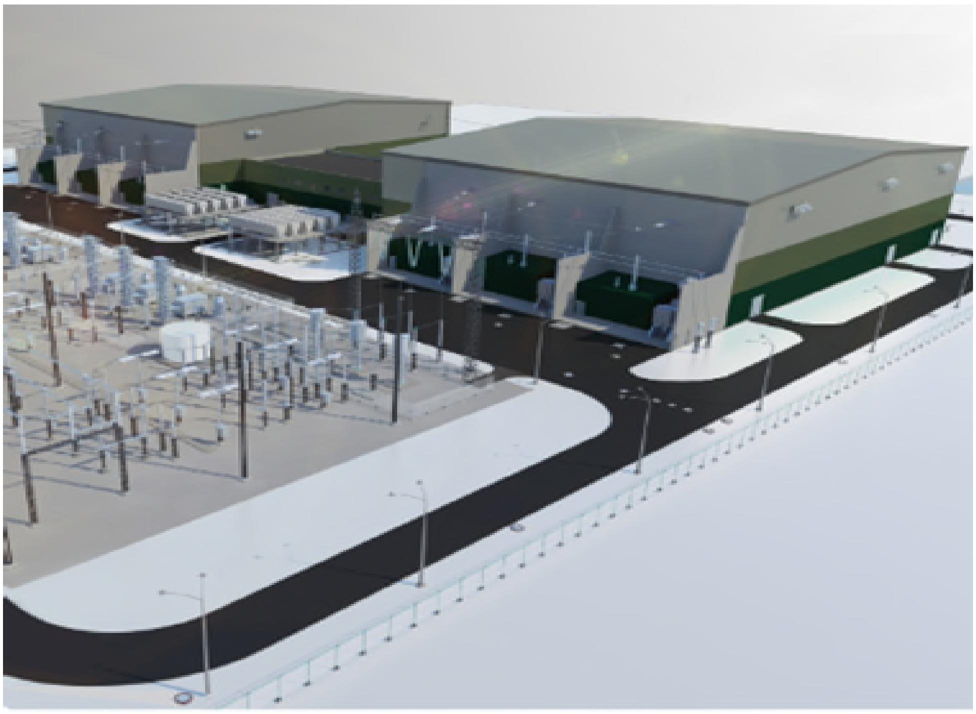
1.5.3 HVDC links may also be used to connect a generating station that is distant from the rest of the electricity system. For example, very remote hydro-electric schemes in China are connected by HVDC technology with overhead lines.

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 midpoint 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 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.

[21] 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.

Figure D.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 D.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 E Economic appraisal

1.1 Introduction

1.1.1 As part of the economic appraisal of strategic options, National Grid makes comparative assessments of the lifetime 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 costs as part 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 D 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 In 2025 the IET have published a new comparison of electricity transmission technologies: Cost and characteristics report[22]. This report is an independent assessment of technologies and costs and is separate to the appraisals. The IET report can be used as third-party verification that the technologies and costs within this report are aligned with industry evaluation provided within the IET report.

1.2 Lifetime costs for transmission

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

- initial capital cost of developing, procuring, installing and commissioning the new transmission assets, and
- net present value ("NPV") of costs that are expected to be incurred during the lifetime of these new transmission assets

1.3 Capital cost estimates

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.

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 D in more detail.

[22] The IET's publication: A comparison of electricity transmission technologies: Costs and characteristics report https://www.theiet.org/impact-society/sustainability-and-climate-change/iet-electricity-transmission-technologies-report

1.4 AC technology capital cost estimates

1.4.1 Table E.1 shows the category sizes that are relevant for AC technology circuit designs:

Table E.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 E.2 provides a summary of technology configuration and capital cost information (in financial year 2020/21 prices) for each of the AC technology options that National Grid considers as part of an appraisal of strategic options.

Table E.2 - AC technology configuration and National Grid capital costs by rating

IET, PB/CCI Report short-form label	Circuit ratings by Voltage		Technology configuration			Capital costs		
	275 kV AC Technologies	400 kV AC Technologies	Overhead Line (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 E.2 provides a summary of the capital costs associated with the key[23] 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 D 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 E.3 provides a summary of the typical reactive gain within AC underground cable circuits forming part of the National Grid's transmission system.

Table E.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 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

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

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 E.4 are:

Table E.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 E.5 shows the capital cost associated with AC underground cable additional equipment.

Table E.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 275 kV 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 E.6 shows the capital cost associated with the SGT requirements.

