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Historic Strategic Options Report (2012)

National Grid (North Wales Connection Project)

Regulation 5(2)(q) of the Infrastructure Planning
(Applications: Prescribed Forms and Procedure) Regulations 2009

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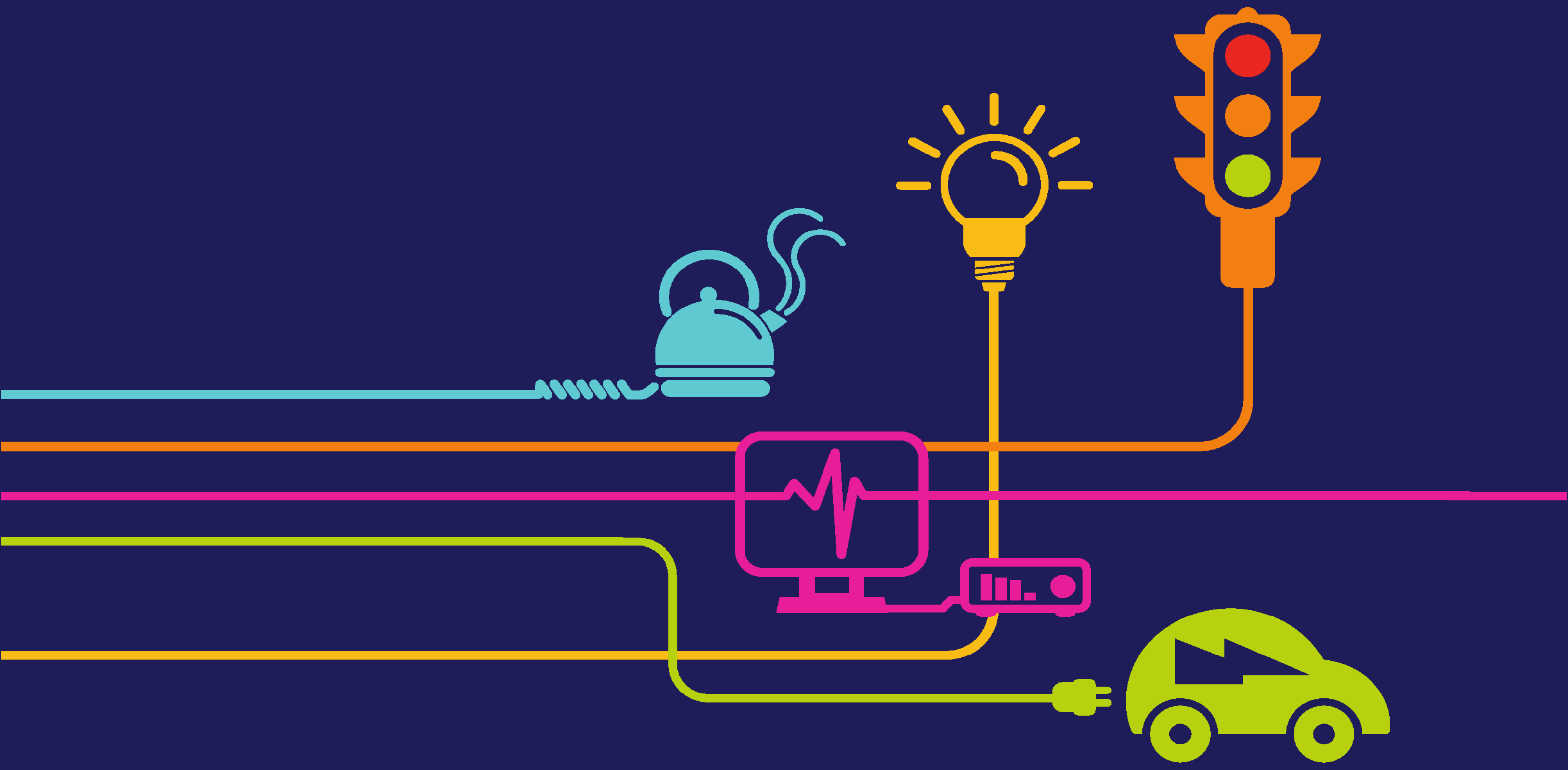

North Wales Connections

Strategic Options Report

National Grid

National Grid House

Warwick Technology Park

Gallows Hill

Warwick

CV34 6DA

3 October 2012

North Wales Connections

Strategic Options Report

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1 Introduction

1.1 This Strategic Options Report has been prepared in accordance with the pre-application procedures adopted by National Grid Electricity Transmission plc ("National Grid") for major infrastructure projects which may require an application to the Planning Inspectorate [1] for development consents.

1.2 National Grid is contractually bound to connect 5.6 GW of new generation to the National Electricity Transmission System ("NETS") in Anglesey:

- a 3.6 GW nuclear power station, which is proposed to be constructed by Horizon Nuclear Power at Wylfa, and
- a 2 GW offshore wind farm which is proposed to be constructed by Celtic Array in the Irish Sea.

1.3 National Grid is also contractually bound to connect three additional wind farms to the NETS on the North Wales mainland:

- Gwynt y Môr Offshore Wind farm, 574 MW, to be located off the coast of North Wales and connected at Bodelwyddan in Denbighshire
- Burbo Bank Extension wind farm, 234 MW, also to be located off the coast of North Wales and connected at Bodelwyddan, and
- Greenwire Wind Farm, 1 GW, located onshore in Ireland, to be connected at Pentir in Gwynedd.

1.4 This level of generation cannot be connected to the transmission system without installing additional transmission infrastructure.

1.5 The Greenwire agreement was signed in July 2012 and the infrastructure required for their connection is still being evaluated. As a result, this report focuses on the connection of the 5.6 GW of new generation to be connected on Anglesey, along with the cumulative effect on the network of the two wind farms to be located off the coast of North Wales.

1.6 Notwithstanding the fact that the Greenwire connection is still being evaluated, section 15 of this report demonstrates that the potential solutions for the

[1] Following the abolition of the Infrastructure Planning Commission (IPC) on 1 April 2012, the Planning Inspectorate became the government agency responsible for examining planning applications for Nationally Significant Infrastructure Projects.

connection of Greenwire would very likely include, as a component part, the Preliminary Preferred Option for the 5.6 GW Anglesey connections, identified in section 14. The conclusions of this report will be reviewed and back-checked on completion of the Greenwire optioneering process.

1.7 More detail on the new generation and impact on the transmission system can be found at

https://www.nationalgrid.com/uk/Electricity/MajorProjects/NorthWalesConnection/

1.8 This Strategic Options Report has been produced by National Grid to inform interested parties of its appraisal of the range of options and technologies which could provide the additional transmission infrastructure. A preliminary preferred option is identified in the report.

1.9 This report provides an overview of the multi-criteria analysis that National Grid uses to appraise strategic options (the "Strategic Optioneering Process"). As part of the Strategic Optioneering Process, National Grid considers relevant technical, environmental, socio-economic and cost factors.

1.10 This document, and other information regarding the North Wales Connections, can be found on the National Grid website at:

http://www.nationalgrid.com/uk/Electricity/MajorProjects/NorthWalesConnection/.

1.11 This report provides:

- background to the electricity industry and National Grid's role (Section 2)
- an explanation of the need case for reinforcements in North Wales (Section 3)
- an overview of National Grid's approach in developing proposals for new transmission routes (Section 4)
- a description of the potential options which were parked prior to the strategic options appraisal process and an explanation of the reasons why (Section 5)

- an overview of the strategic options that National Grid identified for the North Wales Connections (Section 6)
- the results of the strategic options appraisal process (Sections 7 to 13)
- the main conclusions drawn from National Grid's analysis (Section 14), and
- consideration of future scenarios, testing the analysis and conclusion against the possibility that greater or lesser amounts of generation might connect in North Wales (Section 15).

1.12 This report also includes seven appendices and a glossary of terms and abbreviations. These provide further detailed information as follows:

- a summary of National Grid's legal obligations (Appendix A)
- a summary of the requirements for development consent (Appendix B)
- an overview of the technology options for electricity transmission (Appendix C)
- an overview of National Grid's economic appraisal (Appendix D)
- an explanation of the methodology used for AC losses calculation (Appendix E)
- an overview of the environmental and socio-economic appraisal (Appendix F)
- constraint maps for each strategic option (Appendix G), and
- a glossary of the terms and acronyms used in this report.

1.13 Throughout the options appraisal process, National Grid will continue to regularly review the identified need for new transmission infrastructure in North Wales and the strategic options that could meet that need in light of changes of circumstances that could materially affect the analysis. These include, but are not limited to, technology developments, cost updates, changes to generation and demand requirements and consultation responses.

1.14 Comments on the content, analysis and conclusions contained in this report are welcome and will be taken into account in the on-going development of the project.

2 Background

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

2.2 The peak electricity demand in Great Britain is over 60 GW and occurs during winter. The combined capacity of all generators and interconnectors connected to and/or using the electricity transmission system is greater than this peak demand; this excess is generally referred to as plant margin.

2.3 Network infrastructure is needed to ensure that electricity can be transported from where it is generated to where it is used. The transmission system operates at 400 kV and 275 kV and transports bulk supplies of electricity from generating stations to demand centres. Distribution systems operate at 132 kV and below in England and Wales, and are mainly used to transport electricity from bulk infeed points (interface points with the transmission system) to electricity consumers. See Figure 2.1.

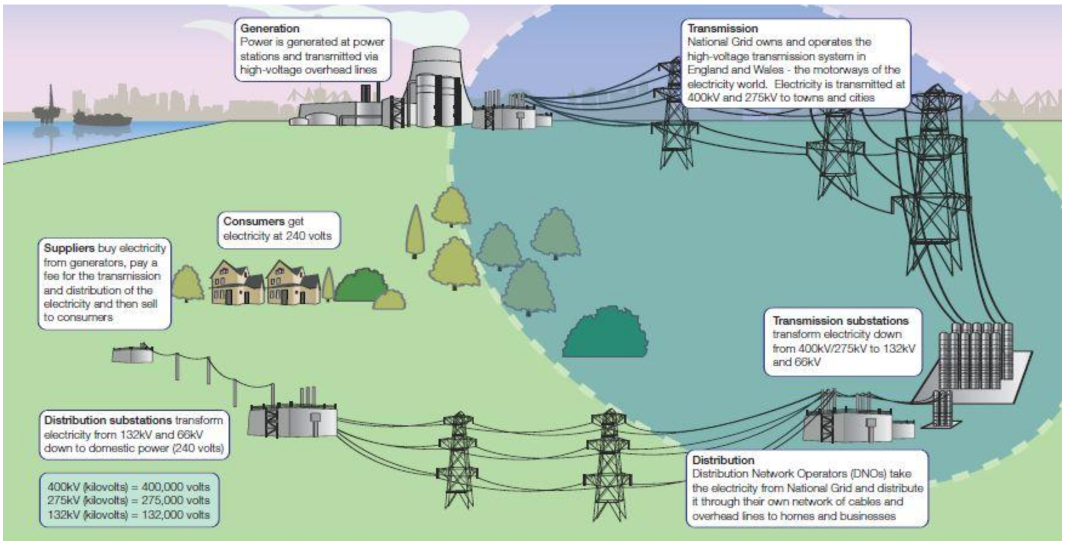

Figure 2.1: The electricity system from generator to consumer

2.4 Electricity generated and supplied in other European countries can also be traded in the GB electricity market. Interconnectors with transmission systems in

France, Northern Ireland and the Netherlands are used to both import and export electricity, which can be bought and sold in the GB market.

National Grid's Role

2.5 Transmission of electricity in Great Britain requires permission by a licence granted under Section 6(1)(b) of the Electricity Act 1989 (the "Electricity Act"). National Grid has been granted a transmission licence and is therefore bound by legal obligations, which are primarily set out in the Electricity Act and the transmission licence. A summary of relevant legal obligations is included in Appendix A.

2.6 National Grid is the operator of the high voltage transmission system in Great Britain and its offshore waters, the NETS, and is the owner of the high voltage transmission system in England and Wales.

2.7 Part of National Grid's role is to provide the contractual interface with those using the NETS (e.g. electricity supply companies) and those connected to, or seeking a connection to, the NETS. (e.g. generators, large factories and interconnectors to other countries)

National Grid's Transmission System

2.8 The transmission system was developed to transport electricity in bulk from power stations to demand centres. Much of National Grid's transmission system was originally constructed in the 1960s. Incremental changes to the transmission system have subsequently been made to meet increasing customer demand, to connect new power stations and to connect interconnectors with other transmission systems.

2.9 National Grid's transmission system consists of approximately 7,200 km of overhead lines and a further 700 km of underground cable, 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 over 300 substations, forming a highly interconnected transmission system. Further details of the transmission system including geographic and schematic representations are published by National Grid annually as part of its Seven Year

Statement. [2]

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

Requirement for Changes to the Transmission System

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

2.12 The transmission system needs to cater for both demand and generation changes. Customers can apply to National Grid for new or modified demand or generation connections to the transmission system; National Grid is then required to respond to each customer application with an offer for a new or a modified connection, as appropriate.

2.13 Until recently, new power station connections have been requested and made at a steady rate that met increasing demand and replaced power stations that had reached the end of their operating lives. More recently, a large volume of applications have been made to National Grid for the connection of new generation at locations that are remote from the existing transmission system or which are in the vicinity of parts of the transmission system that do not have sufficient capacity available for the new connection. The majority of these applications have been for low-carbon generation projects.

2.14 Developing the transmission system in England and Wales may require one or more statutory consents, depending on the type and scale of the project. These may include planning permission or use of permitted development rights under the Town and Country Planning Act 1990, a marine licence under the Marine and

[2] The GB Seven Year Statement can be viewed at https://www.nationalgrid.com/uk/Electricity/SYS/current/

Coastal Access Act 2009 and a Development Consent Order (DCO) under the Planning Act 2008. Developments which require a DCO ("Nationally Significant Infrastructure Projects" or “NSIP”) are the subject of six National Policy Statements ("NPS") for energy infrastructure, the most relevant of which for transmission infrastructure are the Overarching National Policy Statement for Energy (EN-1) and the National Policy Statement for Electricity Networks Infrastructure (EN-5). The requirement for development consent for works on the transmission system is outlined in more detail in Appendix B.

3 The Need for Transmission Reinforcements in North Wales

3.1 The existing transmission system capacity in North Wales is sufficient to comply with the minimum standard for security and quality of supply defined in the NETS SQSS [3] for current levels of generation and demand. However, the amount of new generation expected to connect means that by 2018 the transmission system will no longer be compliant unless National Grid installs new capacity.

3.2 A Need Case has been published [4] which explains in detail the existing capacity of the transmission system and the requirement to add new capacity by 2018.

3.3 Table 1 sets out details of those companies who have connection agreements with National Grid and details of their proposed projects.

Company	Generator Name	Substation	Completion Date	Plant Type	Capacity (MW)
Gwynt y Môr Offshore Wind farm Ltd	Gwynt y Môr	Bodelwyddan (Denbighshire)	2012 - 2014	Offshore wind	574
Dong Wind (UK) Ltd	Burbo Bank Extension	Bodelwyddan (Denbighshire)	2015	Offshore wind	234
Celtic Array Limited	Celtic Array Wind Farm	At or in the vicinity of Wylfa (Anglesey)	2017 - 2021	Offshore wind	2,000
Greenwire Limited	Greenwire Wind Farm - Pentir	Pentir	2018	Onshore Wind	1,000
Horizon Nuclear Power Wylfa Limited	Wylfa	Wylfa (Anglesey)	2020 - 2022	Nuclear	3,600
				Total	**7,408**

Table 3.1 – Generators with agreements to connect in North Wales

3.4 The Need Case demonstrates that the connection of Gwynt y Môr in 2014 and Burbo Bank Extension in 2015 does not require an increase in transmission capacity. However, when combined with the 2 GW of Irish Sea wind and Horizon's proposed 3.6 GW nuclear power station, additional transmission

3 The NETS SQSS can be viewed at https://www.nationalgrid.com/uk/Electricity/Codes/gbsqsscode/
4 The Need Case can be viewed at https://www.nationalgrid.com/uk/Electricity/MajorProjects/NorthWalesConnection/

infrastructure is required by 2018.

3.5 National Grid makes use of notional 'boundaries' on the transmission system when assessing the system against the various criteria contained in the NETS SQSS. In considering the North Wales area three boundaries have been developed and these are shown in Figure 3.1. The Need Case demonstrates that the power transfer capacities across these three notional "boundaries" are insufficient to transfer the required amount of power once the new generators have been connected.

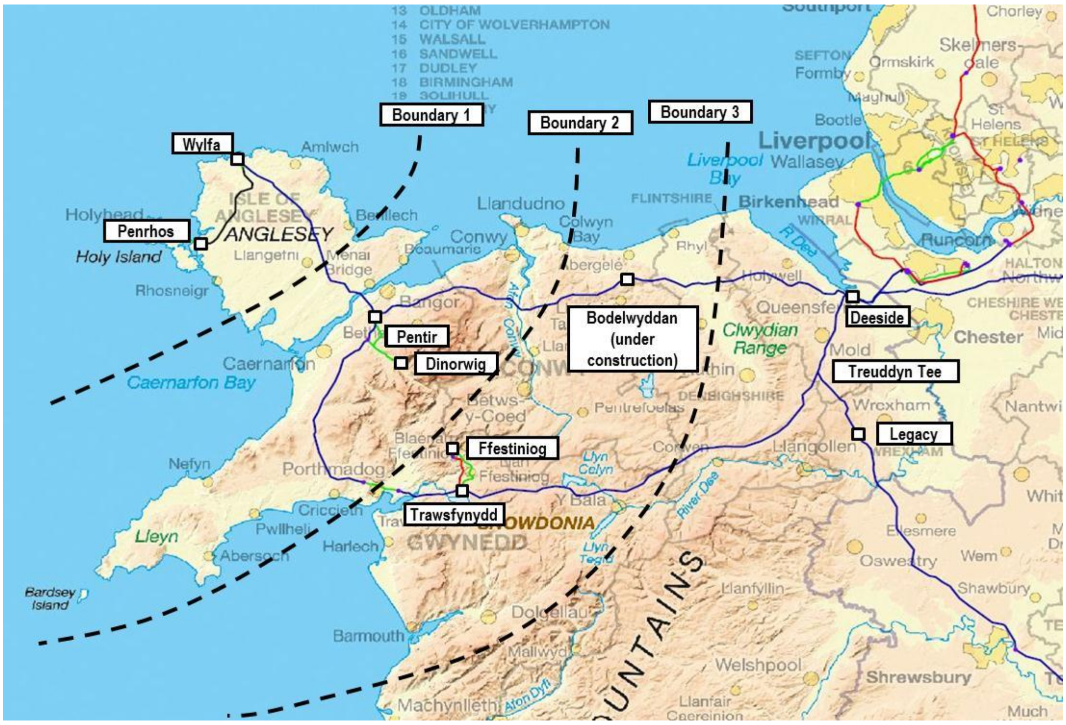

Figure 3.1 – The North Wales Transmission System and System Boundaries

3.6 The transmission system within North Wales consists of:

- a 400 kV double circuit overhead line between Wylfa and Pentir
- a 400 kV double circuit overhead line between Pentir and Deeside
- two 400 kV circuits (partly cable, partly overhead line) between Pentir and Dinorwig
- a 400 kV single circuit between Pentir and Trawsfynydd (an underground cable between Wern and Y Garth and occupying one side of the 400 kV double circuit overhead line over the remainder of the route.)
- a 400 kV double circuit overhead line between Trawsfynydd, Legacy and

Deeside

- a 275 kV double circuit overhead line between Trawsfynydd and Ffestiniog, and
- a 132 kV double circuit overhead line between Wylfa and Penrhos.

3.7 SP Manweb, the local Distribution Network Operator (DNO), has a single 132 kV circuit mounted on part of the Pentir to Trawsfynydd overhead line route which provides supplies to the Llyn Peninsula.

3.8 The double circuit between Wylfa and Pentir connects Wylfa Power Station, a magnox nuclear station, to the transmission system. The owner, the Nuclear Decommissioning Authority, plans to cease generation at the station in 2014.

3.9 The two circuits between Pentir and Dinorwig substations connect Dinorwig Power Station to the transmission system. Dinorwig Power Station is a pumped storage power station owned by First Hydro Company and is located at Llanberis, Gwynedd.

3.10 The 275 kV double circuit overhead line between Trawsfynydd and Ffestiniog connect Ffestiniog Power Station to the transmission system. Ffestiniog Power Station is also a pumped storage power station owned by First Hydro Company and is located at Ffestiniog, Gwynedd.

3.11 The transmission system within North Wales is connected to the rest of the transmission system by six 400 kV circuits:

- a 400 kV double circuit overhead line between Deeside and Daines
- a 400 kV double circuit overhead line between Deeside and the Mersey region, connecting into Capenhurst and Frodsham substations, and
- a 400 kV double circuit overhead line between Legacy and Ironbridge substations.

3.12 Boundary 1 is principally limited by the two circuits connecting Wylfa and Pentir. The Need Case demonstrates that this boundary needs to be reinforced by 2020 to accommodate 5.6 GW of contracted generation.

3.13 Three circuits cross boundary 2 and an additional transmission circuit will be required in this area to prevent overloads in the event of planned and/or unplanned outages.

3.14 Four circuits cross boundary 3 and additional capacity will be required. This can be achieved by upgrading the existing lines.

3.15 As noted in section 1, this report does not consider in detail the 1 GW of Greenwire generation because the infrastructure required for that connection is still being evaluated (section 15 of this report demonstrates that the potential solutions for the connection of Greenwire would very likely include, as a component part, the Preliminary Preferred Option for the 5.6 GW Anglesey connections, identified in section 14).

4 New Transmission Routes – National Grid's Approach

4.1 National Grid has published a document [5] that explains its approach to the design and routeing of new electricity transmission lines. This document sets out how in principle National Grid identifies the most appropriate location and technology for any new transmission route. The approach is then specifically tailored to the circumstances of each case.

4.2 At the initial stage (Stage 1: Strategic Options) of any project that requires a new transmission route, National Grid will:

(a) identify feasible strategic options for meeting the identified transmission system development need;

(b) appraise the strategic options to identify one or more preferred strategic option(s) to be taken forward to the next stage of development, and

(c) consult key stakeholders about the potential strategic options being considered, how they should be assessed and on the results of the options appraisal.

4.3 National Grid refers to this iterative process as strategic optioneering.

<u>National Grid's Strategic Optioneering Process</u>

4.4 As part of the Strategic Optioneering Process, National Grid will:

(a) identify potential strategic options for changes to the transmission system that would meet the reinforcement need

(b) assess whether the options identified are technically compliant with the standards in the NETS SQSS

(c) assess if any one option has some distinct benefit over other options in order to reduce the number of options under consideration

(d) appraise the remaining technically compliant options through options appraisal which is a method used to compare options and analyse their relative costs and benefits, and

5 National Grid's approach to the design and routeing of new electricity transmission lines http://www.nationalgrid.com/NR/rdonlyres/B4AE3FE3-8F16-414F-B65F-F87916BFDA5D/55463/NG_Undergrounding_OurApproach_booklet_AW_v8_WebOpt.pdf

(e) identify one or more preferred strategic option(s) to be taken forward.

4.5 If the preferred strategic option(s) would require changes to National Grid's transmission system which would be regarded as a NSIP, [6] a project-specific Strategic Options Report (SOR) will form part of National Grid's pre-application consultation process. At all stages of the optioneering process National Grid conducts a back-check and review, where new information or changes in the background are considered to have potential implications for any decisions made.

Identify Potential Strategic Options

4.6 In early stages, potential strategic options are identified by National Grid which could provide the additional transmission system capacity that is needed. When developing the initial range of options, National Grid considers possible opportunities to enhance existing transmission system circuits and equipment as well as options that require new transmission system infrastructure.