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

275 kV Equipment	Capital cost (SGT - including civil engineering work)
400/275 kV SGT 1100 MVA (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 E.7provides 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 E.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 (2.12.3 GW each).

1.7.5 Converter costs at each end can also be adjusted, by Linear scaling, from the cost information in Table E.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 E.8 illustrates how comparisons may be drawn using scaling methodology outlined above.

Table E.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 2 GW costs shown in Table D.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 cost assessment.

1.8.3 National Grid’s asset replacement decisions take account of actual asset condition. This may lead to 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 reused 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 reuse 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 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 of 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 D. The majority of expected design lives are of the order of 40 years, which is used to assess the following NPV cost estimates below.

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[24]:

"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."

1.9.5 National Grid considered the impact of using the lower Rate of Return (used by UK Government) on lifetime 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.

1.9.6 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 significantly higher cost associated with them, due to their high maintenance requirements for replacement parts. Table E.9 shows the cost of maintenance for each technology, which unlike capital and losses is not dependent on capacity.

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[24] 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

Table E.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 400 kV 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 needs to be an alternative route to carry power to prevent wide scale loss of electricity for homes, business, towns and cities. Such events would represent a very small part of a circuit's 40-year life, but this availability of alternative routes is an essential requirement at all times to provide secure electricity supplies to the nation.

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 E.10 provides a summary of circuit resistance data for each AC technology and capacity options considered in this Report.

Table E.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 200 Mvar Reactor required for AC underground cables			
Reactor losses	N/A	0.4 MW per reactor	N/A
Additional losses for 275 kV circuits requiring connection to the 400 kV system			
275 kV options only 275/400 kV SGT losses	0.2576 Ω (plus 83 kW of iron losses) per SGT	0.2576 Ω (plus 83 kW of iron losses) per SGT	0.2576 Ω (plus 83 kW of iron losses) per SGT

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 E.11 below shows the typical percentage losses encountered in the conversion process, ignoring losses in the DC cable circuits themselves.

Table E.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 F.

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 F) 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 A^2 x (40 x 0.0065 Ω/km) + (6 x 0.4 MW) = 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.
- Underground 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 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 cost for each technology.

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

Table E.12 – Example lifetime 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 cost	£273m	£1,236m	£1,306m	£2,203m	£2,617m

Appendix F Mathematical principles used for AC Loss Calculation

1.1 Introduction

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 textbooks.

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 $P= \sqrt{3}V_{LL}I_{LL} \cos \theta$. 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 E, which for the each of the two circuits in the “Med” category example is calculated as:

P = 34% x 3190 MVA = 1,084.6 MVA

and, V_{LL} 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 x 106/(√3 x 400 x 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 E, Table **E.10**) as follows:

Overhead Line = 0.0184Ω/km x 40 km = 0.736 Ω

Cable Circuit[25] = 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 $P=I^2R$

1,565.52 x 0.26 = 0.64 MW

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

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 super grid 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.

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

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

$P = 34\% \times 1{,}595 = 542.3$ MVA

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

$I = 542.3\text{x}10^6/(\surd 3 \times 275\text{x}10^3) = 1{,}138.5$ Amps

1.3.3 For this "Lo" category example, the total resistance for the GIL technology option is calculated (from information in Appendix E, Table E.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 $P=3I^2R$

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[26] is calculated (from information in Appendix E, Table E.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:

$I_{HV} = 542.3 \times 10^6/(\surd 3 \times 400\text{x}10^3) = 782.7$ Amps

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

SGT Loss = 3 x 782.7 x 0.2576 = 0.475 MW

Iron Losses in each SGT = 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

- are in the interest of the efficient and economical operation of the total system.