4.7 The options at the early stages are based upon high level strategic designs, which are applied equally at the same level of detail to all the options identified at this stage. As such, these initial designs do not consider the highly detailed final designs needed to deliver and build a complete solution.

4.8 Each potential strategic option that National Grid has identified is initially assessed to ensure that it meets the reinforcement need and that the resultant transmission system would comply with the minimum standard for security and quality of supply defined in the NETS SQSS. National Grid will discount potential strategic options which do not meet the reinforcement need or otherwise would not meet the standards set out in the NETS SQSS. Each of the remaining strategic options is then appraised with regard to its individual technical merits.

Overview of Options Appraisal Methodology

4.9 The options appraisal considers relevant technical, environmental, socio-economic and cost factors associated with each strategic option. Analysis of these factors allows National Grid to identify which option best meets its various statutory and licence obligations.

[6] As defined in the Planning Act 2008. Nationally Significant Infrastructure Projects require a Development Consent Order (DCO). Applications for DCOs will be decided by the Secretary of State for Energy and Climate Change (DECC) from April 2012.

4.10 National Grid has a statutory duty under Section 9 of the Electricity Act to develop and maintain an efficient, co-ordinated and economical system of electricity transmission. It considers options for enhancing existing transmission infrastructure before options requiring wholly new transmission infrastructure. This is consistent with its statutory duty to have regard to amenity under Section 38 and Schedule 9 of the Electricity Act and promotes more sustainable development. National Grid's position in relation to its amenity duty is detailed in National Grid's Stakeholder, Community and Amenity Policy [7] (the "Policy").

4.11 In accordance with the Policy, National Grid will only propose to build new transmission infrastructure where existing infrastructure cannot be technically or economically upgraded to meet system security standards and regulatory obligations. Where there is no viable existing upgrade option, National Grid will apply to develop a solution (e.g. the installation or construction of a new circuit) that seeks to achieve the most appropriate integration of its statutory and licence duties and obligations.

Technical Appraisal

4.12 Each strategic option is appraised with regard to its technical advantages and disadvantages. This appraisal looks at both the effects on and benefits to the transmission system and also considers other engineering issues associated with each strategic option.

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

- AC overhead transmission lines
- AC Underground cables
- AC Gas insulated lines (GIL), and
- High Voltage Direct Current (HVDC) technology.

4.14 Appendix C provides an overview of the technology options that National Grid considers when developing high level designs for strategic options. The Appendix

[7] Stakeholder Community and Amenity Policy: http://www.nationalgrid.com/NR/rdonlyres/21448661-909B-428D-86F0-2C4B9554C30E/39991/SCADocument6_2_Final_24_2_10.pdf

provides a high level description of each technology, its relevant features and capabilities.

4.15 Further information, including more detailed technical information is available in a series of factsheets that can be found at:

https://www.nationalgrid.com/uk/Electricity/MajorProjects/NorthWalesConnection/Documents/Index.htm

4.16 As part of the options appraisal, National Grid assesses how each strategic option could be achieved. National Grid reviews the suitability of each of the technology options for each strategic option. Some technologies may be assessed as not technically viable and are not considered further in the options appraisal process. For example, National Grid would not consider overhead line technology as viable for any offshore circuits.

4.17 National Grid develops an indicative scope of works based on each technology option that is considered viable, for each of the strategic options. This scope of works information is used as part of the option appraisal stages described in the following paragraphs of this section.

Cost Appraisal

4.18 Construction costs are estimated for each viable technology type (overhead lines, AC cables, etc.) for each strategic option. National Grid estimates the capital costs [8] and lifetime costs associated with each option and technology. These estimates are based on the indicative scope of works for each technology option.

4.19 National Grid's capital cost estimates include the supply and installation of transmission equipment. All capital cost estimates within this report are based on current financial year prices that are applicable at the report's publication date.

4.20 The capital cost estimates are based on generalised unit costs for the key elements of the option. The generalised unit cost information reflects recent contract values and/or budget estimates from equipment manufacturers and suppliers or specialist consultants and provides a consistent basis for preparing capital cost estimates. The capital cost estimates prepared at this initial analysis

[8] Capital cost includes the capital cost of system upgrades, generator connection assets and contingent transmission works.

stage are sufficiently detailed to enable comparative economic appraisal of the strategic options.

4.21 For each specific strategic option, operational lifetime costs of any new transmission circuits are then estimated. Lifetime cost estimates include the capital cost estimates and also take account of the transmission losses and maintenance costs for transmission equipment over a 40 year lifetime. The calculated costs for operation, maintenance and transmission losses are based on a net present value (NPV) discount rate of 3.5%, as explained in the summary of National Grid's lifetime cost estimate methodology presented in Appendix D.

Study Areas

4.22 Option specific study areas are identified which within which each of the strategic options is most likely to be developed. These areas are discussed and agreed with key statutory bodies and allow environmental features and sites to be identified which could be affected by the strategic option.

Environmental Appraisal

4.23 When carrying out an environmental appraisal a number of different sub-topics are normally considered. The information required to make comparisons between the different options under the various sub-topics generally relates to constraints or issues of national or international importance, which would be of sufficient importance to influence decision making at the Strategic Optioneering stage.

4.24 Appendix F discusses in some detail the environmental sub-topics considered at this stage. They are:

- Ecology and biodiversity
- Cultural heritage
- Landscape and visual
- Water
- Soils and geology
- Greenhouse gases and energy efficiency
- Noise and vibration, and

- Air quality

Socio-Economic Appraisal

4.25 When carrying out a socio-economic appraisal a number of different sub-topics are considered if National Grid thinks that that they are relevant to decision making at the Strategic Optioneering stage.

4.26 Appendix F discusses in some detail the Socio-Economic sub-topics considered at this stage. They are:

- Economic Activity, and
- People and Communities

5 Potential Strategic Options Parked prior to Detailed Appraisal

5.1 There are countless ways in which the reinforcement need could be met and many of them are very similar. In view of that, the list of potential strategic options taken forward for stakeholder consideration and detailed appraisal was reduced by careful analysis, ensuring that those remaining had a sufficient spread of benefits and disbenefits.

5.2 Those designs which did not offer unique benefits were parked [9] for the time being. They are documented in this section in order that they may be re-visited at any time throughout the project should circumstances change.

5.3 The parked options fall into one of two main categories, AC onshore options and HVDC subsea options.

AC Onshore Options

5.4 As described in section 3 of this report, additional transmission capacity has to be created across Anglesey (boundary 1) and on the mainland east of Pentir 400 kV substation (boundaries 2 and 3). No AC strategic options which provided additional capacity across boundary 1 were parked; they were all taken forward to the strategic options appraisal, the results of which are set out in sections 11 – 13 in this report.

5.5 A number of potential options involving new AC transmission circuits out of Pentir (boundaries 2 and 3) were considered:

- Pentir to Deeside
- Pentir to Treuddyn Tee
- Pentir to Legacy
- Pentir to Mid-Wales.

5.6 Each of these would require new transmission circuits and either new or modified substations, potentially creating significant environmental impacts across Snowdonia National Park and incurring significant levels of capital costs over other options.

[9] The iterative nature of the options appraisal process ensures that 'parked' options will be re-visited at a later stage in the project if circumstances change which might enable that option to offer some unique benefit over another.

5.7 The alternative to a new circuit out of Pentir to the four locations identified in paragraph 5.5 is the development of the second Pentir to Trawsfynydd circuit, which,

- does not require any new transmission routes and could make use of existing pylons
- is less expensive, but
- does require infrastructure work between Wern and Garth and would require modifications to the SP Manweb distribution network.

5.8 National Grid has a statutory duty to "consider the desirability of preserving amenity" when undertaking projects which includes impacts on communities, landscape and visual amenity, cultural heritage and ecological resources. To satisfy this duty, we seek to avoid areas which are nationally or internationally designated for their landscape, wildlife or cultural significance, such as National Parks.

5.9 In addition, National Grid always investigates whether the existing network can be upgraded economically and efficiently to accommodate additional capacity needs before proposing to build new infrastructure.

5.10 The possibility of developing new onshore routes across North Wales was discussed with key statutory stakeholders. Following these discussions, National Grid reached the conclusion that connections between Pentir and Deeside, Legacy, Treuddyn Tee or Mid-Wales would offer no significant benefit over the development of the second Pentir to Trawsfynydd circuit. For these reasons, new transmission routes out of Pentir to Deeside, Legacy, Treuddyn Tee and to Mid-Wales were all parked.

<u>HVDC Subsea Options</u>

5.11 It was evident from an early stage in the project that HVDC subsea connections could offer benefits and therefore merited further assessment. Specifically, connections between the following substations were obvious potential options:

- Wylfa and Deeside
- Wylfa and Pembroke, and

- Wylfa and both Deeside and Pembroke.

5.12 A number of additional potential locations were considered for the connection of HVDC subsea circuits and this section discusses which were parked and why. Various locations on the north coast of Wales and the Lancashire coast were considered as connection points for the 'receiving' end of the HVDC circuits.

5.13 The following paragraphs take each potential connection point for an HVDC subsea connection in turn and discuss their merits, limitations and the result of the preliminary assessment. The potential connection points are shown in Figure 5.1.

Figure 5.1 – Potential Connection Points for Subsea HVDC, along with Other Relevant Substations

<u>Bodelwyddan 400 kV substation</u>

5.14 Bodelwyddan is a new 400 kV substation under construction approximately mid-way along the Pentir to Deeside route and will be the connection point for Gwynt y Môr and Burbo Bank Extension offshore wind farms.

5.15 The substation is located approximately 5 km inland which would require the HVDC cables from Anglesey to be laid underground along the final part of the route.

5.16 While an HVDC connection to Bodelwyddan could resolve the constraints on boundaries 1 and 2 it would not fully resolve the constraint on boundary 3. The power would still need to get across boundary 3, either to Deeside, Legacy or beyond and further reinforcements would be required.

5.17 For these reasons a connection to Bodelwyddan was parked.

<u>Capenhurst and Birkenhead 275 kV substations</u>

5.18 These substations are located near the coast and are connected into the transmission network on Merseyside.

5.19 Connection of significant amounts of HVDC to either or both of these substations could trigger wider reinforcements and upgrades in Merseyside, incurring significant levels of capital costs. In addition, land at Birkenhead is constrained. These connection points would offer no significant advantage over connecting to Deeside which would not require upgrades in Merseyside and for these reasons connections to Birkenhead and Capenhurst were both parked.

<u>Stanah and Heysham 400 kV substations</u>

5.20 Stanah and Heysham substations are located on the Lancashire coast.

5.21 In addition to existing generation at these substations, there are further advanced plans to connect

- West of Duddon Sands offshore wind farm to Heysham, 374 MW by 2014, and
- Walney Extension offshore wind farm to Heysham, 752 MW by 2016.

5.22 Connection in a north-easterly direction from Wylfa to either of these substations would result in increases in power losses, increased circuit lengths (and consequential increases in capital and lifetime costs) and would be likely to trigger additional transmission reinforcements in Lancashire. Power injected at these locations would generally flow south to Penwortham (near Preston), Daines and Deeside so these connections would offer no significant advantage over connecting directly to Deeside. For these reasons connections to Stanah and Heysham were both parked.

6 Strategic Options Identified for the North Wales Connections

6.1 Five strategic options have been identified for the reinforcement of the electricity transmission system in North Wales (following the refinement of the list of potential strategic options discussed in Chapter 5). National Grid considers that each of these options would be able to meet the additional transmission system requirements in North Wales and has taken these options forward for strategic option appraisal.

6.2 The five strategic options are:

Option 1 - Three subsea HVDC circuits between Wylfa and Deeside substations

Option 2 - Two subsea HVDC circuits between Wylfa and Deeside and one subsea HVDC circuit between Wylfa and Pembroke

Option 3 – New onshore circuits connecting Wylfa and Pentir (AC or HVDC), one new AC circuit between Pentir and Trawsfynydd to be installed on existing pylons, a new connection between Wern and Y Garth, a new substation in West Gwynedd, re-conductoring of existing circuits in North Wales, the installation of series compensation equipment and modifications at existing substations.

Option 4 – New offshore circuits east of Anglesey connecting Wylfa and Pentir (AC or HVDC), one new AC circuit between Pentir and Trawsfynydd to be installed on existing pylons, a new connection between Wern and Y Garth, a new substation in West Gwynedd, re-conductoring of existing circuits in North Wales, the installation of series compensation equipment and modifications at existing substations.

Option 5 – New offshore circuits west of Anglesey connecting Wylfa and Pentir (AC or HVDC), one new AC circuit between Pentir and Trawsfynydd to be installed on existing pylons, a new connection between Wern and Y Garth, a new substation in West Gwynedd, re-conductoring of existing circuits in North Wales, the installation of series compensation equipment and modifications at existing substations.

6.3 Strategic Options 3, 4 and 5 have several aspects in common. The common works are all on the mainland and not Anglesey. The common works include

(a) the new connection between Wern and Y Garth

(b) a new substation in West Gwynedd

(c) re-conductoring of existing circuits in North Wales

(d) the installation of series compensation equipment, and

(e) modifications at existing substations.

These common works are considered together in sections 9 and 10 before the discussion of Strategic Options 3, 4 and 5 in later sections.

6.4 These options are discussed in more detail in the following sections.

Strategic Option 1

6.5 This option would provide the required additional transmission capacity across Anglesey and North Wales through the installation of approximately 106 km of subsea and onshore HVDC cable circuits between Wylfa and Deeside 400 kV substations.

6.6 Deeside substation is capable of receiving the additional power, all of which can be transferred deeper into the transmission system without directly triggering the need to construct any new routes east of Deeside.

6.7 A geographical illustration of Strategic Option 1 is shown in Figure 6.1.

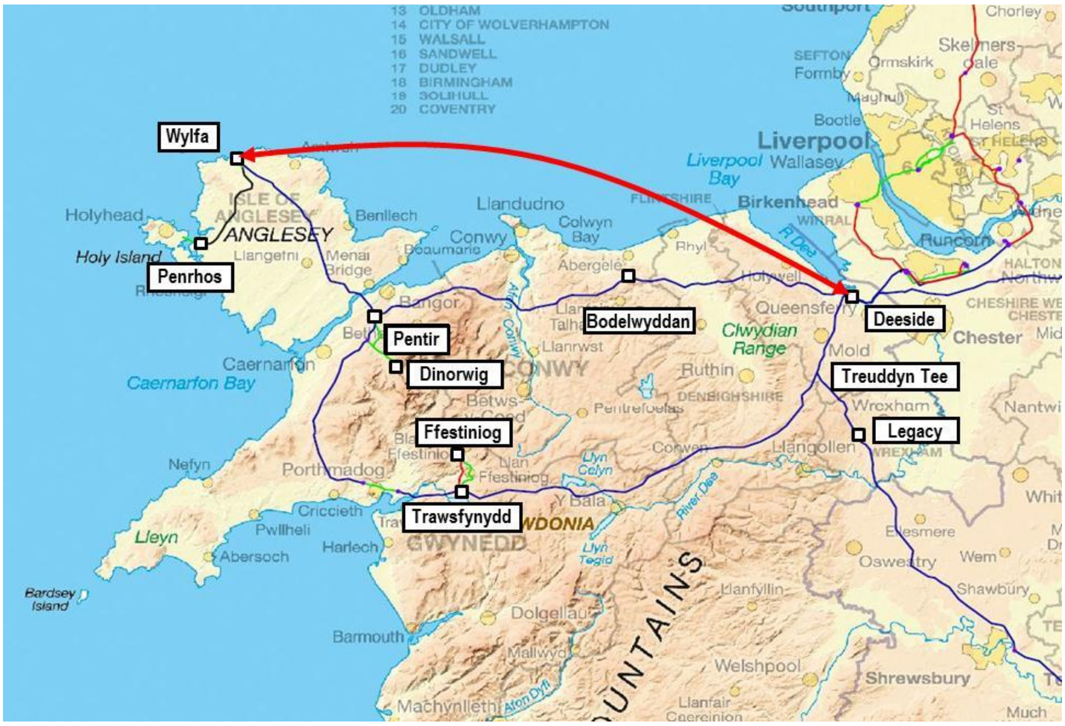

Figure 6.1 – Geographical illustration of Strategic Option 1

Technology considered

6.8 Strategic Option 1 is essentially a subsea / underground option with no new overhead line works.

6.9 Two technologies were initially considered for this option, namely HVDC cables and AC cables. GIL was not considered as it is not suitable for subsea installations.

6.10 The required transmission capacity could be established by the installation of two AC cable circuits each capable of transferring 3,000 MVA. This would result in a capital cost for the cable of £1,250m per circuit, £2.5bn in total. Wylfa and Deeside substations would need to be extended to accommodate the new switchgear bays for the cable circuits at a cost of about £40m.

6.11 With a route length of 106 km, the AC cables would need to be brought ashore at least once along the route for the connection of reactive compensation (shunt reactors) within switchgear compounds. [10] Taking into account the environmental

[10] Mid-point reactive compensation could be installed on offshore platforms but that would be a very expensive solution.

impact of the switchgear compounds, the additional cost of the reactive compensation and the higher cost of the AC cable, National Grid reached the conclusion that AC cable was not a suitable technology for this application as it did not, in this case, offer any benefit over HVDC. This technology was not considered further and was not subject to detailed option appraisal.

6.12 The only remaining technology for this option is HVDC. HVDC does not require reactive compensation along the route and, as such, the cable would not need to be brought to shore for connection to this equipment. Most of the route could be subsea with some underground sections at either end.

6.13 In accordance with the NETS SQSS, three HVDC circuits would be required, each with a capacity of 2,000 MW. [11] Six converter stations would be required, three at or near Wylfa and three at Deeside.

Strategic Option 2

6.14 As with Strategic Option 1, Strategic Option 2 would provide the additional transmission capacity required across Anglesey and North Wales through the installation of approximately 106 km of subsea cable between Wylfa and Deeside and the installation of approximately 231 km of subsea cable between Wylfa and Pembroke.

6.15 A geographical illustration of Strategic Option 2 is shown in Figure 6.2.

[11] All transmission equipment is procured in standard ratings to achieve economies of scale. Following discussions with manufacturers National Grid's appraisal of these options is based on a standard 2 GW converter rating.

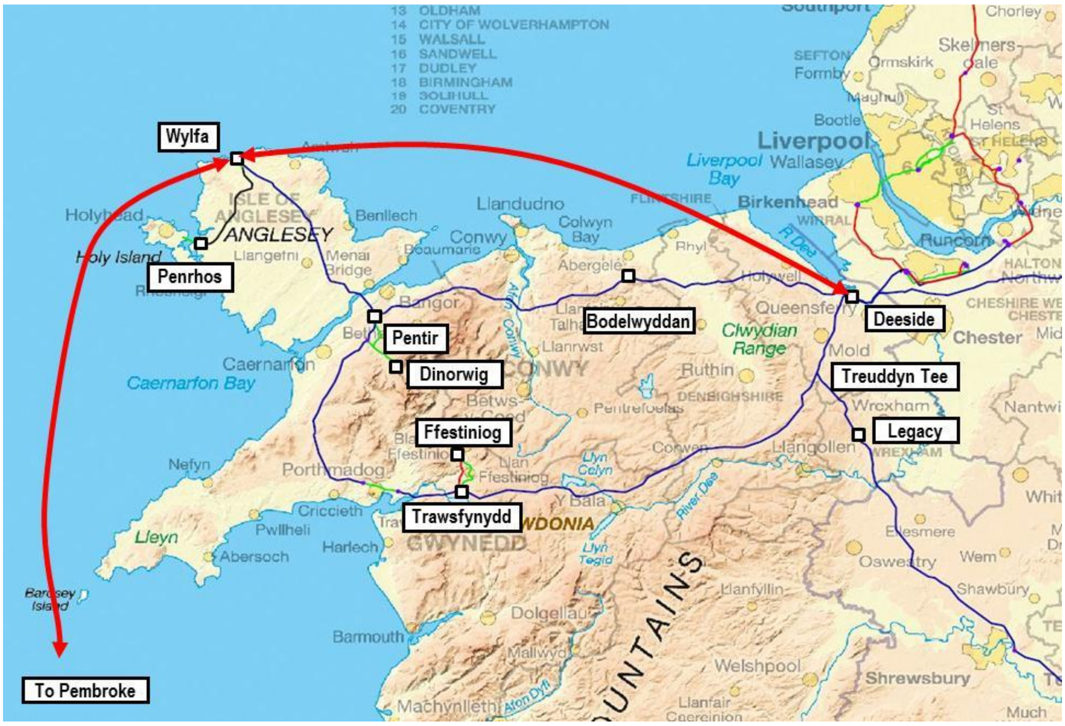

Figure 6.2 – Geographical illustration of Strategic Option 2

<u>Technology considered</u>

6.16 Like Strategic Option 1, option 2 is essentially a subsea / underground option with no new overhead line works.

6.17 Again, two technology options were initially considered for this option, namely HVDC cables and AC cables. GIL was not considered as it is not suitable for subsea installations.

6.18 The required transmission capacity could be established by the installation of two AC cable circuits between Wylfa and Deeside/Pembroke each capable of transferring 3,000 MVA. This would result in capital costs for the cable of £1,250m for each Wylfa – Deeside circuit (£2.5bn in total) and £2.7bn for a Wylfa – Pembroke circuit.

6.19 With route lengths of 106 km and 231 km the AC cables would require to be brought ashore at several locations along the route for the connection of reactive compensation (shunt reactors) within switchgear compounds. [12] Taking into account the environmental impact of the switchgear compounds, the additional

[12] `As with Strategic Option 1, mid-point reactive compensation could be installed on offshore platforms but that would be a very expensive solution.

cost of the reactive compensation and the higher cost of the AC cable, National Grid reached the conclusion that AC cable was not a suitable technology for this application as it did not offer, in this case, any benefit over HVDC. This technology was not considered further and was not subject to detailed option appraisal.

6.20 The only remaining technology for this option is HVDC. HVDC does not require reactive compensation along the route and, as such, the cable would not need to be brought to shore for connection to this equipment. Most of the route could be subsea with some underground sections at either end.

6.21 In accordance with the NETS SQSS, three HVDC circuits would be required, each with a capacity of 2,000 MW. Taking more than 2,000 MW to Pembroke would trigger transmission reinforcements in South Wales and for that reason this option comprises two HVDC circuits to Deeside and the third circuit to Pembroke. Three converter stations would be required at Wylfa, two at Deeside and one at Pembroke.

Strategic Options 3, 4 and 5

6.22 These three options differ mainly in the technology options for connecting Wylfa and Pentir.

- Strategic Option 3 uses onshore technology (AC overhead line, AC underground cable, HVDC underground cable and Gas Insulated Line.)
- Strategic Option 4 uses offshore technology to the east of Anglesey (AC subsea cable and HVDC subsea cable)
- Strategic Option 5 uses offshore technology to the west of Anglesey (AC subsea cable and HVDC subsea cable)

6.23 These options would create the additional transmission capacity required across Anglesey and across North Wales. In addition to the new connections across Anglesey, works are required at the 400 kV substation at Wylfa and at the 400 kV substation at Pentir, and to develop the transmission system on the mainland in North Wales by creating a second Pentir to Trawsfynydd circuit on the same pylons as the existing circuit, by re-conductoring existing circuits, by installing enhanced connections between Wern and Y Garth (near Porthmadog and the

Glaslyn Estuary) and by installing series compensation equipment. [13]

6.24 Creating the additional transmission capacity on the mainland by enhancing the capacity of existing transmission infrastructure accords with the commitments set out in the Policy - to consider upgrades to existing infrastructure before seeking to build new transmission routes.