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

Appendix G Beyond 2030 publication

1.1 Pathway to 2030 – HND

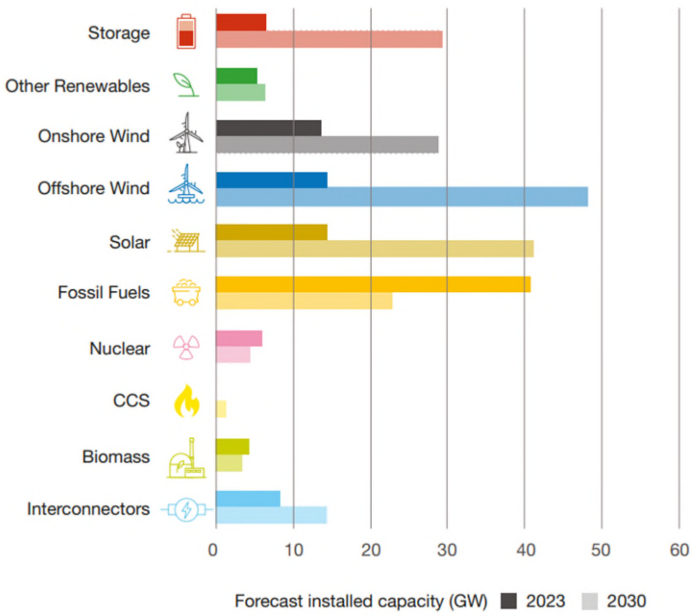
1.3.8 In 2023, 51% of the electricity in Great Britain used was generated by zero-carbon sources. It is expected that by 2030, the electricity system will more commonly run on 100% renewable energy sources for measurable time frames, which will be vital to meet the UK Government's ambition of having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

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

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

1.3.11 The bar chart below from the Beyond 2030 report shows the generation mix in 2023 in comparison to the forecasted mix in 2030.

Figure G.1 – Generation mix comparison (2023 and 2030) [source: Beyond 2030, ESO, March 2024]

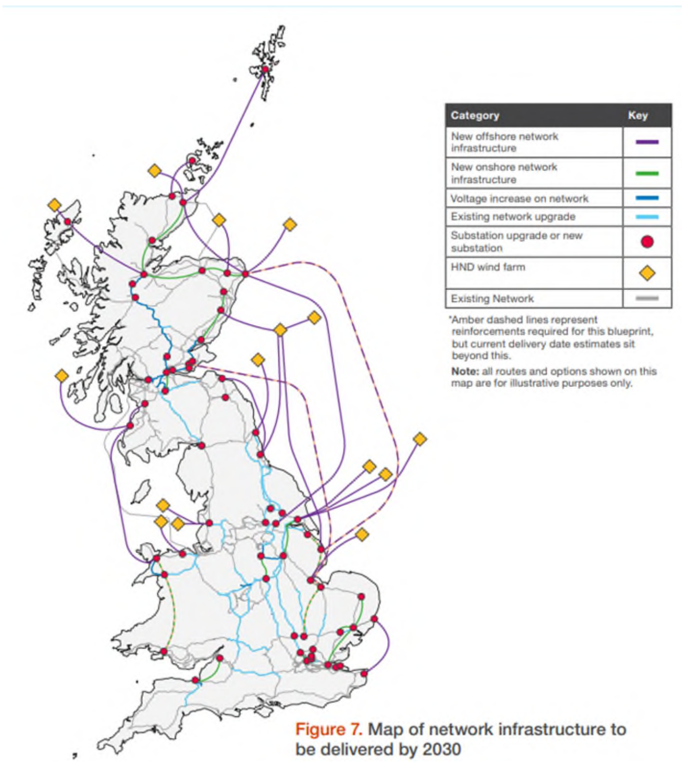


1.3.12 The ESO's Pathway to 2030 Holistic Network Design (HND) 2022 plan to connect 23 GW of offshore wind in the transmission system seeks to reduce reliance on imports of gas and reduce CO2 emissions by up to two million tonnes between 2030 and 2032. To facilitate this growth in the offshore sector, a recommendation of over £60 billion of investment into the transmission system has been made. This investment will comprise of offshore network design and 91 reinforcements to the transmission system, resulting in a holistic approach to network planning.

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

1.3.14 The essential transmission opportunities to enable delivery of the plan in 2030 are presented in the following figure.

Figure G.2 – Network infrastructure to be delivered by 2030 [source: Beyond 2030, ESO, March 2024]