6.25 A geographical illustration of strategic options 3, 4 and 5 is shown in Figure 6.3.

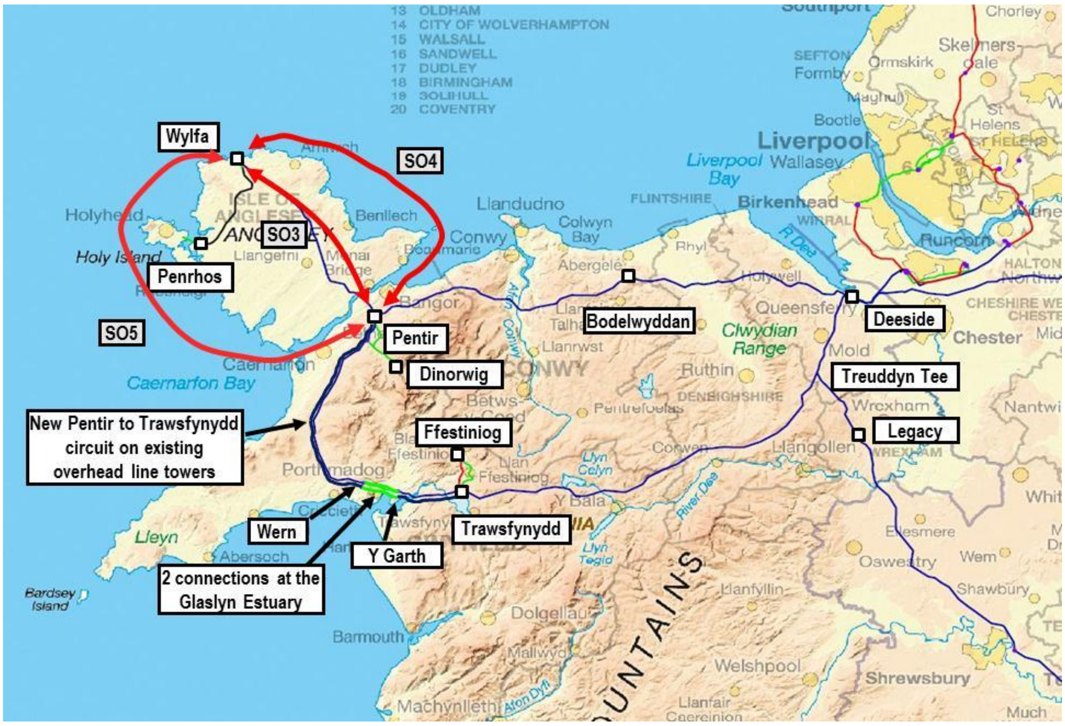

Figure 6.3 – Geographical illustration of Strategic Options 3, 4 and 5

Technology Options between Wylfa and Pentir

6.26 Four technology options were considered to resolve the constraint between Wylfa and Pentir (across boundary 1), namely AC overhead line, AC cables (underground or subsea), GIL and HVDC (underground or subsea).

6.27 There are two key NETS SQSS requirements when assessing this part of the existing system:

- Paragraph 2.6.4 of the NETS SQSS requires that following the concurrent

[13] Further information on series compensation can be found in paragraph 6.45

de-energisation of any two transmission circuits the loss of power infeed to the system shall not exceed a defined value. From 1 April 2014 that value will be set at 1,800 MW

- Paragraph 2.10 of the NETS SQSS requires that the transmission capacity for the connection of a power station(s) shall be planned such that in the event of the de-energisation of two circuits there shall not be any unacceptable overloading of any transmission equipment.

6.28 With 5.6 GW of new generation connected at, or in the vicinity of, Wylfa 400 kV substation all generation must remain connected after the unplanned de-energisation of two circuits.

6.29 Since there is no technology which can accommodate 5.6 GW of power in one circuit then at least two additional circuits are required between Wylfa and Pentir.

AC Overhead Line

6.30 The additional capacity across Anglesey could be established by the construction of a 40 km AC double-circuit overhead line. In the event of outages on these circuits the two existing circuits would be required to carry 5.6 GW of power, which will require the capacity of the existing circuits to be enhanced by re-conductoring.

6.31 Since AC overhead line is only suitable for onshore applications, this technology is only considered for Strategic Option 3.

AC Underground Cable

6.32 The additional transmission capacity could also be established by the installation of two AC cable circuits between Wylfa and Pentir. These cables could be laid either underground or subsea, going round the east or the west of Anglesey. Accordingly, this technology is considered for strategic options 3, 4 and 5.

6.33 This option would require substation modifications at Wylfa and Pentir with the installation of new switchgear and connection of reactive compensation equipment.

6.34 The underground option would require careful consideration at Menai Strait which could involve the construction of a tunnel (or tunnels) for the cable crossing.

GIL

6.35 Two GIL circuits could also provide the necessary capacity for boundary 1. GIL cannot be laid subsea and would therefore be a land-based, underground option only. Accordingly, this technology is only considered for Strategic Option 3.

HVDC

6.36 HVDC could also be used to create the required capacity between Wylfa and Pentir. The HVDC cables could be laid either underground or subsea, going round the east or the west of Anglesey. This technology is therefore considered for strategic options 3, 4 and 5.

6.37 Three 2 GW circuits would be required, with six converter stations, three at Wylfa and three at Pentir.

Common Works – Wern to Y Garth Technology Options

6.38 There are currently three circuits taking the power out of Pentir going east:

- A 400 kV AC double circuit overhead line between Pentir and Deeside, and
- A 400 kV AC single circuit between Pentir and Trawsfynydd, comprising a 6 km underground cable section between Wern and Y Garth (at Porthmadog and the Glaslyn Estuary) and overhead line for the remainder of the circuit.

6.39 SP Manweb utilises part of one side of the Trawsfynydd to Pentir route. There is a circuit operating at 132 kV between Trawsfynydd and Bryncir at which point it leaves the route to run on wood pole structures to Four Crosses substation which provides power to the Llyn Peninsula. This arrangement is illustrated in Figure 6.4.

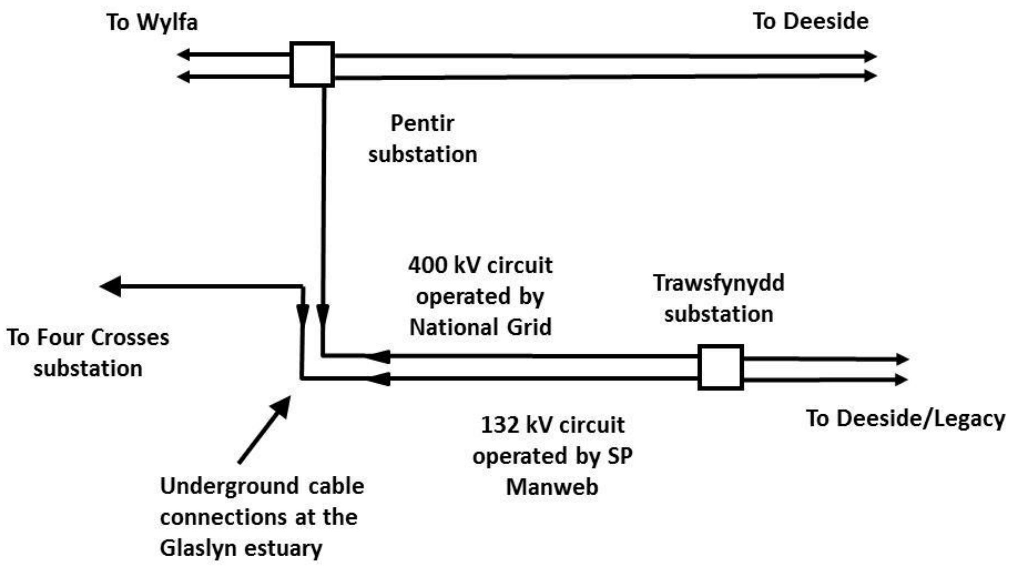

Figure 6.4 – Schematic illustration of the existing arrangement on the Pentir to Trawsfynydd route

6.40 It should be noted that the pylons on the Pentir to Trawsfynydd route are a 400 kV design and the side operating at 132 kV can be easily modified to operate at 400 kV.

6.41 In accordance with the Policy, National Grid will only seek to build electricity lines where our existing infrastructure cannot be technically or economically upgraded. The required transmission capacity can be established by developing a second circuit between Pentir and Trawsfynydd and by some re-conductoring.

6.42 This can be achieved by taking over the second side of the overhead line circuit, which will entail developing, in conjunction with SP Manweb and key stakeholders, an alternative means of supplying the Llyn Peninsula.

6.43 The only technology choices on the mainland for strategic options 3, 4 and 5 therefore relate to the means of connecting Wern and Y Garth (at Porthmadog and the Glaslyn Estuary).

6.44 The existing overhead line was constructed in the 1960s and at that time a condition of the consent was that the Glaslyn section between Wern and Y Garth was completed using underground cable.

6.45 The 6 km section between Wern and Y Garth could be formed by AC overhead lines, AC underground cables or GIL.

Common Works

6.46 Some other works are common to strategic options 3, 4 and 5. The Wylfa to Pentir, the Pentir to Deeside and the Pentir to Trawsfynydd double circuit overhead lines would all need to be re-conductored. Substation modifications would be required at Trawsfynydd and Pentir 400 kV substations.

6.47 Series compensation equipment would be required to be connected to the Pentir to Deeside circuits and to the Pentir to Trawsfynydd circuits. The exact requirements for this equipment have not yet been established. For the purposes of this strategic option appraisal it has been assumed that this electrical equipment could be accommodated at existing substation sites.

6.48 Regardless of the technology utilised between Wern and Y Garth, the existing 132 kV cables owned by SP Manweb and the 400 kV cables owned by National Grid will need to be either removed or made electrically and environmentally safe. [14]

6.49 As previously stated, an alternative means of supplying the Llyn Peninsula would need to be developed if National Grid made use of the side of the Pentir to Trawsfynydd tower route currently used by SP Manweb. This is still being jointly assessed with SP Manweb but for the purposes of the option appraisal it has been assumed that a new grid supply point substation would be constructed in West Gwynedd in the vicinity of where the SP Manweb circuits leave the Pentir to Trawsfynydd route and join the line to Four Crosses substation. A new grid supply point would obviate the need for a new 132 kV route. The exact location of the substation would be subject to more detailed assessment and consultation if this option is taken forward.

[14] The course of action for each set of cables would be agreed between National Grid and SP Manweb and fully discussed with statutory stakeholders.

7 Appraisal of Strategic Option 1

7.1 The main works required for Strategic Option 1, three HVDC circuits connecting Wylfa and Deeside, are:

- installation of new 400 kV GIS switchgear at Wylfa
- modification of the existing 400 kV substation at Deeside
- construction of three converter stations at Wylfa and three at Deeside, and
- installation of three HVDC 2 GW subsea circuits between Wylfa and Deeside, a distance of 106 km.

7.2 The study area for this strategic option is shown in Figure 7.1. It is based on a direct route, which all other things being equal, would give rise to the lowest impacts and costs, with a corridor of 10 km on either side to provide reasonable opportunity to avoid constraints. In recognition of the potential restrictions imposed by existing and proposed wind farms off the North Wales coast, and the ecological sensitivity of the Dee Estuary, the study area has been extended northwards within Liverpool Bay and further inland along the eastern and western banks of the Dee Estuary to include potential cable landfall along the Denbighshire and north Wirral coast. The coast around Great Orme has been omitted from the study area as no landfall would need to be made in this location.

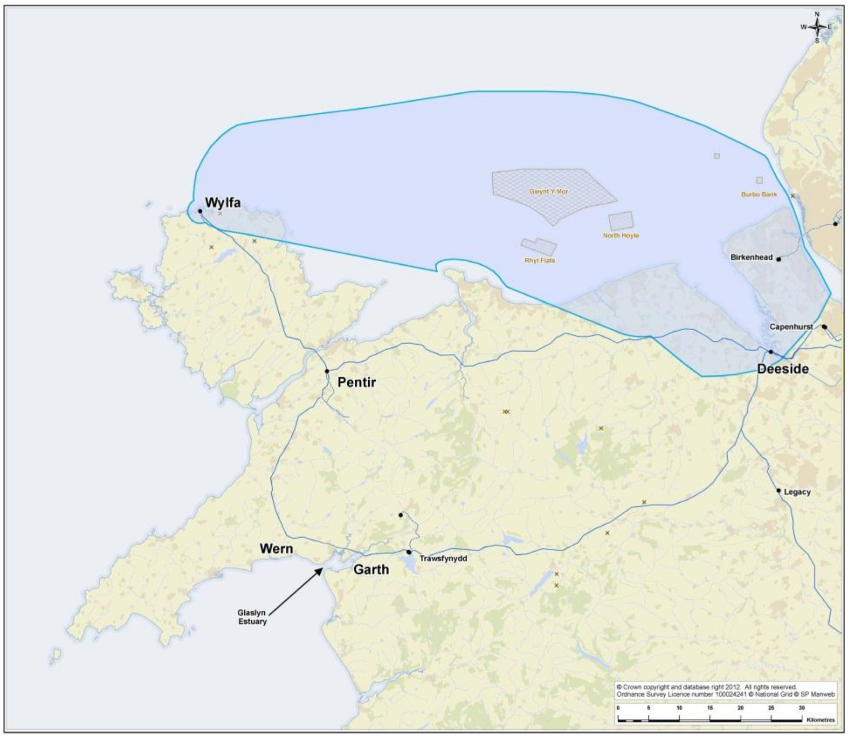

Figure 7.1 – Study Area for Strategic Option 1

7.3 The study area therefore includes an area around the existing Wylfa power station, a small portion of Anglesey's north east coast, a large area offshore including parts of Liverpool Bay, the whole of the Dee Estuary and part of the Irish Sea, a large onshore area either side of the Dee Estuary in Denbighshire, Flintshire and The Wirral, for the routeing of three pairs of DC (marine or terrestrial) cables.

7.4 The following paragraphs set out the results of the option appraisal.

<u>Technical and Cost Appraisal</u>

7.5 This option would require three converter stations at Wylfa and three at Deeside, each typically having a footprint of a large warehouse and being around 25 m high.

7.6 2 GW VSC HVDC converters are not presently available and there may not be sufficient commercial benefit to incentivise manufacturers to develop converters of such ratings. If this were to happen, multiple converter stations of a lower rating would be required. Use of multiple converters would increase delivery costs and land-take requirements. VSC design developments are therefore being monitored closely.

7.7 In the event of the existing AC connection being de-energised (either planned or unplanned), the nuclear power station would be connected to the transmission system solely by HVDC. To date, no nuclear power station in the world has been connected solely by HVDC circuits. The use of HVDC for the nuclear power station connection circuits in this project is thus considered to represent an unproven technology risk which may result in material additional costs and delays being incurred to develop an acceptable solution.

7.8 There is a possibility that harmonic issues could arise at Deeside (distortion of the power waveform quality). However, it is believed these can be designed out.

7.9 Five HVDC circuits [15] terminating at Deeside is likely to introduce complex substation control issues. However, it is believed these can be managed.

7.10 Manufacturing capacity, delivery and installation is a manageable programme risk.

<u>Costs</u>

7.11 The capital and lifetime cost estimates for this option are shown in Tables 7.1 and 7.2.

[15] Three connecting to Wylfa, one to Hunterston (Scotland) and one to Ireland, the latter two currently under construction.

Item	Need	Cost
Wylfa 400 kV substation	Connect power station and HVDC circuits	£165m
Modified substations	Connect HVDC circuits	£20m
HVDC Cable and converter stations	Increase capacity	£1,457m
Total capital cost		**£1,641m**

Table 7.1 Strategic Option 1 – Capital Cost Estimates

Capital Cost of New Circuits	£1,457m
NPV of Cost of Losses over 40 years	£471m
NPV of Operation & Maintenance Costs over 40 years	£128m
Lifetime Cost of New Circuits [16]	**£2,056m**

Table 7.2 Strategic Option 1 – New Circuits: Capital and Lifetime Cost Estimates

7.12 In summary, the estimated capital cost of Strategic Option 1 is £1,641m and the estimated lifetime cost of the new circuits is £2,056m.

Environmental - Ecology and Biodiversity

7.13 The principal ecological sites affecting this option are shown in Figure G.2 in Appendix G of this report. The study area offshore and onshore around the Liverpool Bay and Dee Estuary areas has a high concentration of designated sites. Ecological constraints considered to be material to the decision are:

- Liverpool Bay SPA
- Dee Estuary SAC SPA SSSI and Ramsar
- Halkyn Mountain SAC and SSSI
- Halkyn Common And Holywell Grasslands SSSI
- Gronant Dunes SSSI.

7.14 The Liverpool Bay SPA is considered material to the decision. While it cannot be avoided and there is a high likelihood of there being some effects in combination with other developments, feedback from early consultation suggests that mitigation measures could minimise the impact on the site thereby avoiding the

[16] The lifetime cost calculation methodology is explained in Appendix D. It is used to compare the cost of connecting transmission substations using various technologies for the new circuits. It does not include the capital or lifetime costs of substation equipment. The lifetime cost is the net present value of the costs of transmission losses and maintenance over 40 years. A discount rate of 3.5% is used.

risk of affecting the site's integrity. All of the other ecological sites listed above are also considered to be material although they can be avoided by careful routeing. However, due to the concentration around the Dee Estuary, the only area where the HVDC cables could land that would avoid these material constraints would be between Prestatyn and Rhyl, leading to more extensive onshore works.

Environmental - Cultural Heritage, Landscape and Visual

7.15 The principal cultural heritage and landscape designations affecting this option are shown in Figure G.2 in Appendix G of this report. From a cultural heritage, landscape and visual aspect, the majority of constraints on-land around the North Wales coast and the Wirral can be individually avoided by careful routeing of the HVDC cables, therefore they have not been identified as being material to the decision when considered individually (except for settlements). However, there is a very high concentration of settlements, Scheduled Monuments and Registered Parks and Gardens onshore around the Dee Estuary (east and west). These together with the Holywell Common and Halkyn Mountain Registered Historic Landscape significantly limit route availability, and thus are material to the decision. Given the industrial context of the immediate area around Deeside the landscape and visual impact resulting from converter stations are not considered material to the decision. The study area around Wylfa has a number of cultural heritage, landscape and visual constraints. The risk of directly impacting constraints in the area around Wylfa can be managed through careful routeing, siting and appropriate mitigation. It is, however, noted that converter stations near Wylfa may indirectly affect the Anglesey AONB but this will be seen in context with other developments in this area, such as Horizon's nuclear power station.

Environmental - Other Environmental Sub-topics

7.16 No constraints considered to be material to the decision within the sub-topics noise and vibration, soil and geology, and hydrology and flood risk have been identified.

Environmental - Consideration of combined Environmental Sub-topics

7.17 When considered in combination, the features and designated sites identified across all environmental sub-topics form a number of constrained 'belts' and 'hubs' of high concentrations across the study area. Such constraints are considered to be significant especially within Flintshire and the Wirral. In isolation effects upon these constraints can generally be mitigated or avoided but in combination they are material to the decision.

Socio-Economic - Economic Activity & People and Communities

7.18 Constraints appraised within these sub-topics do not provide sufficient definition between options so as to be considered material to the decision at this level of appraisal. However key socio-economic issues have been identified.

7.19 Socio-economic impacts are considered to be more extensive during construction than during operation for this strategic option. Areas that are considered likely to receive most of the direct socio-economic impacts during construction are around Wylfa and the Dee Estuary.

7.20 Construction of converter stations and the onshore section of the HVDC cables will require a large workforce, a proportion of which can be sourced locally. The works to be undertaken offshore would mostly utilise a specialist workforce. Construction-related employment would particularly benefit Anglesey and Deeside.

7.21 The study area around the Dee Estuary has dense transport infrastructure which will be impacted upon as a result of the trenching for HVDC cables. Some disruption to the road and rail networks around the Dee Estuary area would be expected during construction.

7.22 There are no expected impacts on tourism for this strategic option as any road and rail disruption is unlikely to deter tourists from the area - although locally tourists may substitute one site for another. The most significant economic activity on Anglesey is tourism and there are some tourism destinations in proximity to Deeside; however regionally this option is unlikely to have an impact on the tourism industry.

7.23 Potential benefits from this strategic option include an increase in economic activity due to a specialised work force being located in the area for approximately four years and the opportunities for local employment.

8 Appraisal of Strategic Option 2

8.1 The main works required for Strategic Option 2, two HVDC circuits connecting Wylfa and Deeside and one HVDC circuit connecting Wylfa and Pembroke, are:

- installation of new 400 kV GIS switchgear at Wylfa
- modification of the existing 400 kV substations at Deeside and Pembroke
- construction of three converter stations at Wylfa, two at Deeside and one at Pembroke
- installation of two HVDC 2 GW subsea circuits between Wylfa and Deeside, a distance of 106 km
- installation of one HVDC 2 GW subsea circuits between Wylfa and Pembroke, a distance of 231 km.

8.2 The study area for this strategic option is shown in Figure 8.1. It is based on a direct route, which all other things being equal, would give rise to the lowest impacts and costs, with a corridor of 10 km on either side to provide reasonable opportunity to avoid constraints.

8.3 The area for the two Wylfa to Deeside circuits is as for Strategic Option 1. The study area for the single Wylfa to Pembroke circuit is based upon a reasonable direct route between the two sites. The study area is generally 20 km wide, except where it narrows to exclude consideration of additional onshore constraints on Anglesey and the Llyn Peninsula. An alternative study area, based upon a landfall on the south Pembrokeshire coast was considered, but would have encompassed significant areas of additional constraint and resulted in higher costs due to increased route length.

Figure 8.1 – Study Area for Strategic Option 2

8.4 The study area therefore includes an area around the existing Wylfa power station, a small portion of Anglesey's north east coast, a large area off-shore including parts of the Irish Sea and Liverpool Bay, the whole of the Dee Estuary and a large onshore area either side of the Dee Estuary in Denbighshire, Flintshire and The Wirral. It also includes a separate study area running south from Wylfa, through Cardigan Bay, making landfall on the north Pembrokeshire Coast and includes a large swathe between the coast and Pembroke substation.

8.5 The following paragraphs set out the results of the option appraisal.

<u>Technical and Cost Appraisal</u>

8.6 This option would require three converter stations at Wylfa, two at Deeside and one at Pembroke, each typically having a footprint of a large warehouse and being around 25 m high.

8.7 As with Strategic Option 1, 2 GW VSC HVDC converters are not presently available and there may not be sufficient commercial benefit to incentivise manufacturers to develop converters of such ratings. If this were to happen, multiple converter stations of a lower rating would be required. Use of multiple converters would increase delivery costs and land-take requirements. VSC design developments are therefore being monitored closely.

8.8 In the event of the existing AC connection being de-energised (either planned or unplanned), the nuclear power station would be connected to the transmission system solely by HVDC. To date, no nuclear power station in the world has been connected solely by HVDC circuits. The use of HVDC for the nuclear power station connection circuits in this project is thus considered to represent an unproven technology risk which may result in material additional costs and delays being incurred to develop an acceptable solution.

8.9 There is a possibility that harmonic issues could arise at Deeside (distortion of the power waveform quality). However, it is believed these can be designed out.

8.10 Four HVDC circuits [17] terminating at Deeside is likely to introduce complex substation control issues. However, it is believed these can be managed.

8.11 Manufacturing capacity, delivery and installation is a manageable programme risk.

8.12 This option has a potential advantage over option 1 in that it takes some power to South Wales and might therefore avoid overloading the transmission system in the North West and the West Midlands.

Costs

8.13 The capital and lifetime cost estimates for this option are shown in Tables 8.1 and 8.2.

[17] Two connecting to Wylfa, one to Hunterston (Scotland) and one to Ireland, the latter two currently under construction.

Item	Need	Cost
Wylfa 400 kV substation	Connect power station and HVDC circuits	£165m
Modified substations	Connect HVDC circuits	£37m
HVDC Cable and converter stations	Increase capacity	£1,675m
Total capital cost		**£1,877m**

Table 8.1 Strategic Option 2 – Capital Cost Estimates

Capital Cost of New Circuits	£1,675m
NPV of Cost of Losses over 40 years	£471m
NPV of Operation & Maintenance Costs over 40 years	£128m
Lifetime Cost of New Circuits [18]	**£2,274m**

Table 8.2 Strategic Option 2 – New Circuits: Capital and Lifetime Cost Estimates

8.14 In summary, the estimated capital cost of Strategic Option 2 is £1,877m and the estimated lifetime cost of the new circuits is £2,274m.

Environmental - Ecology and Biodiversity

8.15 The principal ecological sites affecting this option are shown in Figure G.3 in Appendix G of this report. The study area offshore and on-land around the Liverpool Bay, Dee Estuary and in Pembrokeshire has a high concentration of designated sites. Ecological constraints considered to be material to the decision are;

- Liverpool Bay SPA
- Dee Estuary SAC SPA SSSI and Ramsar
- Halkyn Mountain SAC and SSSI
- Halkyn Common And Holywell Grasslands SSSI
- Gronant Dunes SSSI
- Cleddau Rivers SAC
- St David's SAC

[18] The lifetime cost calculation methodology is explained in Appendix D. It is used to compare the cost of connecting transmission substations using various technologies for the new circuits. It does not include the capital or lifetime costs of substation equipment. The lifetime cost is the net present value of capital costs, the costs of transmission losses and maintenance costs over 40 years. A discount rate of 3.5% is used.

- Milford Haven Waterway SSSI
- Pembrokeshire Marine SAC
- Eastern Cleddau River SSSI
- Strumble Head - Llechdafad Cliffs SSSI
- Western Cleddau River SSSI.

8.16 Milford Haven Waterway SSSI and Pembrokeshire Marine SAC are considered material to the decision as these cannot be avoided. However, it is recognised that mitigation measures may be available which would minimise the impact on all of these sites. The Liverpool Bay SPA is considered material to the decision. While it cannot be avoided and there is a high likelihood of there being some effects in combination with other developments, feedback from early consultation suggests that mitigation measures could minimise the impact on the site thereby avoiding the risk of affecting the site's integrity. All of the other constraints are considered to be material as they can be avoided by careful routeing. However, due to the concentration around the Dee Estuary and the north Pembrokeshire coast, the only area where the HVDC cables can come ashore avoiding material constraints is between Prestatyn and Rhyl and in the vicinity of Fishguard respectively.

Environmental - Cultural Heritage, Landscape and Visual

8.17 The principal cultural heritage and landscape designations affecting this option are shown in Figure G.3 in Appendix G of this report. From a cultural heritage, landscape and visual aspect, the majority of constraints on-land around the North Wales coast and the Wirral can be individually avoided by careful routeing of the HVDC cables, and therefore they have not been identified as being material to the decision when considered individually (except for settlements). However, there is a very high concentration of settlements, Scheduled Monuments and Registered Parks and Gardens onshore around the Dee Estuary (east and west). These together with the Holywell Common and Halkyn Mountain Registered Historic Landscape significantly limit route availability, and thus are material to the decision. Given the industrial context of the immediate area around Deeside the landscape and visual impact resulting from converter stations are not considered significant. The study area around Wylfa has a number of cultural heritage, landscape and visual constraints. The direct risk of impacting constraints in the area around Wylfa can be managed through careful routeing, siting and appropriate mitigation. It is, however, noted that converter stations near Wylfa may indirectly affect the Anglesey AONB but this will be seen in context with other developments in this area such as Horizon's nuclear power station.

8.18 Within the Pembrokeshire study area, there is also a high concentration of cultural heritage, landscape and visual constraints which are considered material to the decision

- Milford Haven Waterway, Registered Historic Landscape of Outstanding Interest
- Pembrokeshire Coast National Park
- Dinas Head Heritage Coast
- St.David's Peninsula Heritage Coast
- Pen Gaer: Garn Fawr and Strumble Registered Historic Landscape of Special Interest
- Seven areas of landscape along the Pembrokeshire coast identified as having outstanding value in visual terms (CCW LANDMAP Visual and Sensory aspect).

8.19 Milford Haven Historic Landscape cannot be avoided, however the landscape around Pembroke substation is industrial in character, therefore there would be minimal impacts to this constraint due to the nature of the area. All of the other constraints listed above can be avoided through careful routeing; however the concentration of constraints limits available landing points and cable routes.

8.20 There are a significant number of constraints, specifically on-land around the Dee Estuary and along the coast of Pembrokeshire, but of a type where mitigation is generally believed to be effective.

Environmental – Other Environmental Sub-topics

8.21 No constraints considered to be material to the decision within the sub-topics noise and vibration, soil and geology and hydrology and flood risk have been identified.

Environmental - Consideration of combined Environmental Sub-topics

8.22 When considered in combination, the constraints identified across all environmental sub-topics form a number of constrained 'belts' across the study area, and hubs of high concentrations of assets considered to be significant especially within Flintshire, the Wirral and north Pembrokeshire. In isolation effects upon these constraints can generally be mitigated or avoided but in combination they are material to the decision.

Socio-Economic - Economic Activity & People and Communities

8.23 No constraints appraised within this sub-topic are considered material to the decision at this level of appraisal. However key socio-economic issues have been identified.

8.24 Socio-economic impacts are considered to be more extensive during construction than during operation for this strategic option. Areas that are considered likely to receive most of the direct socio-economic impacts during construction are around Wylfa, the Dee Estuary and Pembrokeshire.

8.25 Construction of converter stations and the on-shore section of the HVDC cables will require a large workforce, a proportion of which can be sourced locally. The works to be undertaken off-shore would mostly utilise a specialist workforce. Construction-related employment would particularly benefit Anglesey, Deeside and south Pembrokeshire.

8.26 The study areas around the Dee Estuary and Pembroke have dense transport infrastructure which will be impacted upon as a result of the trenching of HVDC cable. Disruption to the road and rail networks in these areas is expected during construction.

8.27 There are no expected impacts to tourism for this option as any road and rail disruption is unlikely to deter tourists from the areas - although locally tourists may substitute one site for another. The most significant economic activity on Anglesey is tourism and there are tourism destinations in Pembrokeshire and in proximity to Deeside. However, regionally this option is unlikely to have an impact on the tourism industry.

8.28 Potential benefits from this strategic option include an increase in economic activity due to a specialised work force being located in the area for approximately four years and the opportunities for local employment.

9 Common Works for Strategic Options 3, 4 and 5 - Appraisal of Technology Options between Wern and Y Garth

9.1 It was described in section 6 of this report that strategic options 3, 4 and 5 all require new works between Wern and Y Garth to:

- increase the capacity of this section of the existing Pentir to Trawsfynydd circuit, currently comprising ageing cables of inadequate capacity for future needs, and
- install a new connection to form part of the new Pentir to Trawsfynydd circuit.

9.2 Rather than repeating the results of the appraisal of these works in the three sections covering strategic options 3, 4 and 5 (sections 11 to 13) the results are presented only once in this section.

9.3 When reading the appraisal of strategic options 3, 4 and 5 in sections 11 to 13, it should be remembered that the works set out in this section are also required as part of a complete strategic option.

9.4 There are some generation and demand scenarios, for example those set out in the Offshore Development Information Statement ("ODIS") [19] and The Electricity Networks Strategy Group ("ENSG") report, [20] which would create a clear, standalone driver for these works. National Grid may decide to progress these works independently, and to a different timescale, than other works, for example, the Wylfa to Pentir connection.

9.5 The main works required in this area for strategic options 3, 4 and 5 are:

- installation of new AC connections between Wern and Y Garth at the Glaslyn Estuary near Porthmadog, a distance of 6 km, and
- modification of the 400 kV cable sealing ends in the compounds at Wern and Y Garth.

9.6 There is a 6 km cable between Wern and Y Garth sealing end compounds, forming part of the existing Pentir to Trawsfynydd circuit. The capacity of this cable is

[19] The Offshore Development Information Statement http://www.nationalgrid.com/uk/Electricity/OffshoreTransmission/ODIS/
[20] The Electricity Networks Strategy Group http://www.decc.gov.uk/en/content/cms/meeting_energy/network/ensg/ensg.aspx

insufficient for future needs and, in addition, it is reaching the end of its asset life.

9.7 A second circuit will also be developed between Pentir and Trawsfynydd making use of the existing overhead line route and with new connections between Wern and Y Garth.

9.8 The existing overhead line was constructed in the 1960s and at that time it was proposed that 4 km was installed underground at the Glaslyn estuary. The Secretary of State refused consent for an adjacent 2 km section of overhead line, largely to protect views of the Snowdon Massif from the coast, and therefore the installed cable length was extended to 6 km.

9.9 The study area for this element of strategic options 3, 4 and 5 is shown in Figure 9.1 and is 20 km wide across the Glaslyn estuary near Porthmadog, centred upon a direct line between the two ends of the existing cable at Wern and Y Garth.

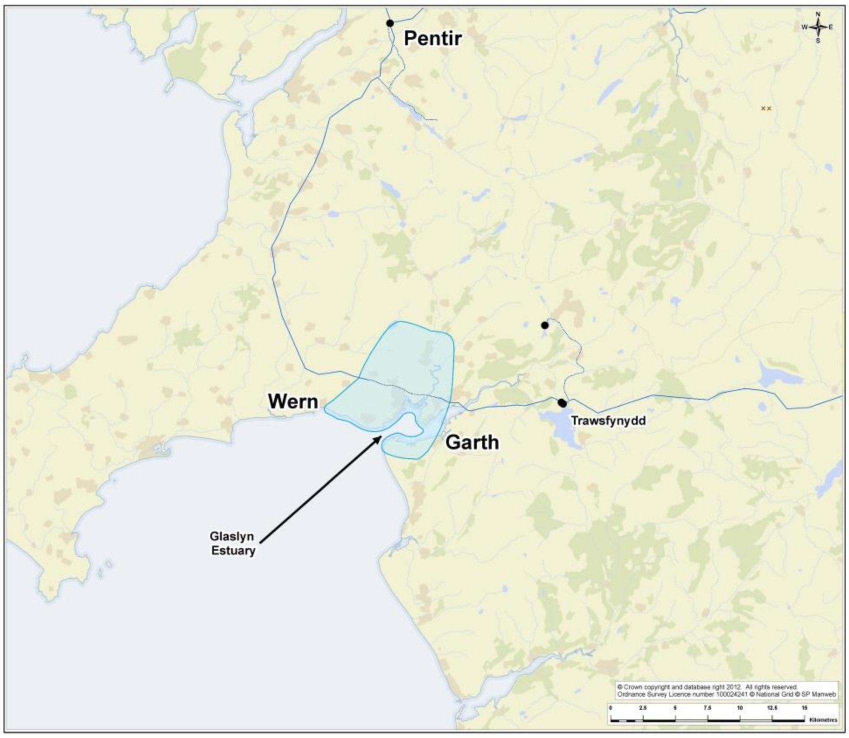

Figure 9.1 – Study area for the Wern to Y Garth connection

9.10 The study area therefore includes a large area around the Glaslyn estuary including the settlements of Porthmadog and Tremadog, part of Snowdonia National Park to the north and the coast to the south.

9.11 The following paragraphs set out the results of the appraisal of these works.

Technical and Cost Appraisal

9.12 The connection between the cable sealing ends at Wern and Y Garth could be made using either of the following technologies:

- AC Underground cable
- AC Overhead Line, and
- GIL.

9.13 HVDC was not considered for this connection. HVDC has economic advantages over longer distances but, due to the fixed cost of the converter stations, it is very expensive at shorter distances when compared with other technologies. Furthermore, the considerable environmental impact of three converter stations at Wern and three at Y Garth means that this technology offers no advantage over AC cables at this location.

9.14 The connections would follow an appropriate route across the estuary and terminate at the existing towers, in the case of overhead line, or at the existing sealing end compounds in the case of the underground technologies.

9.15 Overhead line is a well proven technology and, although vulnerable in adverse weather conditions, most faults are temporary and self-rectifying. Faults which require remedial work are normally repaired quicker than faults on underground cables.

9.16 Installation of AC cable presents a number of technical issues which are likely to be surmountable but which must be carefully considered in cable system design and implementation.

9.17 GIL is an alternative technology to underground cable and is similar in capital cost. GIL has not been installed with the capacity or length required for this application.

Costs

9.18 The capital and lifetime cost estimates for this option are shown in tables 9.1 and 9.2.

Item	Need	Capital Cost		
New Circuits		**OHL**	**AC Cable**	**GIL**
Wern to Y Garth ('Hi' Capacity, 6 km)	Connect Wern to Y Garth, creating additional capacity	£11m	£132m	£138m
Total Capital Cost		**£11m**	**£132m**	**£138m**

Table 9.1 Strategic Options 3, 4 and 5 – Glaslyn Technology options: Capital Cost Estimates

	OHL	AC Cable	GIL
Capital Cost of New Circuits	£11m	£132m	£138m
NPV of Cost of Losses over 40 years	£17m	£5m	£8m
NPV of Operation & Maintenance Costs over 40 years	Negligible	£1m	Negligible
Lifetime Cost of New Circuits [21]	**£28m**	**£138m**	**£146m**

Table 9.2 Strategic Options 3, 4 and 5 – Glaslyn Technology options: Capital and Lifetime Cost Estimates

9.19 In summary, the estimated capital costs for connecting Wern to Y Garth range from £11m for overhead line to £138m for GIL. The estimated lifetime costs for the new circuits range from £28m for overhead line to £146m for GIL.

Environmental - Ecology and Biodiversity

9.20 The principal ecological sites affecting the study area at Glaslyn are shown in Figure G.4 in Appendix G of this report. The study area around the Glaslyn Estuary has four ecological constraints which are considered material to the decision

- Glaslyn SSSI
- Morfa Harlech SSSI
- Meirionnydd Oakwoods and Bat Sites SAC, and
- areas of Ancient and Semi Natural Woodland.

[21] The lifetime cost calculation methodology is explained in Appendix D. It is used to compare the cost of connecting transmission substations using various technologies for the new circuits. It does not include the capital or lifetime costs of substation equipment. The lifetime cost is the net present value of capital costs, the costs of transmission losses and maintenance costs over 40 years. A discount rate of 3.5% is used.

9.21 All can be avoided individually. However, routeing around Glaslyn SSSI and the Meirionnydd Oakwoods SAC would result in Morfa Harlech SSSI being impacted which is considered a significant constraint. One of these SSSIs would therefore be impacted which is considered material to the decision.

9.22 The existing underground cables are routed through Glaslyn SSSI and Meirionnydd Oakwoods and Bat Sites SAC. Removing these cables could result in severe ecological impacts, which are considered material to the decision. However leaving the redundant cables in-situ would largely avoid these impacts. Consultation feedback also highlighted local populations of Schedule 1 bird species (Whooper swans and Osprey) the former of which is known to be susceptible to the risk of striking overhead lines.

Environmental - Cultural Heritage, Landscape and Visual

9.23 The principal cultural heritage and landscape designations affecting the study area at Glaslyn option are shown in Figure G.4 in Appendix G of this report. Constraints within the Glaslyn estuary area considered to be material to the decision are:

- settlements (most notably Porthmadog and Tremadog)
- Wern Registered Park and Garden
- Tan-yr-Alt Registered Park and Garden
- Aberglaslyn Registered Historic Landscape
- Snowdonia National Park.

9.24 Settlements, both Registered Park and Gardens and Snowdonia National Park can be avoided; however the high risk of ongoing indirect visual impacts remains in the case of overhead line technology. Aberglaslyn Registered Historic Landscape cannot be avoided. The study area has a high concentration of cultural heritage, landscape and visual constraints which are of significant value.

9.25 There are potential impacts to the visual setting on a high number of cultural heritage assets and to the historic landscape, although this would be largely limited to the construction phase and is therefore not material.

9.26 In the case of overhead line technology it is assumed that the area within the

National Park would be avoided. However the risk of significant visual impacts on views into and out of the National Park and to the visual amenity of a number of registered parks and gardens would remain. The close proximity of settlements and high visitor numbers to this area would also increase the visual impacts. Concern over the likely impact of an overhead line on the National Park, even after mitigation and practical offsetting measures, was shared by key statutory bodies during early consultation.

Environmental - Other Sub-topics

9.27 No constraints considered to be material to the decision within the sub-topics noise and vibration, soil and geology and hydrology and flood risk have been identified. The overall risk to these sub-topics is considered to be low. While much of the Glaslyn Estuary lies within the identified flood plain, appropriate design and construction could limit impacts during the operational phase.

Environmental - Consideration of combined Environmental Sub-topics

9.28 In combination the designations and constraints identified would act to significantly restrict the potential routes for a new overhead line or underground cable route. This would be particularly important in the case of overhead technology, where the landscape and visual effects in particular have the potential to adversely affect nearby designations and features beyond the route itself.

Socio-Economic - Economic Activity and People and Communities

9.29 No constraints appraised within this sub-topic are considered material to the decision at this level of appraisal. However key socio-economic issues have been identified.

9.30 Socio-economic impacts are considered to be more extensive during construction than during operation.

9.31 It has been assumed that a small proportion of the workforce required for this project will need to be specialised, however a proportion could be sourced locally for some construction works. Construction is estimated to take approximately four years in the case of underground cable and approximately two years in the case of overhead line.

9.32 Some localised disruption during construction is expected for road networks across Gwynedd and North Wales.

9.33 Disruption to the transport network is unlikely to deter tourists from visiting North Wales. At this strategic level, it is not possible to ascertain whether an overhead line at Glaslyn would have any longer term impact upon the local tourism industry, although it is assumed that the potential for any such long term impacts would be lower for underground technology.

9.34 Potential benefits from this strategic option include an increase in economic activity due to a specialised work force being located in the area for between two years or four years (overhead line and underground cables respectively) and the associated opportunities for local employment.

10 Common Works for Strategic Options 3, 4 and 5 – Appraisal of other Common Works

10.1 As well as new works between Wern and Y Garth (discussed in section 9) there are other works which are common to strategic options 3, 4 and 5. Rather than repeating the presentation of the appraisal results for these works in the three sections covering strategic options 3, 4 and 5 (sections 11 to 13) the results are presented only once in this section. In reading the appraisal of strategic options 3, 4 and 5 it should be remembered that the works set out in this section are also required as part of a complete strategic option.

10.2 There are some generation and demand scenarios, for example those set out in ODIS and the ENSG report, which would create a separate driver for the mainland elements of these works. At the moment there is no separate driver and these works are only required as part of this project. Should a separate driver arise at some point in the future National Grid may decide to progress the mainland parts of these works independently and to a different timescale.

10.3 The common works required for strategic options 3, 4 and 5 are:

- modification of Pentir 400 kV substation
- re-conductoring of the Pentir to Deeside double circuit overhead line
- re-conductoring of the Wylfa to Pentir double circuit overhead line
- re-conductoring of the Pentir to Trawsfynydd double circuit overhead line
- modifications at Trawsfynydd 400 kV substation
- installation of series compensation equipment on the Pentir to Deeside and Pentir to Trawsfynydd circuits, and
- a new supply to SP Manweb in West Gwynedd.

10.4 As described in section 6 of this report, a consequence of establishing the second Pentir to Trawsfynydd circuit is that the local DNO, SP Manweb, requires an alternative means of supplying electricity to the Llyn Peninsula. The associated works that would be required by SP Manweb have yet to be fully established and an options report is currently being jointly produced by National Grid and SP Manweb. It has been assumed for the purposes of this appraisal that a new grid supply point substation is established in West Gwynedd, fed from one of the Pentir to Trawsfynydd 400 kV circuits.

10.5 The study area for these works, shown in Figure 10.1, is defined by a 2 km wide area centred upon those overhead lines which are to be re-conductored. This study area includes the area in the vicinity of Bryncir for the siting of the new substation.

Figure 10.1 – Study Area for the Common Works of Strategic Options 3, 4 and 5

10.6 The following paragraphs set out the results of the appraisal of these works.

Technical and Cost Appraisal

10.7 There are no specific technical issues or impacts relating to re-conductoring existing circuits or substation works.

10.8 Series compensation is an unproven technology in the UK but less so worldwide and technical risks are not considered to be significant.

Costs

10.9 The capital cost estimates for these common works are shown in table 10.1.

Item	Need	Cost
Pentir 400 kV substation	Connect the new circuits	£140m
Re-conductoring of existing circuits	Increase capacity at boundaries 1, 2 and 3	£153m
Install series compensation	Increase stability	£35m
West Gwynedd GSP	New supply for SP Manweb	£21m
Trawsfynydd 400 kV substation	Connect the new circuits	£38m
Total Capital Cost		**£387m**

Table 10.1 – Strategic Options 3, 4 and 5 – Common Works: Capital Cost Estimates

10.10 In summary, the estimated capital cost for the common works for strategic options 3, 4 and 5 is £387m.

Environmental and Socio-Economic Appraisal

10.11 The principal environmental designations affecting the common works are shown in Figure G.5 in Appendix G of this report. Within the study areas where re-conductoring will be undertaken, 17 ecological constraints (7 SACs, 1 Ramsar site and 9 SSSIs) have been identified as being material to the decision. None can be avoided; however potential impacts can be mitigated through appropriate access and construction management plans.

10.12 The study area for the re-conductoring of the existing Pentir - Deeside and Pentir - Trawsfynydd lines passes through Snowdonia National Park. The northern route also passes through the Clwydian Range AONB. While the re-conductoring works would result in temporary disruption and visual impacts to these nationally important landscape designations during the engineering phase, the operational impacts would not increase significantly from those currently associated with the line. As such these designations are not considered material to the selection of a preferred strategic option.

10.13 While rural in character there are few constraints in the vicinity of the existing 400 kV line in West Gwynedd that would substantially limit site options for a new substation. Therefore the environmental and socio-economic effects of a new substation are not considered material to the selection of a preferred option at this strategic level of appraisal.

10.14 For the purposes of this appraisal it has been assumed that the series compensation could be located adjacent to or within one or more of the existing substation sites at Pentir, Deeside or Trawsfynydd. While the final design of this electrical equipment is not known, locating it at existing sites would significantly reduce the potential for adverse environmental and socio-economic effects. As such these aspects of the strategic appraisal are not considered material to the selection of a preferred strategic option.

Socio-Economic - Economic Activity & People and Communities

10.15 No constraints appraised within this sub-topic are considered material to the decision at this level of appraisal.

11 Appraisal of Strategic Option 3

11.1 The main works required for Strategic Option 3, Wylfa to Pentir Onshore, are:

- installation of new 400 kV GIS switchgear at Wylfa
- installation of circuits (AC or HVDC) between Wylfa and Pentir, a distance of 40 km
- common works to connect Wern and Y Garth, as described in section 9
- other common works, as described in section 10, and
- for HVDC, the installation of three converter stations at Wylfa and three at Pentir.

11.2 The study area for this strategic option, shown in Figure 11.1, It is based on a direct route, which all other things being equal, would give rise to the lowest impacts and costs, with a corridor of 10 km on either side to provide reasonable opportunity to avoid constraints. The study area therefore includes an extensive area that encompasses much of Anglesey and a large area on the mainland.