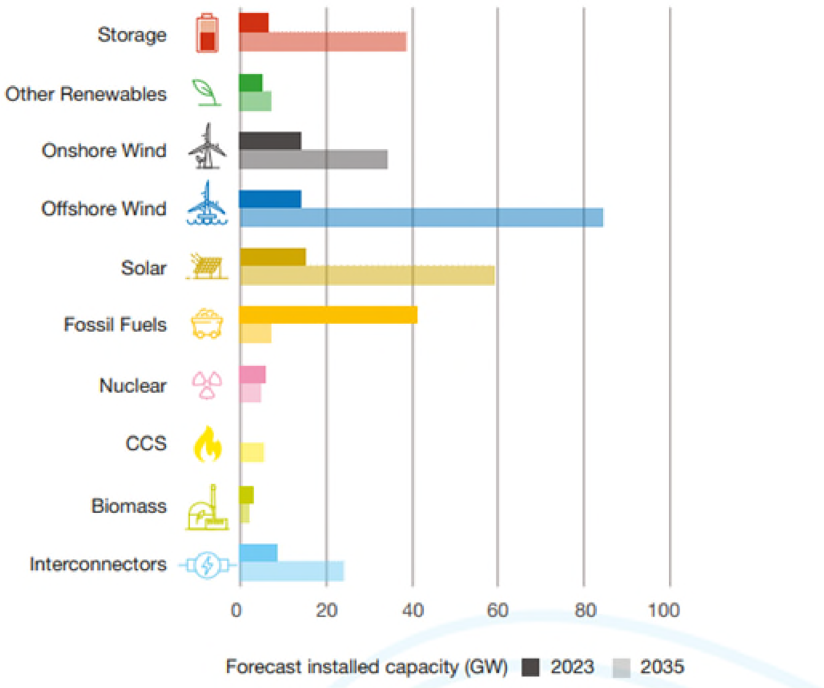
1.4 Beyond 2030 – HND FUE

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

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

1.4.3 The bar chart below from the Beyond 2030 report shows the generation mix in 2023 in comparison to the forecasted mix in 2035.

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



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

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

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

1.4.7 The map below depicts the network infrastructure to be delivered beyond 2030 within the transmission system.

Figure G.4 – Network infrastructure to be delivered beyond 2030 [source: Beyond 2030, ESO, March 2024]

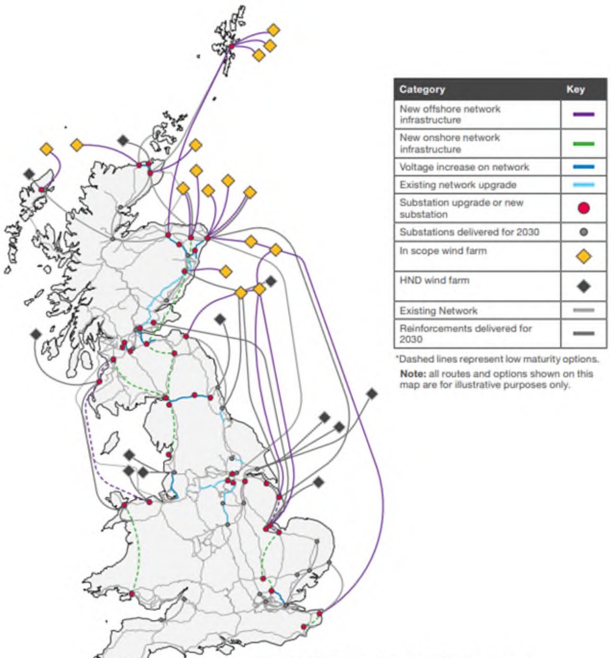


Figure 10. Map of network infrastructure to be delivered beyond 2030

1.5 Way Forward

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

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

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

1.5.4 The Beyond 2030 report has set out information on key policies and proposals, listed below, that are either under consideration or will be taken forward. These policies and proposals should not be viewed in isolation but as holistic changes to the design and operation of the energy system:

- Energy Act and creation of the National Energy System Operator (NESO) – NESO is built upon the principles and structure of the ESO and will cover Great Britain, spanning electricity and gas, giving an independent view of the whole energy system.
- Strategic Spatial Energy Plan (SSEP) – The SSEP will see UK Government targets across the whole energy system mapped spatially across Great Britain over a period of several years and define the optimal mix and location of clean generation and storage to meet forecast demand, net-zero targets and security of supply for all consumers.
- Centralised Strategic Network Plan (CSNP) – NESO will take on the role of central whole-system planner for the energy system, at both national and regional levels, and be responsible for a new CSNP.
- Regional Energy Strategic Planners (RESP) - As part of the new approach to energy planning, RESPs will support net-zero ambitions through the creation of strategic energy plans at a regional and national level, providing critical planning assumptions to inform system and network needs.
- Connections Reform – NESO will lead the development of several tactical and strategic reforms that have the potential to result in radical changes to both the size of the connections queue and how long it takes for projects which are ‘ready to connect’ to connect to the network.
- Network Competition - In November 2023, the TAAP outlined the Government’s commitment to introduce competition for onshore transmission projects as soon as reasonably possible.
- Net Zero Market Reform - The objective of the NZMR programme is to outline holistic market design and complementary investment policy for net zero, and contribute to the Review of Electricity Market (REMA) debate from the perspective of Great Britain’s electricity system operator.

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