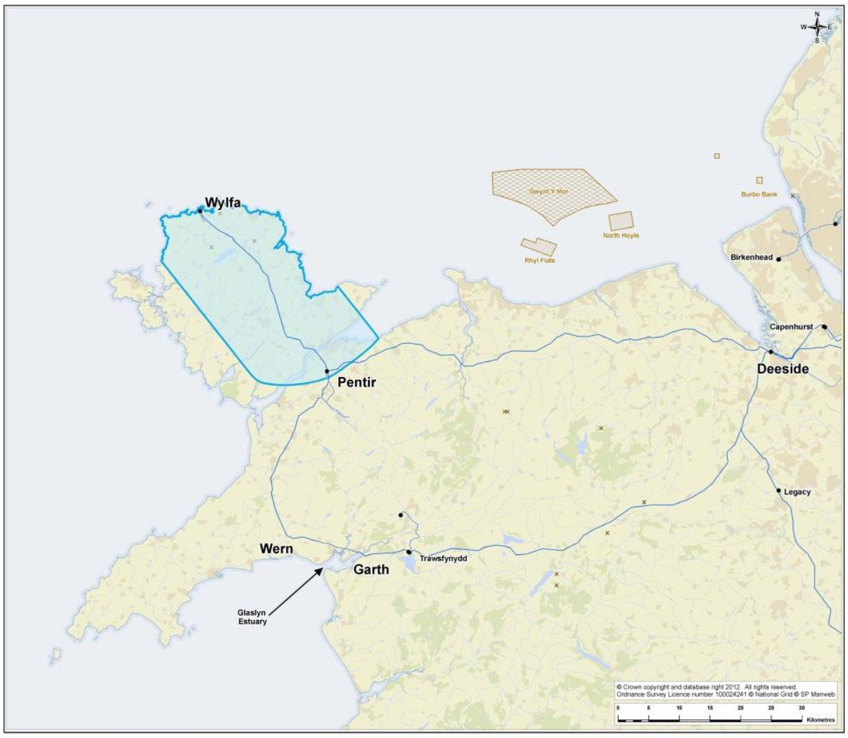

Figure 11.1 – Study Area for Strategic Option 3

11.3 The following paragraphs set out the results of the option appraisal.

Technical and Cost Appraisal

11.4 The onshore connections between Wylfa and Pentir could be made using any of the following technologies:

- AC Overhead lines (double circuit)
- AC Underground cables (two circuits)
- AC Gas Insulated Line (two circuits), and
- HVDC (three circuits)

AC Overhead Line

11.5 The double circuit overhead line would follow a route across Anglesey, as yet unidentified, and would cross Menai Strait at a suitable location before heading inland to Pentir. Overhead line is a well proven technology and, although vulnerable in adverse weather conditions, most faults are temporary and self-rectifying. Faults which require remedial work are normally repaired quicker than faults on underground cables.

All Underground Technologies

11.6 The three underground technologies would also follow a suitable route. While it may be technically possible to directly bury both AC and DC cables in the seabed across Menai Strait, GIL would need to be installed in a tunnel. For the purposes of the appraisal the use of a tunnel beneath the Strait has been assumed for all three underground technologies. A tunnel system would increase costs and create a manageable operational risk as it will require constant ventilation and emergency pumping capability.

HVDC

11.7 The HVDC option would require three converter stations at Wylfa and three at Pentir, each typically having a footprint of a large warehouse and being around 25 m high.

11.8 2 GW VSC HVDC converters are not presently available and there may not be sufficient commercial benefit to incentivise manufacturers to develop converters of such ratings. If this were to happen, multiple converter stations of a lower rating would be required. Use of multiple converters would increase delivery costs and land-take requirements. VSC design developments are therefore being monitored closely.

11.9 In the event of the existing AC connection being de-energised (either planned or unplanned), the nuclear power station would be connected to the transmission system solely by HVDC. To date, no nuclear power station in the world has been connected solely by HVDC circuits. The use of HVDC for the nuclear power station connection circuits in this project is thus considered to represent an unproven technology risk which may result in material additional costs and delays being incurred to develop an acceptable solution.

AC Underground Cable

11.10 Installation of this scale of AC cable system presents a number of technical issues which are likely to be surmountable but which must be carefully considered in cable system design and implementation.

GIL

11.11 GIL is an alternative technology to underground cable and is similar in capital cost. GIL has not been installed with the capacity or length required for this application.

Costs

11.12 The capital and lifetime cost estimates for this option are shown in tables 11.1 and 11.2.

Item	Need	Cost			
AC Cable between Wern and Y Garth *	Increase capacity across boundaries 2 and 3.	£132m			
Common works	Increase capacity in North Wales	£387m			
Wylfa 400 kV substation	Connect Wylfa power station and the new circuits	£154m			
New Circuits		**OHL**	**AC Cable**	**GIL**	**HVDC**
Wylfa to Pentir ('Hi' Capacity, 40 km)	Connect Wylfa to Pentir creating Wylfa export capability	£76m	£1,000m	£999m	£1,189m
Total Capital Cost		**£749m**	**£1,673m**	**£1,672m**	**£1,862m**

Table 11.1 Strategic Option 3 Wylfa - Pentir Onshore: Capital Cost Estimates

	OHL	AC Cable	GIL	HVDC
Capital Cost of New Circuits	£76m	£1,000m	£999m	£1,189m
NPV of Cost of Losses over 40 years	£95m	£75m	£44m	£501m
NPV of Operation & Maintenance Costs over 40 years	£2m	£5m	£2m	£128m
Lifetime Cost of New Circuits [22]	**£169m**	**£1,080m**	**£1,045m**	**£1,818m**

Table 11.2 Strategic Option 3 Wylfa - Pentir Onshore New Circuits: Capital and Lifetime Cost Estimates

* Note that for the purposes of comparison and to understand the total cost of this strategic option, the capital cost of an AC cable between Wern and Y Garth has been included in this table.

11.13 In summary, the estimated capital costs for this option vary between £749m for overhead line and £1,862m for HVDC. The estimated lifetime costs for the new routes vary between £169m for overhead line and £1,818m for HVDC.

Environmental - Ecology and Biodiversity

11.14 The principal ecological sites affecting this option are shown in Figure G.6 in Appendix G of this report. There are seven ecological constraints within the study area between Wylfa and Pentir which are considered to be material to the

[22] The lifetime cost calculation methodology is explained in Appendix D. It is used to compare the cost of connecting transmission substations using various technologies for the new circuits. It does not include the capital or lifetime costs of substation equipment. The lifetime cost is the net present value of capital costs, the costs of transmission losses and maintenance costs over 40 years. A discount rate of 3.5% is used.

decision:

- Menai Strait and Conwy Bay SAC (not considered material for overhead line)
- Coedydd Afon Menai SSSI
- Anglesey Fens SAC
- Cors Erddreiniog SSSI
- Llyn Alaw SSSI
- Glannau Porthaethwy SSSI
- Malltraeth Marsh SSSI
- Traeth Lafan SSSI.

11.15 All but one can be avoided through careful routeing, Menai Strait and Conwy Bay SAC. However, the use of an overhead line or tunnel (in the case of the underground technologies) would reduce or avoid impacts to this constraint.

Environmental - Cultural Heritage, Landscape and Visual

11.16 The principal cultural heritage and landscape designations affecting this option are shown in Figure G.6 in Appendix G of this report. Within the study area between Wylfa and Pentir, cultural heritage, landscape and visual constraints considered to be material to the decision across all technology options are the Isle of Anglesey Coastal Path, (a Designated National Trail) and settlements.

11.17 In addition, for overhead line technology other designations and protected sites that are material to the decision are the Anglesey Area of Outstanding Natural Beauty, which while it could be avoided around much of the Anglesey coastline, could not be avoided at Menai Strait. In addition the Registered Park and Gardens of Plas Newydd overlooking Menai Strait and Vaynol on the mainland shore of the Strait are also considered material to the consideration of the use of an overhead line. The AONB and coastal path would experience long term visual impacts from an overhead line, most notably where the route would cross the Menai Strait; however the registered parks and gardens can be directly avoided but may experience indirect long term visual impacts.

11.18 In the case of underground technologies, significant effects upon the AONB may be avoided, and would in any event be largely restricted to the construction phase. Impacts to settlements from underground technologies can be easily avoided through careful routeing.

11.19 It is noted that converter stations near Wylfa may indirectly affect the AONB but this will be seen in context with other developments in this area.

11.20 Converter stations located in the vicinity of Pentir substation would be around 5 km from the boundary of Snowdonia National Park, and due to the elevation of the land within the Park and the scale of the converter station buildings, impacts to views from the Park are possible. While Pentir's remote rural location is likely to result in adverse landscape effects (despite the presence of existing transmission infrastructure) visual effects are likely to be localised.

<u>Environmental – Other Sub-topics</u>

11.21 No constraints considered to be material to the decision within the sub-topics noise and vibration, soil and geology and hydrology and flood risk have been identified.

<u>Environmental – Consideration of combined Environmental Sub-topics</u>

11.22 The study areas around Menai Strait and Beaumaris both have a high concentration of cultural heritage, landscape and visual constraints. The Beaumaris area can be easily avoided but the high concentration around Menai Strait limits the available transmission routes across the Strait. This concentration is considered to be material to the decision in the case of overhead line technology.

<u>Socio-Economic - Economic Activity & People and Communities</u>

11.23 No constraints appraised within this sub-topic are considered material to the decision at this level of appraisal. However key socio-economic issues have been identified.

11.24 Socio-economic impacts are considered to be more extensive during construction than during operation. Areas that are considered likely to receive most of the direct socio-economic impacts during construction are Anglesey and Menai Strait.

Construction is estimated to take approximately two years for overhead line technology and around four years for buried technology.

11.25 Some localised disruption during construction is expected for road networks across Anglesey, Gwynedd and North Wales. This could temporarily impact local communities, businesses and access to public service infrastructure.

11.26 Regionally, transport disruption could have a low to moderate impact on the tourism industry as tourism is one of the region's largest sources of employment.

11.27 Potential benefits from this option include an increase in economic activity due to a specialised work force being located in the area for approximately four years and the opportunities for local employment.

12 Appraisal of Strategic Option 4

12.1 The main works required for Strategic Option 4, Wylfa to Pentir Offshore East, are:

- installation of new 400 kV GIS switchgear at Wylfa
- installation of subsea cable circuits (AC or HVDC) between Wylfa and Pentir, a distance of 64 km around the east of Anglesey
- common works to connect Wern and Y Garth, as described in section 9
- other common works, as described in section 10, and
- for HVDC, the installation of three converter stations at Wylfa and three at Pentir.

12.2 The study area for this strategic option is shown in Figure 12.1. It is based on a direct route, which all other things being equal, would give rise to the lowest impacts and costs. It is bounded by the Anglesey coast to the west and a 10 km wide swathe to the east and south to provide reasonable opportunity to avoid constraints.

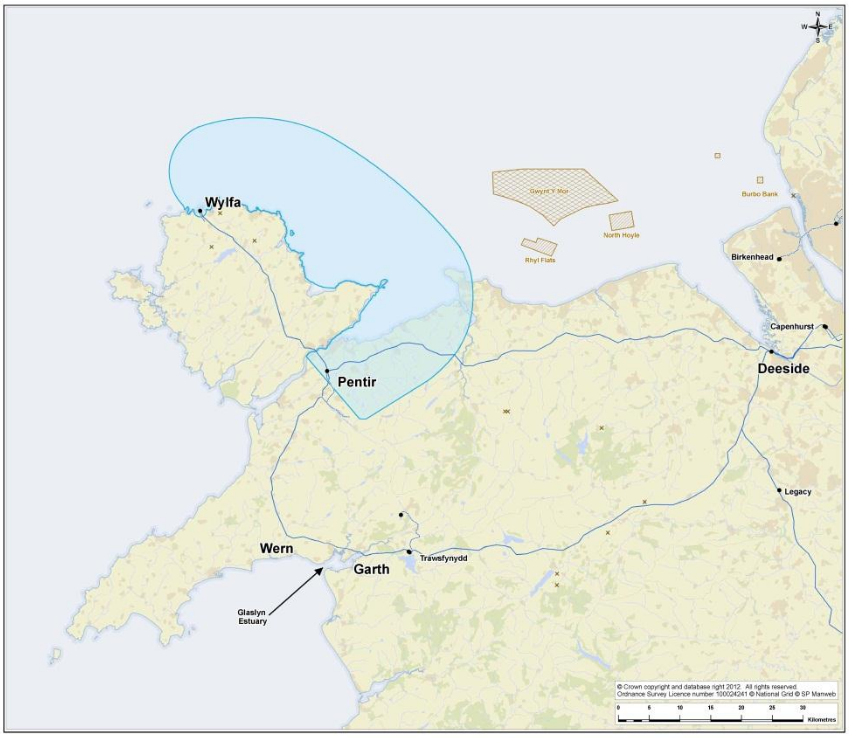

Figure 12.1 – Study Area for Strategic Option 4

12.3 The study area therefore includes an area around the existing Wylfa power station, a large area on the North Wales mainland including Bangor and Llandudno, a large area offshore, east of Anglesey including the Irish Sea and Conwy Bay.

12.4 The following paragraphs set out the results of the option appraisal.

Technical and Cost Appraisal

12.5 The offshore connections between Wylfa and Pentir could be made using either of the following technologies:

- Subsea AC cables (two circuits), and
- HVDC (three circuits)

Subsea AC and HVDC Cables

12.6 The cable installations would have landfall sites at or near Wylfa substation and also somewhere on the North Wales mainland west of Llandudno. They would follow a route from the landfall to Pentir substation.

12.7 There is a security risk relating to subsea cable close into shorelines with tidal movements.

12.8 In the event of faults, cable installations are out of service for longer periods than overhead lines, particularly subsea cable installations.

Subsea AC Cables

12.9 Installation of this scale of AC cable system presents a number of technical issues which are likely to be surmountable but which must be carefully considered in cable system design and implementation.

HVDC

12.10 The HVDC option would require three converter stations at Wylfa and three at Pentir, each typically having the footprint of a large warehouse and being around 25 m in height.

12.11 2 GW VSC HVDC converters are not presently available and there may not be sufficient commercial benefit to incentivise manufacturers to develop converters of such ratings. If this were to happen, multiple converter stations of a lower rating would be required. Use of multiple converters would increase delivery costs and land-take requirements. VSC design developments are therefore being monitored closely.

12.12 In the event of the existing AC connection being de-energised (either planned or unplanned), the nuclear power station would be connected to the transmission system solely by HVDC. To date, no nuclear power station in the world has been connected solely by HVDC circuits. The use of HVDC for the nuclear power station connection circuits in this project is thus considered to represent an unproven technology risk which may result in material additional costs and delays being incurred to develop an acceptable solution.

Costs

12.13 The capital and lifetime cost estimates for this option are shown in tables 12.1 and 12.2.

Item	Need	Cost	
AC Cable between Wern and Y Garth *	Increase capacity across boundaries 2 and 3.	£132m	
Common works	Increase capacity in North Wales	£387m	
Wylfa 400 kV substation	Connect Wylfa power station and the new circuits	£154m	
New Circuits		**AC Cable**	**HVDC**
Wylfa to Pentir ('Hi' Capacity, 64 km)	Connect Wylfa to Pentir creating Wylfa export capability	£1,484m	£1,236m
Total Capital Cost		**£2,157m**	**£1,909m**

Table 12.1 Strategic Option 4 – Wylfa - Pentir Offshore East: Capital Cost Estimates

	AC Cable	HVDC
Capital Cost of New Circuits	£1,484m	£1,236m
NPV of Cost of Losses over 40 years	£138m	£471m
NPV of Operation & Maintenance Costs over 40 years	£9m	£128m
Lifetime Cost of New Circuits [23]	**£1,631m**	**£1,835m**

Table 12.2 Strategic Option 4 Wylfa - Pentir Offshore East New Circuits: Capital and Lifetime Cost Estimates

* Note that for the purposes of comparison and to understand the total cost of this strategic option, the capital cost of an AC cable between Wern and Y Garth has been included in this table.

12.14 In summary, the estimated capital costs for connections off the east coast of Anglesey range from £1,909m for an HVDC system to £2,157m for AC cables. The estimated lifetime costs ranges from £1,631m for AC cables to £1,835m for an HVDC system.

Environmental - Ecology and Biodiversity

12.15 The principal ecological sites affecting this option are shown in Figure G.7 in Appendix G of this report. There are nine ecological constraints within the study

[23] The lifetime cost calculation methodology is explained in Appendix D. It is used to compare the cost of connecting transmission substations using various technologies for the new circuits. It does not include the capital or lifetime costs of substation equipment. The lifetime cost is the net present value of capital costs, the costs of transmission losses and maintenance costs over 40 years. A discount rate of 3.5% is used.

area on the east side of Anglesey which are considered to be material to the decision.

- Menai Strait and Conwy Bay SAC
- Liverpool bay SPA
- Lavan Sands SSSI, Important Bird Area and Lavan Sands Conway Bay SPA
- Coedydd Aber SSSI and SAC
- Aber Afon Conwy SSSI
- Eryi SSSI
- Great Ormes Head SSSI

12.16 All but two can be avoided through careful routeing; Liverpool Bay SPA and Menai Strait and Conwy Bay SAC. The high concentration of ecological constraints near Menai Strait results in available landing points and transmission routes to Pentir being limited, and increases the risk of significant effects upon the integrity of two Natura 2000 sites as a result of the installation of the submarine cables.

Environmental - Cultural Heritage, Landscape and Visual

12.17 The principal cultural heritage and landscape designations affecting this option are shown in Figure G.7 in Appendix G of this report. The study area including Anglesey and the Gwynedd mainland between the coast and Pentir has four cultural heritage, landscape and visual constraints considered to be material to the decision. All are registered as outstanding Landscapes of Historic Interest in Wales.

- North Arllechwedd, Gwynedd / Conwy
- Ogwen Valley, Gwynedd
- Penmon, Anglesey
- Dinorwig, Gwynedd.

12.18 While Penmon landscape can be easily avoided and North Arllechwedd and the Ogwen Valley can also be avoided. However due to their large geographical spread avoiding both of these would significantly limit available transmission routes to Pentir. The Dinorwig landscape is unavoidable as the existing substation is within this landscape. While the 'Landscape of Outstanding Interest' designation affords no additional statutory protection, they are likely to be areas of greater landscape sensitivity from a heritage perspective, especially susceptible to the greater intrusion that would be associated with HVDC technology and the related converter stations at Pentir.

12.19 It is noted that converter stations near Wylfa may indirectly affect the AONB but this will be seen in context with other developments in this area.

12.20 Converter stations located in the vicinity of Pentir substation would be around 5 km from the boundary of Snowdonia National Park, and due to the elevation of the land within the Park and the scale of the converter station buildings, impacts to views from the Park are possible. While Pentir's remote rural location is likely to result in adverse landscape effects (despite the presence of existing transmission infrastructure) visual effects are likely to be localised.

Environmental – Other Sub-topics

12.21 No constraints considered to be material to the decision within the sub-topics noise and vibration, soil and geology and hydrology and flood risk have been identified. It should be noted that Menai Strait and Wharf Bay are designated Shellfish Waters and are considered material to the decision. Both can be avoided, however Menai Strait shellfish waters would significantly reduce available transmission routes for the offshore cables.

Environmental - Consideration of combined Environmental Sub-topics

12.22 The study areas around Menai have a high concentration of environmental constraints. The concentration of environmental constraints around the east end of Menai Strait (onshore and offshore) is considered material to the decision as it is not possible to bring the cables on land to Pentir without impacting on one or more constraints (offshore constraints and onshore).

Socio-Economic - Economic Activity & People and Communities

12.23 No constraints appraised within this sub-topic are considered material to the decision at this level of appraisal. However key socio-economic issues have been identified.

12.24 Socio-economic impacts are considered to be more extensive during construction than during operation.

12.25 It has been assumed that a high proportion of the workforce required for this project will need to be specialised. This would be expected to result in migration to the respective regions for the duration of the construction works (approximately four years).

12.26 Any localised disruption during construction for road and rail networks between Wylfa and Pentir is expected to be slight as the majority of the works is offshore. However, it is expected to be moderate around the Bangor and Bethesda area due to the installation of underground cables between the coast and Pentir.

12.27 Potential benefits from this strategic option include an increase in economic activity due to a specialised work force being located in the area for approximately four years and the opportunities for local employment.

13 Appraisal of Strategic Option 5

13.1 The main works required for Strategic Option 5, Wylfa to Pentir Offshore West, are:

- installation of new 400 kV switchgear at Wylfa
- installation of subsea cable circuits (AC or HVDC) between Wylfa and Pentir, a distance of 80 km around the west of Anglesey
- common works to connect Wern and Y Garth, as described in section 9
- other common works, as described in section 10, and
- for HVDC, the installation of three converter stations at Wylfa and three at Pentir.

13.2 The study area for this strategic option is shown in Figure 13.1. It is based on a direct route, which all other things being equal, would give rise to the lowest impacts and costs. It is bounded by the Anglesey coast to the east and a 10 km wide swathe to the west and south to provide reasonable opportunity to avoid constraints, and includes a large tract of the east of Penygroes.

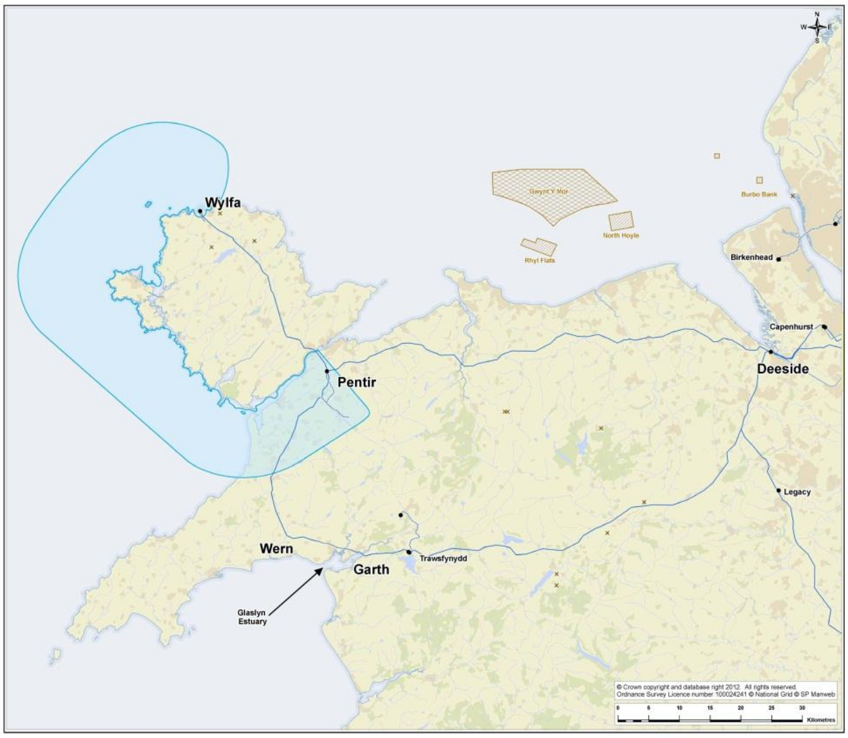

Figure 13.1 – Study Area for Strategic Option 5

13.3 The study area therefore includes an area around the existing Wylfa power station, a large area on the North Wales mainland including Caernarfon and a large area offshore west of Anglesey, including the Irish Sea and Caernarfon Bay.

13.4 The following paragraphs set out the results of the option appraisal.

Technical and Cost Appraisal

13.5 The offshore connections between Wylfa and Pentir could be made using either of the following technologies:

- AC Subsea cables (two circuits), and
- HVDC (three circuits)

Subsea AC and HVDC Cables

13.6 The cable installations would have landfall sites at or near Wylfa substation and also somewhere on the North Wales mainland west of Pentir. They would follow a route from the landfall to Pentir substation.

13.7 There is a security risk relating to subsea cable close into shorelines with tidal movements.

13.8 In the event of faults, cable installations are out of service for longer periods than overhead lines, particularly subsea cable installations.

AC Subsea Cables

13.9 Installation of this scale of AC cable system presents a number of technical issues which are likely to be surmountable but which must be carefully considered in cable system design and implementation.

HVDC

13.10 The HVDC option would require three converter stations at Wylfa and three at Pentir, each typically having the footprint of a large warehouse and being around 25 m in height.

13.11 2 GW VSC HVDC converters are not presently available and there may not be sufficient commercial benefit to incentivise manufacturers to develop converters of such ratings. If this were to happen, multiple converter stations of a lower rating would be required. Use of multiple converters would increase delivery costs and land-take requirements. VSC design developments are therefore being monitored closely.

13.12 In the event of the existing AC connection being de-energised (either planned or unplanned), the nuclear power station would be connected to the transmission system solely by HVDC. To date, no nuclear power station in the world has been connected solely by HVDC circuits. The use of HVDC for the nuclear power station connection circuits in this project is thus considered to represent an unproven technology risk which may result in material additional costs and delays being incurred to develop an acceptable solution.

Costs

13.13 The capital and lifetime cost estimates for this option are shown in tables 13.1 and 13.2.

Item	Need	Cost	
AC Cable between Wern and Y Garth *	Increase capacity across boundaries 2 and 3.	£132m	
Common works	Increase capacity in North Wales	£387m	
Wylfa 400 kV substation	Connect Wylfa power station and the new circuits	£154m	
New Circuits		**AC Cable**	**HVDC**
Wylfa to Pentir ('Hi' Capacity, 80 km)	Connect Wylfa to Pentir creating Wylfa export capability	£1,859m	£1,320m
Total Capital Cost		**£2,532m**	**£1,993m**

Table 13.1 Strategic Option 5 – Wylfa - Pentir Offshore West: Capital Cost Estimates

	AC Cable	HVDC
Capital Cost of New Circuits	£1,859m	£1,320m
NPV of Cost of Losses over 40 years	£171m	£471m
NPV of Operation & Maintenance Costs over 40 years	£12m	£128m
Lifetime Cost of New Circuits [24]	**£2,042m**	**£1,919m**

Table 13.2 Strategic Option 5 Wylfa - Pentir Offshore West New Circuits: Capital and Lifetime Cost Estimates

* Note that for the purposes of comparison and to understand the total cost of this strategic option, the capital cost of an AC cable between Wern and Y Garth has been included in this table.

13.14 In summary, the estimated capital costs for connections off the west coast of Anglesey range from £1,993m for an HVDC system to £2,532m for AC cables. The estimated lifetime costs range from £1,919m for an HVDC system to £2,042m for AC cables.

Environmental - Ecology and Biodiversity

13.15 The principal ecological sites affecting this option are shown in Figure G.8 in Appendix G of this report. There are five ecological constraints within the study area on the west side of Anglesey which are considered to be material to the

[24] The lifetime cost calculation methodology is explained in Appendix D. It is used to compare the cost of connecting transmission substations using various technologies for the new circuits. It does not include the capital or lifetime costs of substation equipment. The lifetime cost is the net present value of capital costs, the costs of transmission losses and maintenance costs over 40 years. A discount rate of 3.5% is used.

decision;

- Abermenai to Aberffraw Dunes SAC
- Afon Gwyrfai A Llyn Cwellyn SAC and SSSI
- Y Foryd SSSI
- Morfa Dinlle SSSI.

13.16 All but two sites can be avoided - Afon Gwyrfai A Llyn Cwellyn SAC and SSSI. Given the limited width of this protected river corridor, appropriate construction techniques should be able to mitigate effects to these designations.

Environmental - Cultural Heritage, Landscape and Visual

13.17 The principal cultural heritage and landscape designations affecting this option are shown in Figure G.8 in Appendix G of this report. Within the study area on Anglesey and the Gwynedd mainland between the coast and Pentir three landscape and visual constraints are considered to be material to the decision:

- Dinorwig Landscape of Historic Interest, Gwynedd (registered as outstanding)
- North Anglesey Coast Heritage Coast
- Isle of Anglesey Coastal Path Designated National Trail.

13.18 Dinorwig landscape and the coastal path cannot be avoided. Caernarfon and Llandwrog have a high concentration of heritage assets. However, both areas can be avoided.

13.19 It is noted that converter stations near Wylfa may indirectly affect the AONB but this will be seen in context with other developments in this area.

13.20 Converter stations located in the vicinity of Pentir substation would be around 5 km from the boundary of Snowdonia National Park, and due to the elevation of the land within the Park and the scale of the converter station buildings, impacts to views from the Park are possible. While Pentir’s remote rural location is likely to result in adverse landscape effects (despite the presence of existing transmission infrastructure) visual effects are likely to be localised.

Environmental – Other Sub-topics

13.21 No constraints considered to be material to the decision within the sub-topics noise and vibration, soil and geology and hydrology and flood risk have been identified. It should be noted that Menai Strait and Malltraeth Bay are designated Shellfish Waters and are considered material to the decision. Both can be avoided, however Menai Strait shellfish waters would significantly reduce available transmission routes for the offshore cables.

Environmental - Consideration of combined Environmental Sub-topics

13.22 While there are a number of cultural heritage and ecological constraints within and close to Menai Strait in combination they are not considered to represent a more material consideration than if considered in isolation, as route options to avoid these constraints would not be further restricted in a significant way.

Socio-Economic - Economic Activity & People and Communities

13.23 No constraints appraised within this sub-topic are considered material to the decision at this level of appraisal. However, key socio-economic issues have been identified.

13.24 Socio-economic impacts are considered to be more extensive during construction than during operation.

13.25 It has been assumed that a high proportion of the workforce required for this project will need to be specialised. This would be expected to result in migration to the respective regions for the duration of the construction works (approximately four years).

13.26 Any localised disruption during construction for road and rail networks across Anglesey, Gwynedd and North Wales is expected to be slight as the majority of the works is offshore.

13.27 Potential benefits from this strategic option include an increase in economic activity due to a specialised work force being located in the area for approximately four years and the opportunities for local employment.

14 Conclusions

14.1 National Grid has identified a need to develop the electricity transmission system within North Wales which is based on contracts between National Grid and parties committed to connecting their generation projects.

14.2 An initial set of potential strategic options which might meet the requirements was identified.

14.3 Designs which did not satisfy the requirements of the NETS SQSS were discounted and not explored further.

14.4 The remaining potential strategic options were reviewed to identify those which would not offer any significant benefit over other options. Section 5 of this report identifies those options which did not get through this process and have been parked. However, they have been documented in order that some or all may be re-visited at any stage in the project if appropriate.

14.5 Five strategic options remained:

Option 1 - Three subsea HVDC circuits between Wylfa and Deeside substations, modifications at Wylfa and Deeside 400 kV substations and three converter stations at Wylfa and three at Deeside.

Option 2 - Two subsea HVDC circuits between Wylfa and Deeside, one subsea HVDC circuit between Wylfa and Pembroke, modifications at Wylfa, Deeside and Pembroke 400 kV substations, three converter stations at Wylfa, two at Deeside and one at Pembroke

Option 3 – New onshore circuits connecting Wylfa and Pentir (AC or HVDC), one new AC circuit installed on existing pylons between Pentir and Trawsfynydd, a new connection between Wern and Y Garth, a new substation in West Gwynedd, re-conductoring of existing circuits in North Wales, the installation of series compensation equipment and modifications at existing substations.

Option 4 – New offshore circuits east of Anglesey connecting Wylfa and Pentir (AC or HVDC), one new AC circuit between Pentir and Trawsfynydd, a new connection between Wern and Y Garth, a new substation in West Gwynedd, re-conductoring of existing circuits in North Wales, the installation of series compensation equipment and modifications at existing substations.

Option 5 – New offshore circuits west of Anglesey connecting Wylfa and Pentir (AC or HVDC), one new AC circuit between Pentir and Trawsfynydd, a new connection between Wern and Y Garth, a new substation in West Gwynedd, re-conductoring of existing circuits in North Wales, the installation of series compensation equipment and modifications at existing substations.

14.6 These strategic options (described in more detail in section 6 of this report) were assessed having regard to the following matters:

- relevant technical, environmental, socio-economic and cost factors relevant to each option
- the technology options available for each strategic option
- capital and lifetime costs of each strategic option, as well costs for each technology option,

and the results of this appraisal are set out in sections 7 to 13 of this report. These appraisals represent the first step to ensuring that any final proposal is an appropriate design response to the functional requirements and aesthetic considerations.

14.7 There are a number of different technologies associated with the strategic options:

- AC overhead line
- AC underground cable
- AC subsea cable
- AC Gas Insulated Line, and
- High Voltage Direct Current.

14.8 The following paragraphs discuss the main conclusions of the strategic option appraisal.

Strategic Option 1 - Three HVDC subsea circuits connecting Wylfa and Deeside

14.9 There is a high concentration of environmental constraints that could be material to this option; offshore, in the Dee Estuary and along both banks of the Dee Estuary. These include the 'Natura 2000' sites of the Dee Estuary SAC and SPA (and Ramsar site) and Liverpool Bay SPA, the latter of which could not be avoided (although it might be possible to avoid significant effects upon the site, which is primarily designated for its overwintering populations of seabirds, through appropriate mitigation). The concentration of other onshore constraints could limit the opportunities for cable routeing in both North Wales and the Wirral. The converter stations at Wylfa would indirectly impact views from the Anglesey AONB, although this would be seen in the context of the potential new nuclear power station. Similarly, the converter stations at Deeside are not anticipated to result in unacceptable landscape or visual impacts given the industrial nature of the landscape in the vicinity.

14.10 2 GW VSC HVDC converters are not currently installed anywhere in the world. While National Grid is reasonably confident that such a system will be available in time for this project there is a significant degree of uncertainty relating to the final cost. VSC design developments are therefore being monitored closely.

14.11 An additional technical risk is that, in the event of the existing AC circuits being de-energised, the proposed nuclear power station would be connected to the transmission system solely by HVDC. This represents a technology risk which may result in material additional costs and delays being incurred to develop an acceptable solution.

Costs

14.12 With an estimated capital cost of £1,641m and an estimated lifetime cost of the new circuits of £2,056m, this option is significantly more expensive than the onshore overhead line options (more than double) and broadly comparable with the onshore underground options.

Strategic Option 2 - Two HVDC subsea circuits connecting Wylfa and Deeside and one HVDC subsea circuit connecting Wylfa and Pembroke

14.13 The principal receptors and risk levels for the two HVDC circuits and associated converter stations at Wylfa and Deeside are as described above for Strategic Option 1. The reduction in the number of circuits and converter stations from three to two at Deeside is not considered to alter the assessment of risk associated with these elements at this strategic level.

14.14 The introduction of an HVDC cable route to Pembroke would result in impacts to additional receptors. While the industrial nature of the landscape around Pembroke substation means a significant visual impact is not anticipated, the HVDC cable route would have to pass through two additional ecological sites, the Pembrokeshire Marine SAC being of particular note. The general concentration of other constraints in Pembrokeshire, including Pembrokeshire Coast National Park and Heritage Coasts, would also limit opportunities for cable routeing.

14.15 As with Strategic Option 1, this option also has the significant technical and financial risks that no VSC HVDC system of this capacity is currently installed anywhere in the world and that the proposed nuclear power station would be connected to the transmission system solely by HVDC in the event of the existing AC circuits being de-energised, the implications of which are still being assessed.

Costs

14.16 The estimated capital cost of this option is £1,877m and the estimated lifetime cost of the new circuits is £2,247m. It has a higher estimated cost than Strategic Option 1 (about 10%) due to the additional distance to Pembroke.

Strategic Option 3 New onshore circuits connecting Wylfa and Pentir (AC or HVDC), one new AC circuit between Pentir and Trawsfynydd to be installed on existing pylons, a new connection between Wern and Y Garth, a new substation in West Gwynedd, re-conductoring of existing circuits in North Wales, the installation of series compensation equipment and modifications at existing substations.

14.17 There are a number of technology options relating to this strategic option. The use of AC underground cable, GIL, HVDC and AC overhead line were considered for the Wylfa to Pentir connection. Underground cable, GIL and overhead line were considered for the connection between Wern and Y Garth. The main conclusions of the assessment of this option are discussed in the following paragraphs.

Wylfa to Pentir connection

14.18 The use of underground cables (AC or HVDC) or GIL between Wylfa and Pentir would avoid significant impact arising from landscape and visual effects in the study area. While the cable route would necessarily pass through a 'Natura 2000' site, Menai Strait SAC, the assumed use of an underground tunnel should reduce or avoid significant impacts to this receptor. The high concentration of cultural heritage receptors, especially around Menai Strait, would limit available route options.

14.19 GIL as an alternative technology is unproven for designs of this voltage, scale and capacity.

14.20 A wholly overhead line between Wylfa and Pentir, including across Menai Strait, would necessarily pass through the Anglesey AONB. Other constraints on the island are scattered and more easily avoided by routeing. Various mitigation measures would be possible to reduce or avoid impacts to the AONB and other sensitive receptors. The high concentration of sensitive receptors bordering Menai Strait, both from a landscape and visual and cultural heritage perspective, would limit transmission route options.

Wern to Y Garth connection

14.21 Within the study area at Glaslyn, there are two Registered Parks and Gardens, Snowdonia National Park and a number of settlements, particularly Porthmadog and Tremadog. While it would be possible to route around these areas, an overhead line would result in a very high impact from landscape and visual effects, especially in the case of an overhead line. The route would also have to pass through one of two SSSIs in the area, and close to or though the Meirionnydd Oakwoods and Bat Sites SAC. Impacts to these sites would be less material in the case of an overhead line.

New substation in West Gwynedd

14.22 Establishing the second Pentir to Trawsfynydd circuit means that the local DNO, SP Manweb, requires an alternative means of supplying electricity to the Llyn

Peninsula. The associated works that would be required by SP Manweb have yet to be fully established but the working assumption is that a new substation will be required in West Gwynedd.

Costs

14.23 The capital costs for this option range from £749m for overhead line between Wylfa and Pentir to £1,862m for HVDC, both assuming underground AC cables are used between Wern and Y Garth. Lifetime costs for the new circuits range from £169m to £1,818m, again for overhead line and HVDC, with underground AC cables between Wern and Y Garth.

Strategic Option 4 New offshore circuits east of Anglesey connecting Wylfa and Pentir (AC or HVDC), one new AC circuit between Pentir and Trawsfynydd to be installed on existing pylons, a new connection between Wern and Y Garth, a new substation in West Gwynedd, re-conductoring of existing circuits in North Wales, the installation of series compensation equipment and modifications at existing substations.

14.24 There are a number of technology options relating to this strategic option. The use of subsea AC cable and HVDC were considered for the Wylfa to Pentir connection and, as with Strategic Option 3, underground AC cable, GIL and overhead line were considered for the connection between Wern and Y Garth. The main conclusions of the assessment of this option are discussed in the following paragraphs.

Wylfa to Pentir connection

14.25 The use of subsea cables would largely avoid terrestrial impacts on Anglesey. However, the cables buried in the seabed to the east of the Island would have to pass through both the Liverpool Bay SPA and Menai Strait and Conwy Bay SAC. While the impact to the SPA is likely to be limited due to the nature of its features of interest, the potential impacts to the SAC represent a risk that the works could affect the site's integrity although mitigation measures would be available.

Wern to Y Garth connection and the new substation in West Gwynedd

14.26 For Strategic Option 4, works between Wern and Y Garth and the new substation in West Gwynedd would be the same as for Strategic Option 3 (see paragraphs 14.21 and 14.22 above).

Costs

14.27 The capital costs for this option range from £1,909m for HVDC between Wylfa and Pentir to £2,157m for subsea AC cables, both assuming underground AC cables are used between Wern and Y Garth. Lifetime costs for the new circuits range from £1,613m to £1,835m, again for subsea AC cables and HVDC, with underground AC cables between Wern and Y Garth.

Strategic Option 5 New offshore circuits west of Anglesey connecting Wylfa and Pentir (AC or HVDC), one new AC circuit between Pentir and Trawsfynydd to be installed on existing pylons, a new connection between Wern and Y Garth, a new substation in West Gwynedd, re-conductoring of existing circuits in North Wales, the installation of series compensation equipment and modifications at existing substations.

14.28 There are a number of technology options relating to this strategic option. The use of subsea AC cable and HVDC were considered for the Wylfa to Pentir connection and, as with strategic options 3 and 4, underground AC cable, GIL and overhead line were considered for the connection between Wern and Y Garth. The main conclusions of the assessment of this option are discussed in the following paragraphs.

Wylfa to Pentir connection

14.29 The use of subsea cables would largely avoid terrestrial impacts on Anglesey. Routeing the cables to the west of the Island would avoid the marine 'Natura 2000' sites that the east route would impact. Cable routeing opportunities between the coast and Pentir also appear less constrained for the western marine cable options.

Wern to Y Garth connection and new substation in West Gwynedd

14.30 For Strategic Option 5, works between Wern and Y Garth and the new substation in West Gwynedd would be the same as for Strategic Option 3 (see paragraphs 14.21 and 14.22 above).

Costs

14.31 The capital costs for this option range from £1,993m for HVDC between Wylfa and Pentir to £2,532m for subsea AC cables, both assuming underground AC cables are used between Wern and Y Garth. Lifetime costs for the new circuits range from £1,919m to £2,042m, for HVDC and subsea AC cables, with underground AC cables between Wern and Y Garth.

Differentiating factors between all options

14.32 When comparing the results of the option appraisals, it is clear that the appraisal topics which differentiate the strategic options most significantly are (i) visual and landscape amenity, and (ii) cost, both capital and lifetime. Other material impacts were also identified but these are the most significant differentiating factors.

14.33 Those strategic options with an overhead line component have the highest risk of visual and landscape effects, particularly given the proximity of a number of sensitive areas, such as the Anglesey AONB and Snowdonia National Park, impacts which cannot be completely avoided by careful route selection (although noting these may be mitigated by other means). The strategic option with the most significant overhead line component (in terms of absolute distance) is option 3 with an overhead line from Wylfa to Pentir. Strategic options 1 and 2 (subsea HVDC options) and strategic options 4 and 5, with underground technology between Wern and Y Garth, do not include any overhead line component. These strategic options, therefore, have the lowest risk of visual and landscape impacts. Strategic options 4 and 5 could include an overhead line component between Wern and Y Garth only.

14.34 In terms of cost, it is generally true that the more extensive the overhead line component of an option the lower the cost. The relative and absolute capital costs of each strategic option (and technology options) are illustrated in Figure 14.1. (Note that for simplification, each option includes the capital cost of underground cable between Wern and Y Garth.)

14.35 It can be seen that the difference in cost is very significant with the estimated cost of the most expensive option (AC cable offshore west and underground at Wern to Y Garth) being more than three times the estimated cost of the least expensive option (overhead line between Wylfa and Pentir and underground at

Wern to Y Garth).

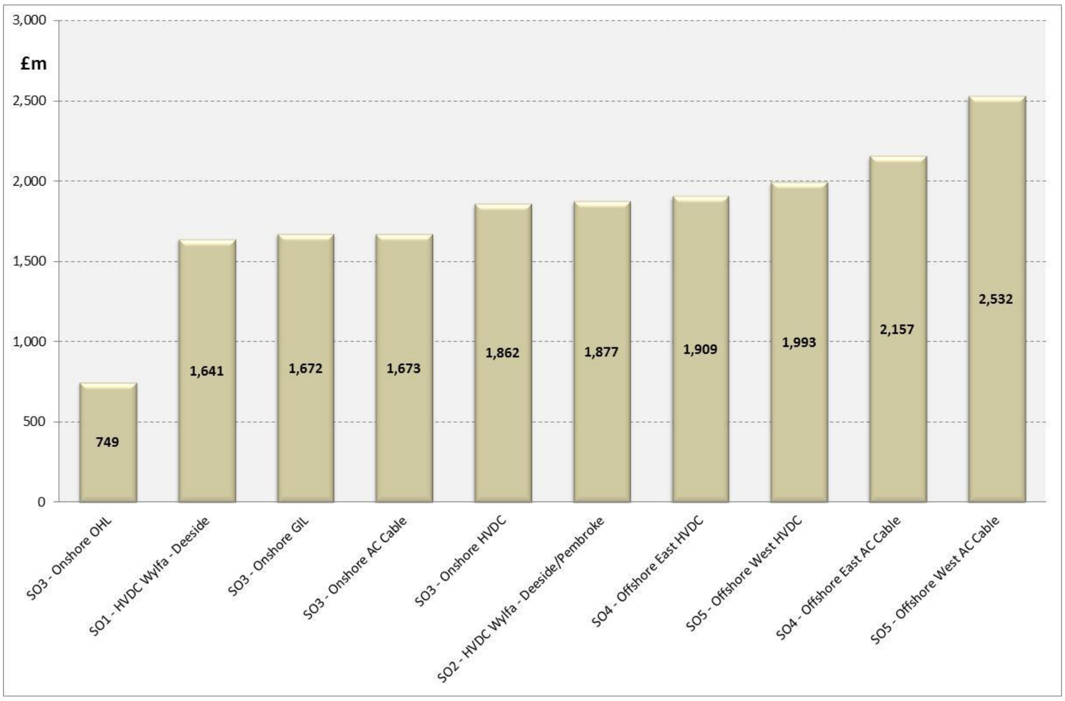

Figure 14.1 – Estimated Capital Costs

14.36 It is also evident that the lowest cost option without an overhead line element is more than double the cost of those with an overhead line element.

Decision Making

14.37 With regard to cost, National Grid has a statutory duty to develop and maintain an efficient, co-ordinated and economical system of electricity transmission under Section 9 the Electricity Act.

14.38 This statutory duty is specifically recognised in paragraph 2.3.5 of the National Policy Statement for Electricity Networks Infrastructure, EN-5, which states that the IPC should take into account that National Grid is required under 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."*

14.39 With regard to visual and landscape impacts, National Grid also has statutory duties including those under the Electricity Act to have regard to amenity and mitigate the impacts of its projects. However, paragraph 2.8.2 of EN-5 states that the Government does not believe that the development of overhead lines is generally incompatible in principle with this statutory duty. While recognising that overhead lines can give rise to adverse landscape and visual impacts it also recognises that for the most part these impacts can be mitigated. It is acknowledged that at particularly sensitive locations the potential adverse landscape and visual impacts of an overhead line proposal may make it unacceptable in planning terms, taking account of the specific local environment and context.

14.40 Paragraph 2.8.9 of EN-5 states that *"the IPC should […] 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."*

Development Consents Required

14.41 On the basis of the strategic options appraisal, early consultation feedback and mitigation likely to be available, National Grid believes that the risks of impacts identified so far are not sufficient for it to conclude that any of the strategic options are likely to be incapable in principle of receiving the necessary development consents.

14.42 In particular, National Grid believes that appropriate mitigation, potentially including the selective use of underground technologies, would be available to reduce the visual and landscape effects arising from an overhead line between Wylfa and Pentir to acceptable levels in terms of paragraph 2.8.2 of EN-5. National Grid also believes that the benefit of a reduced visual and landscape impact between Wylfa and Pentir would not clearly outweigh, in terms of paragraph 2.8.9 of EN-5, the very significant additional cost of more than £900m such that the Planning Inspectorate should refuse consent for an overhead line in favour of an underground or subsea line.

Preliminary Preferred Option

Wern to Y Garth Connection

14.43 Before drawing conclusions on the preliminary preferred option, it is helpful to first consider the most appropriate technology to be used between Wern and Y Garth in strategic options 3, 4 and 5. The strategic options appraisal and results of early consultation feedback have identified sensitive receptors that could be affected by all or much of any overhead transmission route crossing the Estuary. Furthermore, National Grid has identified that none of the technology options could avoid the Estuary through careful routeing. On this basis, National Grid believes that the higher comparative cost of £121m (£132m less £11m in table 9.1) and other impacts arising from the installation of a cable under the Estuary are likely to be justified by avoiding the higher landscape and visual impacts associated with an overhead line. This accords with a previous decision made by the Secretary of State in 1964, which determined that the proposed transmission line between Wern and Y Garth should be underground. Therefore, National Grid believes that, on the basis of the appraisal undertaken to date, an underground cable between Wern and Y Garth is likely to achieve the most appropriate balance between its technical, economic, amenity and environmental obligations.

Overall Comparison of Strategic Options

14.44 Having made a preliminary decision to utilise underground cable between Wern and Y Garth, only one option, Strategic Option 3, potentially has a new overhead line element – connecting Wylfa and Pentir. National Grid needs to consider, therefore, the benefits and disbenefits of strategic options 1, 2, 3 (non-overhead line), 4 and 5 in comparison with the overhead line version of Strategic Option 3 ("SO3-OHL").

14.45 National Grid recognises that appropriately balancing technical requirements, its economic duties and its duty to have regard to amenity and mitigate impacts means that the lowest cost consentable solution is not necessarily the most appropriate option in every case. However, in this case National Grid considers that any benefits of strategic options 1, 2, 3 (non-overhead line), 4 and 5 do not outweigh the very significant additional economic impact (£892m – £1,783m in capital cost) as compared to SO3 – OHL.

14.46 Accordingly, in the light of the options appraisal to date and early consultation feedback, the initial view of National Grid is that Strategic Option 3, new overhead line circuits connecting Wylfa and Pentir (with appropriate mitigation, potentially including the use of underground technologies), one new circuit connecting Pentir and Trawsfynydd, underground cables connecting Wern and Y Garth, a new substation in West Gwynedd, along with re-conductoring of existing circuits, could achieve an appropriate balance between National Grid's technical, economic, amenity and environmental obligations.

14.47 Figure 14.2 illustrates the relative and absolute capital costs for the Wylfa to Pentir onshore technology options and illustrates emphatically the very significant cost differences. It excludes all common costs such as Wylfa 400 kV substation and modifications at Pentir 400 kV substation.

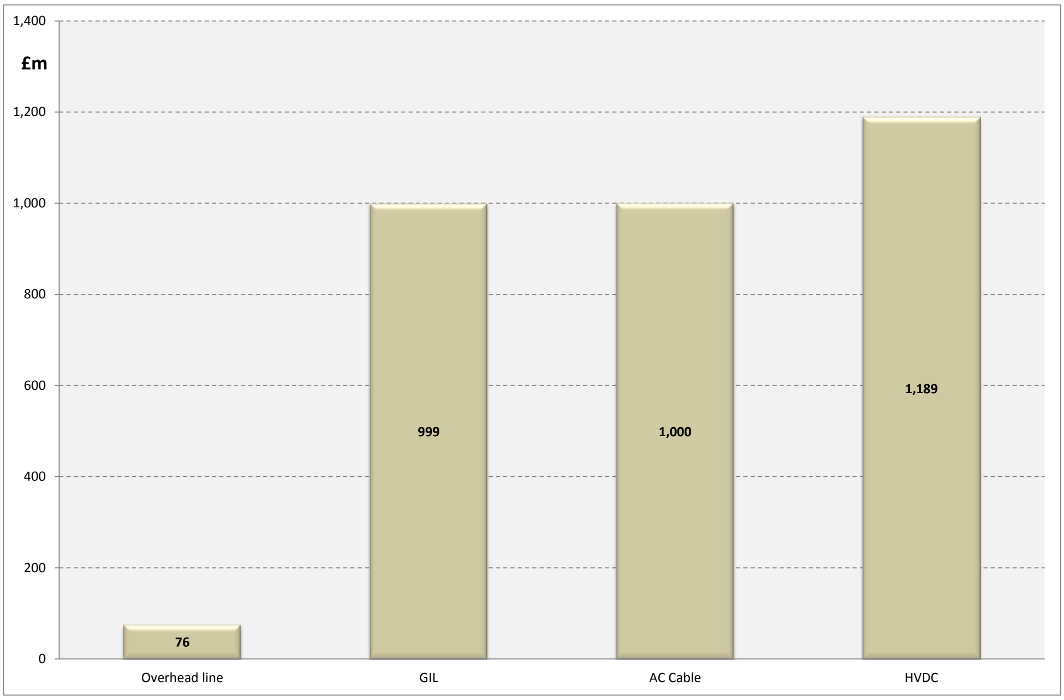

Figure 14.2 – Wylfa to Pentir Onshore Estimated Capital Costs

Conclusion

14.48 Following the strategic options appraisal, National Grid's preliminary preferred option is for an overhead line (with appropriate mitigation, potentially including the use of underground technologies) between Wylfa and Pentir and an underground AC cable between Wern and Y Garth, the "Preliminary Preferred Option". National Grid has decided to take forward the Preliminary Preferred Option to the route corridor stage of the options appraisal process for further detailed appraisal and consultation.

Assumptions

14.49 Certain assumptions have been made in reaching the conclusions set out above. These include an assumption that adequate mitigation of landscape and visual and other impacts will be possible between Wylfa and Pentir. As indicated, such mitigation potentially includes the use of underground technologies for certain parts of the route. Until route corridors are identified and the sensitivity established through further detailed appraisal and consultation, it is generally not possible to identify where the use of underground technologies might be appropriate. The use of underground technologies is likely to be most appropriate in those areas subsequently identified as particularly sensitive. In this context early feedback from key statutory consultees has already raised concerns about the sensitivity of the Anglesey AONB to overhead line development which would be considered in more detail at the next stage of option appraisal. The potential benefits in environmental terms of using underground cables at particularly sensitive locations between Wylfa and Pentir will need to be considered in light of any associated technical challenges, especially those associated with crossing Menai Strait. A tunnel may be required at significant additional cost.

14.50 Other assumptions made at this stage of the assessment include that the use of underground technologies between Wern and Y Garth, and any other areas where the use of overhead line may be inappropriate, is technically feasible and still appropriate in light of the other impacts, including ecological impacts, associated with it.

14.51 National Grid recognises that the cost of mitigation measures will increase the capital cost of any strategic option. However, having regard to the outcomes of the strategic option appraisal and early stakeholder consultation, National Grid believes that these additional costs (including the cost of a tunnel under Menai Strait) are unlikely to be so significant as to sufficiently close the cost gap between the Preliminary Preferred Option and other options so as to alter the choice of Preliminary Preferred Option.

14.52 These assumptions, including those made on available mitigation, will be considered in more detail as the options appraisal process continues. In particular, National Grid acknowledges that the extent of undergrounding which would be appropriate as mitigation is currently uncertain. In order to assess whether the conclusion on the Preliminary Preferred Option remains valid and robust, National Grid's judgment will be back-checked and re-evaluated throughout the project's development.

15 Other Generation Scenarios

15.1 As explained in section 1, this report is based on 5.6 GW of contracted generation connecting at, or in the vicinity of, Wylfa 400 kV substation, along with the cumulative effect on the network of the two wind farms to be located off the coast of North Wales. Specifically:

(a) a connection agreement with Horizon Nuclear Power in respect of a proposed 3.6 GW nuclear power station at Wylfa

(b) a connection agreement with Celtic Array Limited in respect of a 2 GW offshore wind farm to be located in the Irish Sea

(c) Gwynt y Môr Offshore Wind farm, 574 MW, to be located off the coast of North Wales and in the process of being connected at Bodelwyddan in Denbighshire, and

(d) Burbo Bank Extension wind farm, 234 MW, also to be located off the coast of North Wales and also in the process of being connected at Bodelwyddan.

15.2 Section 1 also explained that a connection agreement was signed in July 2012 with Greenwire Wind Farm, a 1 GW wind farm to be constructed onshore in Ireland and connected at Pentir in Gwynedd.

15.3 Section 14 of this report concludes that, while keeping all other options under review and back-checking, National Grid will take the Preliminary Preferred Option forward to the next stage of option appraisal. In doing so, it is acknowledged that the options available to upgrade the transmission system for the Greenwire connection have not yet been fully identified and appraised.

15.4 However, a high-level assessment of potential options has been carried out for both higher and lower generation scenarios in order to assess whether or not the Preliminary Preferred Option might constitute part of the works required once the Greenwire connection is factored in, or if lower levels of generation were to connect in North Wales. This is to test whether or not it is reasonable for National Grid to proceed with consultation on the Preliminary Preferred Option at this stage, with the objective of avoiding abortive effort and investment.

Generation Scenarios

15.5 This section describes two generation scenarios :

(1) Higher Generation Scenario: Additional generation, e.g. 1 GW of Greenwire, requires to be connected in North Wales, and

(2) Lower Generation Scenario: Irish Sea wind does not connect at, or in the vicinity of, Wylfa leaving only the nuclear connection in Anglesey.

Higher Generation Scenario – Additional generation, e.g. 1 GW of Greenwire, requires to be connected in North Wales

15.6 1 GW from Greenwire is already contracted, albeit recently, and the transmission infrastructure options are still being evaluated. The following analysis was initiated in advance of the recent agreement with Greenwire. Given the pace of renewable development in this area, National Grid considered it appropriate to take into account the potential for more generation to seek connections in this area.

15.7 The Preliminary Preferred Option identified in this report will cater for the connection of 5.6 GW of generation on Anglesey, along with the cumulative effect on the network of the two wind farms to be located off the coast of North Wales. Connecting in excess of 5.6 GW would trigger the need for additional transmission capacity out of North Wales.

15.8 National Grid has concluded that, for a 6.6 GW generation scenario (3.6 GW of nuclear generation, 2 GW of Irish Sea wind and the additional 1 GW from Greenwire, plus the cumulative effect on the network of Gwynt y Môr and the Burbo Bank Extension wind farms), the principal options will fall into one of two categories :

A Predominantly [25] or wholly subsea HVDC options. An example of an option in this category would be two HVDC links connecting Wylfa and Deeside plus an HVDC link connecting Wylfa and Pembroke, essentially Strategic Option 2 in this report.

B The Preliminary Preferred Option plus either additional onshore or offshore reinforcements, for which we will, as in this report, consider the use of all

[25] Depending on the offshore design, some additional onshore reinforcements could be required, for which we would, as in this report, consider the use of all appropriate transmission technologies. For example, taking all the HVDC circuits to Deeside would require some reinforcements beyond Deeside but if the HVDC circuits were taken to several different locations including, for example, Pembroke, onshore reinforcements may not be necessary.

appropriate transmission technologies. An example of an option in this category would be the Preliminary Preferred Option plus an HVDC circuit connecting Wylfa and Pembroke.

15.9 While further work is required to define the precise requirements for these options, high level costs have been developed to provide a broad comparison between the costs of options in each category. These show that the capital costs for options in category A are likely to be substantially greater than the costs of options in category B. Furthermore, VSC HVDC systems have high electrical losses in the converter stations and high maintenance costs so that, when lifetime costs are taken into account, the category A options look even less favourable when compared to those options in category B which have either no or fewer HVDC elements.

15.10 Taking into account high-level environmental, socio-economic, technical and cost considerations, it is National Grid's view that an option from category B would emerge as preferred, all of which would include the Preliminary Preferred Option as an essential element. Furthermore, it is also National Grid's view that an HVDC circuit connecting Wylfa and Pembroke is most likely to emerge as the preferred additional reinforcement which, when integrated with the Preliminary Preferred Option, meets the system capacity needs at higher generation levels.

15.11 Also, when considering options within category B it is of note that ODIS, [26] ENSG [27] and the Offshore Transmission Network Feasibility Study, a study prepared in co-operation with The Crown Estate, [28] have all concluded that a subsea HVDC link between Wylfa and Pembroke would enable additional power export from North Wales, while ensuring that National Grid continues to meet its requirement to be co-ordinated, efficient and economical. [29] While these three reports make use of different generation backgrounds to the one used in this report, National Grid believes that the strong correlation of results provides additional support to the proposal to move forward with consultation on the Preliminary Preferred Option.

15.12 While a detailed appraisal of options for a higher generation scenario will be required, including a back-check of previous work (as is ongoing for Greenwire),

[26] http://www.nationalgrid.com/uk/Electricity/OffshoreTransmission/ODIS/CurrentStatement/
[27] http://www.decc.gov.uk/en/content/cms/meeting_energy/network/ensg/ensg.aspx
[28] http://www.nationalgrid.com/uk/Electricity/OffshoreTransmission/OffshoreApproach/
[29] It should be noted that ODIS, ENSG and the Crown estate feasibility study make use of generation scenarios developed by the industry. This report mainly deals with the contracted position and need case.

National Grid considers in light of this high-level analysis that proceeding with consultation on the Preliminary Preferred Option at this stage would be appropriate.

Lower Generation Scenario – Irish Sea wind generation does not connect at, or in the vicinity of, Wylfa

15.13 While National Grid is confident that the connection of 2 GW of Irish Sea wind generation will be at or in the vicinity of Wylfa, this is not currently within National Grid's power to deliver as it is not, as yet, defined contractually. [30] There is always a need to retain flexibility within contractual agreements between National Grid and offshore developers until such time as offshore and onshore transmission system designs are confirmed. In the case of Irish Sea wind this is no different, and the location of the National Grid / OFTO boundary onshore is not yet confirmed. As such, there remains a minor degree of uncertainty around the works required to form the connection and associated reinforcements onshore.

15.14 This is not the case for the connection between the proposed nuclear power station at Wylfa and the transmission system. The connection design and location is reasonably certain and set out in the connection agreement.

15.15 To establish a fall-back position for 3.6 GW (nuclear only) it is necessary to form a view, using high-level optioneering, on what the preferred option at 3.6 GW might be.

15.16 As is the case with 5.6 GW of generation, the options for the connection of 3.6 GW at Wylfa include both onshore and subsea options. The most likely principal options are:

A An onshore AC option, and

B A subsea HVDC option.

15.17 The main works for option A consist of the Preliminary Preferred Option less some

[30] The regulatory framework requires an offshore generator and National Grid to enter into a connection agreement before the design (offshore and onshore) is fully developed. In general, the design of the offshore transmission system, and changes to the onshore infrastructure, will be developed jointly by National Grid and either an OFTO or a generation developer.

As a consequence of National Grid's duties, the connection offers to offshore developers must provide for designs which are efficient, co-ordinated and economical. Therefore, in advance of the OFTO (or developer) being appointed, National Grid is required to make assumptions about the offshore transmission system that would be required and the point at which the offshore transmission system would connect to the onshore transmission system in order to provide connection offers. Any agreement between National Grid and an offshore generator is subject to changes to the offshore assumptions until the detailed design work has been completed and the design has been confirmed by the responsible transmission licensee.

re-conductoring of existing transmission circuits and the capital cost of option A is estimated to be £611m.

15.18 All of the transmission elements of this option have already been assessed through the option appraisal methodology.

15.19 The main works for option B, an offshore HVDC option, consist of:

- Two 2 GW subsea HVDC circuits between Wylfa and Deeside, and
- Two converter stations at Wylfa and two at Deeside.

15.20 The capital cost for option B is estimated to be £1.2bn.

15.21 All of the transmission elements of this option have also been assessed through the option appraisal methodology.

15.22 The estimated capital cost for option A is just over half that of option B, meaning about £600m could be spent on mitigation for option A before the costs exceed that of option B.

15.23 Given the capital costs of these options and taking into account at a high-level the results of the environmental, socio-economic and technical appraisals, it is National Grid's view that option A is most likely to emerge as the preferred option at 3.6 GW.

15.24 In the unlikely event of Irish Sea wind not connecting on Anglesey then the difference in infrastructure requirements between Option A and the Preliminary Preferred Option is essentially the elimination of the requirement to re-conductor existing circuits. These are likely to be works that could be deferred as long as possible, therefore, proceeding cautiously with the Preliminary Preferred Option would minimise the risk of unnecessary works on the transmission system in North Wales. In light of this high-level analysis on lower generation scenarios, National Grid considers that proceeding with the Preliminary Preferred Option at this stage would be appropriate.

Conclusions

15.25 In this section two generation scenarios are described:

- A higher generation scenario (6.6 GW) which recognises that the Greenwire infrastructure options have not yet been fully identified, optioneered and appraised, and
- A lower generation scenario (3.6 GW) which recognises that there remains some uncertainty, albeit small, relating to the exact location of the connection of Irish Sea wind.

15.26 Potential transmission reinforcement options were developed for both of these scenarios and high-level capital cost estimates developed, using a variety of technologies for the new connections.

15.27 In the case of the higher generation scenario, based on the above high-level analysis, it is National Grid's view that an HVDC circuit connecting Wylfa and Pembroke is most likely to emerge as the preferred additional reinforcement which, when integrated with the Preliminary Preferred Option, would meet the system capacity needs at the higher generation level. For the avoidance of doubt, the works which might be required in addition to the Preliminary Preferred Option to meet the system needs at higher levels of generation are outside the scope of this consultation.

15.28 In the case of the lower generation scenario, it is National Grid's view that the option which is most likely to be the preferred option is option A, the Preliminary Preferred Option less some re-conductoring of existing circuits.

15.29 In either scenario, this high level analysis confirms that the Preliminary Preferred Option would be an essential element of the subsequent preferred solution. Therefore, National Grid believes that proceeding with consultation on the Preliminary Preferred Option at this stage is appropriate. This conclusion will be reviewed and back-checked on completion of the Greenwire optioneering process and also where new information or changes in the generation or demand background are considered to have potential implications for any decisions made.

Appendix A – Summary of National Grid Legal Obligations [31]

A.1 Transmission of electricity in Great Britain requires permission by a licence granted under Section 6(1)(b) of the Electricity Act 1989 ("the Electricity Act").

A.2 National Grid has been granted a transmission licence and is therefore bound by the legal obligations primarily set out in the Electricity Act and the transmission licence.

A.3 National Grid owns and operates the transmission system in England and Wales and is also responsible for operation of parts of the onshore transmission system that are owned by other transmission licensees (SP Transmission Limited and Scottish Hydro Electricity Transmission Limited).

A.4 National Grid has a statutory duty to develop and maintain an efficient, coordinated and economical system of electricity transmission under Section 9 of the Electricity Act.

A.5 The relevant Standard Licence Conditions [32] are summarised in the following paragraphs.

A.6 Standard Condition C8 [33] (Requirement to offer terms) of National Grid's transmission licence sets out obligations on National Grid regarding provision of offers to provide connections to and/or use of the transmission system. In summary, where a party applies for a connection National Grid shall offer to enter into an agreement(s) [34] to connect, or to modify an existing connection, to the transmission system and the offer shall make detailed provision regarding the:

- carrying out of works required to connect to the transmission system
- carrying out of works (if any) in connection with the extension or reinforcement of the transmission system, and
- date by when any works required permitting access to the transmission system (including any works to reinforce or extend the transmission system) shall be completed.

[31] Summary is not intended as an exhaustive list of National Grid's legal obligations but provides information about the obligations that are particularly relevant to this report.
[32] Standard conditions of the electricity transmission licence http://epr.ofgem.gov.uk/document_fetch.php?documentid=15184
[33] The condition also relates to the use of system and some embedded generating plant.
[34] Paragraph 6 of Licence Condition C8 sets out exceptions where National Grid is not obliged to make an offer e.g. where to do so would put it in breach of certain other contracts or regulations.

A.7 Standard Condition C10 (Connection and Use of System Code) requires National Grid to prepare a connection and use of system code ("CUSC") which sets out, among other things, the terms of the arrangements for connection to and use of the transmission system.

A.8 Standard Condition C14 (Grid Code) requires National Grid to "prepare and at all times have in force and shall implement and comply with the Grid Code". This document (among other things), sets out the technical performance and data provision requirements that need to be met by users connected to or seeking to connect to the transmission system. The document also sets out the process by which demand data from Network Operators and other users of the transmission system should be presented on an annual basis to allow National Grid to plan and operate the transmission system.

A.9 Standard Condition C17 (Transmission system security standard and quality of service) requires National Grid to at all times plan, develop and operate the transmission system in accordance with the National Electricity Transmission System Security and Quality of Supply Standard (NETS SQSS). This condition includes specific arrangements (Connect and Manage Derogation) that permit National Grid to offer to connect a customer to the Transmission System before all reinforcement works to achieve compliance with the NETS SQSS are complete. Such permissions are subject to National Grid publishing Connect and Manage Derogations and reporting to Ofgem.

A.10 Standard Condition C26 (Requirements of a connect and manage connection) supplements the obligations [35] applicable to National Grid when making an offer of connection to the Transmission System. The connect and mange connection regime was introduced in August 2010. One intention of this regime is to facilitate the timely connection of new generation projects.

A.11 As well as the technical obligations described above, Schedule 9 of the Electricity Act 1989 require 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

[35] Standard condition C8 of the electricity transmission licence.

interest; and shall do what [it] reasonably can to mitigate any effect which the proposals would have on the natural beauty of the countryside or on any such flora, fauna, features, sites, buildings or objects".

A.12 National Grid's Stakeholder, Community and Amenity Policy ("the Policy") sets out how the company will meet the duty to the environment placed upon it. These commitments 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 seek to avoid areas nationally or internationally designated for their landscape, wildlife or cultural significance, and
- minimising the effects of new infrastructure on other sites valued for their amenity.

A.13 The Policy also refers to the application of best practice methods to assess the environmental impacts of proposals and identify appropriate mitigation and/or offsetting measures. Effective consultation with stakeholders and the public is also promoted by the Policy.

A.14 In addition, the following other statutory duties are relevant to National Grid's development of new infrastructure:

- Section 11A(2) of the National Parks and Access to the Countryside Act 1949 (Duty of certain bodies and persons to have regard to the purposes for which National Parks are designated): "In exercising or performing any functions in relation to, or so as to affect, land in a National Park, any relevant authority shall have regard to the purposes specified in subsection (1) of section five of this Act and, if it appears that there is a conflict between those purposes, shall 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."

- Section 85 of the Countryside and Rights of Way Act 2000 (General duty of public bodies etc): "(1) In exercising or performing any functions in relation to, or so as to affect, land in an area of outstanding natural beauty, a relevant authority shall have regard to the purpose of conserving and enhancing the natural beauty of the area of outstanding natural beauty."

- Section 40 of the Natural Environment and Rural Communities Act 2006 states that "Every public body must, in exercising its functions, have regard, so far as is consistent with the proper exercise of those functions, to the purpose of conserving biodiversity."

Appendix B – Requirement for Development Consent

B.1 Developing the transmission system in England and Wales may require one or more statutory consents, depending on the type and scale of the project. These may include planning permission or use of permitted development rights under the Town and Country Planning Act 1990, a marine licence under the Marine and Coastal Access Act 2009 and a Development Consent Order ("DCO") under the Planning Act 2008.

B.2 Certain developments are defined in the Planning Act 2008 as 'Nationally Significant Infrastructure Projects' ("NSIP"). These include the development of new overhead lines operating at a voltage of 132 kV or above and these projects require a DCO granted by the Secretary of State for Energy and Climate Change. Such developments are the subject of six National Policy Statements ("NPS") for energy infrastructure which were published by the Secretary of State for Energy and Climate Change in July 2011. The most relevant NPSs for transmission infrastructure are the Overarching National Policy Statement for Energy (EN-1) and the National Policy Statement for Electricity Networks Infrastructure (EN-5), which must be read in conjunction with EN-1. [36]

B.3 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 circumstances. These include where the adverse impact of the proposed development would outweigh its benefits. The energy NPSs provide the primary policy basis for decisions and may also be a material consideration for decisions on other types of development consent in England and Wales (including offshore projects).

Demonstrating the Need for a Project

B.4 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 the types of energy infrastructure covered by the NPS to achieve energy security at the same time as dramatically reducing greenhouse gas emissions. It states that "substantial weight" should be given to the contribution which projects would make towards satisfying this need. A need for new transmission infrastructure is set out in EN-1 and EN-5, and a need for new nuclear and

[36] The National Policy Statements can be viewed at http://www.decc.gov.uk/en/content/cms/meeting_energy/consents_planning/nps_en_infra/nps_en_infra.aspx

onshore/offshore wind generation (i.e. the type of generation giving rise to the need for new transmission infrastructure for this project) is set out in EN-1, EN-3 and EN-6. The need for new transmission infrastructure for this project is described in section 3 of this report.

Assessment Principles

B.5 Part 4 of EN-1 sets out the assessment principles to be applied in determining DCO applications for energy NSIPs. Paragraphs 2.3 - 2.5 of EN-5 do the same in the specific context of electricity networks infrastructure.

B.6 Principles of particular importance for transmission infrastructure projects include:

Presumption in Favour of Development

B.7 Section 4.1 of EN-1 provides a presumption in favour of granting consent for energy NSIPs (subject to specific policies in an NPS indicating otherwise or to the specific exceptions in the Planning Act, including where the adverse impacts outweigh the benefits). Adverse impacts include long term and cumulative impacts but take into account mitigation measures. Potential benefits include the contribution to meeting the need for energy infrastructure, job creation and long term wider benefits.

Consideration of Alternatives

B.8 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 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."

B.9 Section 4.4 of EN-1 also makes clear that there will be circumstances where a promoter is specifically required to consider alternatives. These may include requirements under the Habitats Directive and the Birds Directive.

Good Design

B.10 Section 4.5 of EN-1 stresses the importance of 'good design' for energy infrastructure and explains this goes beyond aesthetic considerations and is also important for fitness for purpose and sustainability. It is acknowledged 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 to demonstrate the principles of good design in the approach to mitigating the potential adverse impacts which can be associated with overhead lines.

Climate Change

B.11 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. This requires DCO applications 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).

Networks DCO Applications Submitted in Isolation

B.12 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. It explains that the need for the transmission project can be assessed on the basis of both contracted and reasonably anticipated generation.

Electricity Act Duties

B.13 Paragraph 2.3.5 of EN-5 recognises National Grid's 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.

Adverse Impacts and Potential Benefits

B.14 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.

B.15 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, socio-economic 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 to a network project, will vary. EN-5 considers specific potential impacts of electricity networks on biodiversity and geological conservation, landscape and visual and noise and vibration.

B.16 Potential impacts of particular importance for transmission infrastructure projects include:

Landscape and Visual

B.17 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 National Grid's statutory duty under Section 9 of the Electricity Act 1989 to have regard to amenity and to mitigate impacts but recognises that 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 transmission projects, paragraph 2.8.9 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 Planning Inspectorate 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 endorses the Holford Rules which are a set of "common sense" guidelines for routeing new overhead lines.

Biodiversity

B.18 Paragraph 2.7 of EN-5 highlights the potential impacts of overhead lines on large birds.

Appendix C – Technology Overview

C.1 This section provides an overview of the technologies available when installing new transmission infrastructure. It provides a high level description of the relevant features of each technology. The costs of each technology are presented in Appendix D.

C.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. 230 V for domestic customers and 11 kV for large factories and hospitals. The voltage level is relatively easy to change when using AC electricity, which means a more economical electricity network can be developed to suit customer requirements. This has meant that the electrification of whole countries could be and was delivered quickly and efficiently using AC technology.

C.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.

C.4 In terms of voltage, the transmission system in England and Wales operates at both 275 kV and 400 kV. The majority of National Grid's transmission system is now constructed and operated at 400 kV, which facilitates higher power transfers and lower transmission losses.

C.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:

- AC Overhead lines
- AC Underground cables
- AC Gas Insulated Lines (GIL) and
- High Voltage Direct Current (HVDC).

C.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.

Overhead lines

C.7 Overhead lines form the majority of the existing transmission system circuits in Great Britain and in transmission systems across the world. As such there is established understanding of their construction and use.

C.8 Overhead lines are made up of three main component parts which are; conductors (used to transport the power), pylons (used to support the conductors) and insulators (used to safely connect the conductors to pylons)

C.9 Figure C.1 shows a typical pylon used to support two 275 kV or 400 kV overhead line circuits. This type of pylon has six arms (three either side), each carrying a set (or bundle) of conductors.

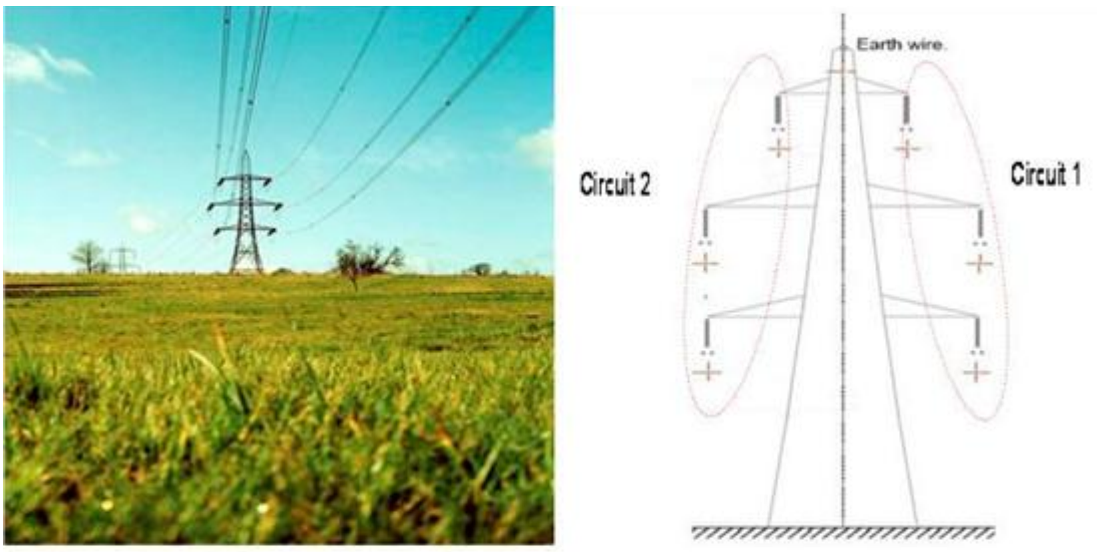

Figure C.1: Example of a 275/400 kV Double-Circuit Tower

C.10 The number of conductors supported by each arm depends on the amount of power to be transmitted and will be either two, three or four conductors per arm. Technology developments have increased the capacity that can be carried by a single conductor and therefore, new overhead lines tend to have two or three conductors per arm.

C.11 With the conclusion of the Royal Institute of British Architects (RIBA) pylon design competition [37] and other recent work with manufacturers to develop alternative pylon designs, National Grid is now able to consider a broader range of pylon types, including steel lattice and monopole designs. The height and width is different for each pylon type, which may help National Grid to manage the impact on landscape and visual amenity better. Figure C.2 shows an image of the winning design from the RIBA pylon design competition, a monopole design called the T-pylon, currently being developed by National Grid.

Figure C.2: The T-pylon

C.12 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 [38] between objects and the lowest point of the conductor as shown in Figure C.3.

[37] Press notice issued by DECC on 14 October 2011 http://www.decc.gov.uk/en/content/cms/news/pn11_82/pn11_82.aspx
[38] More information can be found in the brochure "Development near overhead lines" at http://www.nationalgrid.com/uk/LandandDevelopment/DDC/devnearohl_final/.

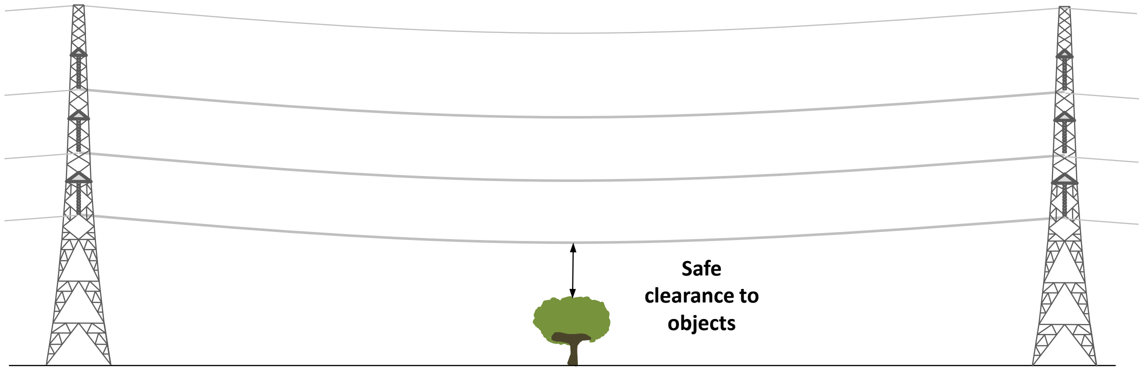

Figure C.3: Safe height between lowest point of conductor and other obstacle ("Safe Clearance")

C.13 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 360 m.

C.14 Lower voltages need less clearance and therefore the pylons needed to support 132 kV lines are not as high as traditional 400 kV and 275 kV pylons. However, lower voltage circuits are unable to transport the same levels of power as higher voltage circuits.

C.15 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, short emergency restoration times are achievable on overhead lines as compared to, for example, underground cables. This provides additional operational flexibility if circuits need to be rapidly returned to service to maintain a secure supply of electricity when, for example, another transmission circuit is taken out of service unexpectedly.

C.16 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 electricity consumers.

C.17 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, and
- between 20 and 40 years for insulators

C.18 National Grid expects an initial design life of around 40 years, based on the specified design life of the component parts. However, pylons can be easily refurbished and so substantial pylon replacement works are not normally required at the end of the 40 year design life.

C.19 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.

Underground AC Cables

C.20 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.

C.21 Underground cable systems are made up of two main components - the cable and connectors. Connectors can be cable joints, which connect a cable to another cable, or overhead line connectors in a substation.

C.22 Cables consist of an electrical conductor in the centre, which is usually copper or aluminium, surrounded by insulating material and sheaths of protective metal and plastic. The insulating material ensures that although the conductor is operating at a high voltage, the outside of the cable is at zero volts (and therefore safe). Figure C.4 shows a cross section of a transmission cable and a joint that is used to connect two underground cables.

Figure C.4: Cable Cross-Section and Joint

C.23 Underground cables can be connected to above-ground electrical equipment at a substation, enclosed within a fenced compound. The connection point is referred to as a cable sealing end. Figure C.5 shows two examples of cable sealing end compounds.

Figure C.5: Cable Sealing End Compounds

C.24 An electrical characteristic of a cable system is capacitance between the conductor and earth. Capacitance causes a continuous 'charging current' to flow, the magnitude of which is dependent on the length of the cable circuit (the longer the cable, the greater the charging current) and the operating voltage (the higher the voltage the greater the current). Charging currents have the effect of reducing the power transfer through the cable.

C.25 High cable capacitance also has the effect of increasing the voltage along the length of the circuit, reaching a peak at the remote end of the cable.

C.26 National Grid can reduce cable capacitance problems by connecting reactive compensation equipment to the cable, either at the ends of the cable, or, in the case of longer cables, at regular intervals along the route. Specific operational arrangements and switching facilities at points along the cable circuit may also be needed to manage charging currents.

C.27 Identifying faults in underground cable circuits often requires multiple excavations to locate the fault and some repairs require removal and installation of new cables, which can take a number of weeks to complete.

C.28 High voltage underground cables must be regularly taken out of service for maintenance and inspection and, should any faults be found and depending on whether cable excavation is required, emergency restoration for security of supply reasons typically takes a lot longer than for overhead lines (days rather than hours).

C.29 The installation of underground cables requires significant civil engineering works. These make the construction times for cables significantly longer than overhead lines.

C.30 The construction swathe required for two AC circuits comprising two cables per phase (twelve cables in total) will be between 35-50 m wide.

C.31 Each of the two main components that make up an underground cable system has a design life of between 40 and 50 years.

C.32 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.

Gas Insulated Lines (GIL)

C.33 GIL has been developed from the well-established technology of gas-insulated switchgear, which has been installed on the transmission system since the 1960s.

C.34 GIL uses a mixture of nitrogen and sulphur hexafluoride (SF_6) gas to provide the electrical insulation. GIL is constructed from welded or flanged metal tubes with an aluminium conductor in the centre. Three tubes are required per circuit, one tube for each phase. Six tubes are therefore required for two circuits, as illustrated in Figure C.6.

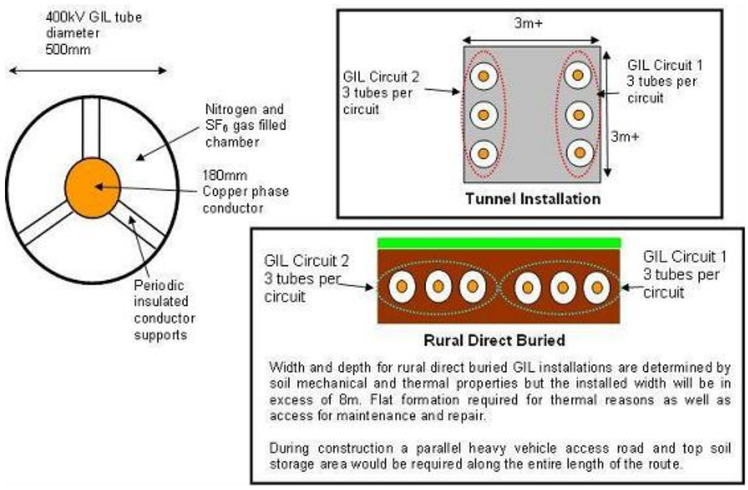

Figure C.6: Key Components of GIL [39]

C.35 GIL tubes are brought to site in 10 - 20 m lengths and they are joined in situ. It is important that no impurities enter the tubes during construction as impurities can cause the gas insulation to fail. GIL installation methods are therefore more onerous than those used in, for example, natural gas pipeline installations.

C.36 A major advantage of GIL compared to AC underground cable is that it does not require reactive compensation.

C.37 The installation widths along the route length are narrower than cable installations, especially where more than one cable per phase is required.

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

C.38 GIL can have a reliability advantage over cable in that it can be re-energised immediately after a fault (similar to overhead lines) whereas a cable requires investigations prior to re-energisation. If the fault was a transient fault it will remain energised and if the fault was permanent the circuit will automatically and safely de-energise again.

C.39 There are environmental concerns with GIL as the SF_6 [40] gas used in the insulating gas mixture is a potent 'greenhouse gas'. Since SF_6 is an essential part of the gas mixture GIL installations are designed to ensure that the risk of gas leakage is minimised.

C.40 There are a number of ways in which the risk of gas leakage from GIL can be managed, which include:

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

C.41 At decommissioning the SF_6 can be separated out from the gas mixture and either recycled or disposed of without any environmental damage.

C.42 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 . These are both in electricity substations; one is above ground and the other is in a trough. The longest directly buried transmission voltage GIL in the world is approximately one kilometre long and was recently installed on the German transmission system around Frankfurt Airport.

C.43 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.

C.44 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

40 SF6 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

life) will also take account of actual asset condition and may lead to actual life being longer than the design life.

High Voltage Direct Current ("HVDC")

C.45 HVDC technology can provide efficient solutions for the bulk transmission of electricity between AC electricity systems (or between points on an electricity system).

C.46 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 such as France, The Netherlands and Ireland.

C.47 HVDC links may also be used to connect a generating station that is distant from the rest of the electricity system. For example, very remote hydro-electric schemes in China are connected by HVDC technology with overhead lines.

C.48 Proposed offshore wind farms to be located over 60 km from the coast of Great Britain are likely to be connected using HVDC technology as an alternative to an AC subsea cable. This is because AC subsea cables over 60 km long have a number of technical limitations, such as high charging currents and the need for mid-point compensation equipment.

C.49 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.

C.50 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)

C.51 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.

C.52 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.

Appendix D – Economic Appraisal

D.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.

D.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 C and an overview of the method that National Grid uses to assess the Net Present Value ("NPV") of costs that are expected to be incurred during the lifetime of new transmission assets.

D.3 The IET, PB/CCI Report [41] presents cost information in size of transmission circuit capacity categories for each circuit design that was considered as part of the independent study. To aid comparison between the cost data presented in the IET PB/CCI Report and that used by National Grid for appraisal of strategic options, this appendix includes cost estimates using National Grid cost data for circuit designs that are equivalent to those considered as part of the independent study. Examples in this Appendix are presented using the category size labels of "Lo", "Med" and "Hi" as used in the IET PB/CCI Report for the IET PB/CCI calculations.

Lifetime Costs for Transmission

D.4 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 associated with new routes, and
- net present value ("NPV") of costs that are expected to be incurred during the lifetime of these new transmission assets.

[41] "Electricity Transmission Costing Study – An Independent Report Endorsed by the Institution of Engineering & Technology" by Parsons Brinckerhoff in association with Cable Consulting International. Page 10 refers to double circuit capacities. http://www.theiet.org/factfiles/transmission-report.cfm

Capital Cost Estimates

D.5 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.

D.6 This section considers the capital costs in two parts, firstly the AC technology costs are discussed, followed by HVDC technologies. Each of these technologies is described in Appendix C in more detail.

AC Technology Capital Cost Estimates

D.7 Table D.1 shows the category sizes that are relevant for AC technology circuit designs:-

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

Table D.1 – AC Technology Circuit Designs

D.8 Table D.2 provides a summary of technology configuration and capital cost information (in financial year 2010/11 prices) for each of the AC technology options that National Grid considers as part of an appraisal of strategic options.

IET, PB/CCI Report short-form label	Circuit Ratings by Voltage		Technology Configuration			National Grid Capital Costs		
	275 kV	400 kV	Overhead Line	AC Underground Cable	Gas Insulated Line	Overhead Line	AC Underground Cable	Gas Insulated Line
	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 on each arm (per circuit)	No. of Cables per phase (per circuit)	No of direct buried GIL tubes per phase (per circuit)	Cost for a "double" two circuit pylon route (Cost per circuit, of a double circuit pylon route)	Cost for a two circuit AC cable route (Cost per circuit, of a two circuit AC cable route)	Cost for a two circuit GIL route (Cost per circuit, of a two circuit GIL route)
Lo	3,190 MVA (2 x 1,595 MVA) [2,000 MVA 2 x 1,000 MVA for AC cable only]	3,190 MVA (2 x 1,595 MVA)	Two (Six)	One (Three)	One (Three)	£1.5m/km (0.75m/km)	£8.8m/km (£4.4m/km)	£13.5m/km (£6.75m/km)
Med	N/A [3,190 MVA 2 x 1,595 MVA for AC cable only]	6,380 MVA (2 x 3,190 MVA)	Two (Six)	Two (Six)	One (Three "developing" new large GIL tubes)	£1.6m/km (£0.8m/km)	£18m/km (£9m/km)	£16.0m/km (£8.0m/km)
Hi	N/A	6,930 MVA (2 x 3,465 MVA)	Three (Nine)	Three (Nine)	Two (Six standard GIL tubes)	£1.8m/km (£0.9m/km)	£22m/km (11m/km)	£23m/km (£11.5m/km)

Table D.2 - AC Technology Configuration and National Grid Capital Costs by Rating

Notes: -

1. Capital costs for all technologies are based upon rural/arable land installation with no major obstacles (examples of major obstacles would be roads, rivers, railways etc.)
2. All underground AC cable and GIL technology costs are for direct buried installations only. AC cable and GIL tunnel installations would have a higher capital installation cost than direct buried rural installations. However, AC cable or GIL replacement costs following the end of conductor life would benefit from re-use of the tunnel infrastructure.
3. AC cable installation costs exclude the cost of reactors and mid-point switching stations, which are described later in this appendix.
4. 275 kV circuits will often require Super-Grid Transformers (SGT) to allow connection into the 400 kV system, SGT capital costs are not included above but described later in this appendix.
5. 275 kV AC cable installations above 1,000 MVA, as indicated in the table above, would require two cables per phase to be installed to achieve ratings of 1,595 MVA per circuit at 275 kV.
6. National Grid is aware of changes in cable sizes which are being developed by cable manufacturers that would potentially allow the use of two cables per phase at the "Hi" capacity rating. This would utilise these larger cables, but could facilitate an amendment of cost in the "Hi" capacity rating, currently £22m/km, by a reduction of up to £2.5m per kilometre. "Med" and "Lo" costs are unaffected by this potential change, "Hi" rating AC cable costs would be amended when better information becomes available.
7. 2011/12 cost for GIL has been raised to £8m from £7.6m for "Med" capacities and to £23m from £22.8m for "Hi" capacities. This is based upon latest information from projects and worldwide manufacturer information.

D.9 Table D.2 provides a summary of the capital costs associated with the key [42] components of transmission circuits for each AC 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 transmission system.

D.10 The following sections provide an overview of the additional requirements associated with each of these technology options and indicative capital costs of additional equipment.

AC Underground Cable additional equipment

D.11 Appendix C of this report provides a summary of the electrical characteristics of AC underground cable systems and explains that reactive gain occurs on AC underground cables.

D.12 Table D.3 provides a summary of the typical reactive gain within AC underground cable circuits forming part of the Transmission System.

Category	Voltage	Design	Reactive Gain per circuit
Lo	275 kV	One 2,500 mm^2 cable per phase	5 Mvar/km
Med	275 kV	Two 2,500 mm^2 cables per phase	10 Mvar/km
Lo	400 kV	One 2,500 mm^2 cable per phase	10 Mvar/km
Med	400 kV	Two 2,500 mm^2 cables per phase	20 Mvar/km
Hi	400 kV	Three 2,500 mm^2 cables per phase	30 Mvar/km

Table D.3 – Reactive Gain Within AC underground cable circuits

D.13 National Grid is required to ensure that reactive gain on any circuit that forms part of the Transmission System does not exceed 225 Mvar. Above this limit, reactive gain would lead to unacceptable voltages (voltage requirements are

42 Components that are not required for all technology options are presented separately in this appendix.

defined in the NETS SQSS). In order to manage reactive gain and therefore voltages, reactors are installed on AC underground cable circuits to ensure that reactive gain in total is less than 225 Mvar.

D.14 For example a 50 km 400 kV "Med" double circuit would have an overall reactive gain of 1,000 Mvar per circuit (2,000 Mvar in total for two circuits). The standard shunt reactor size installed at 400 kV on the National Grid System is 200 MVAr. Therefore four 200 Mvar reactors (800 Mvar) need to be installed on each circuit or eight 200 Mvar reactors (1,600 Mvar) reactors for the two circuits. Each of these reactors cost £3m adding £24m to an overall cable cost for the example above.

D.15 Mid-point switching stations may be required as part of a design to meet the reactive compensation requirements for AC underground circuits. The need for switching stations is dependent upon cable design, location and requirements which cannot be fully defined without detailed design.

D.16 For the purposes of economic appraisal of strategic options, National Grid includes a cost allowance that reflects typical requirements for switching stations. These allowances shown in table D.4 are:-

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

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

D.17 It is noted that more detailed design of AC underground cable systems may require a switching station after a shorter or longer distance than the typical values used by National Grid at the initial appraisal stage.

D.18 Table D.5 shows the capital cost associated with AC underground cable additional equipment.

Category	Cost per mid-point switching station	Cost per 200 Mvar reactor
Lo	£9m	£3m
Med	£11m	
Hi	£11m	

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

D.19 Equipment that transform voltages between 275 kV and 400 kV (a 400/275 kV supergrid transformer or "SGT") is required for any new 275 kV circuit that connects to a 400 kV part of the Transmission System (and vice versa). The number of SGTs needed is dependent on the capacity of the new circuit. National Grid can estimate the number of SGTs required as part of an indicative scope of works that is used for the initial appraisal of strategic options.

D.20 Table D.6 shows capital cost associated with the SGT requirements.

275 kV Equipment	Capital Cost (SGT - including civil engineering work)
400/275 kV SGT 1,100 MVA (excluding switchgear)	£3.9m

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

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

D.21 Conventional HVDC technology sizes are not easily translated into the "Lo", "Med" and "Hi" ratings suggested in the IET, PB/CCI report. While National Grid information for HVDC is presented for each of these categories, there are differences in the circuit capacity levels. As part of an initial appraisal, National Grid's assessment is based on a standard 2 GW converter size. Higher ratings are achievable using multiple circuits.

D.22 The capital costs of HVDC installations can be much higher than for equivalent AC overhead line transmission routes. Each individual HVDC link, between each converter station, requires its own dedicated set of HVDC cables. HVDC may be more economic than equivalent AC overhead lines where the route length is many hundreds of kilometres.

D.23 Table D.7 provides a summary of technology configuration and capital cost information (in financial year 2010/11 prices) for each of the HVDC technology options that National Grid considers as part of an appraisal of strategic options.

HVDC Converter Type	2 GW Total Converter Capital Costs (Converter Cost at Each End)	2 GW DC Cable Pair Capital Cost
Current Source Technology or "Classic" HVDC	£290m (£145m at each end)	£1.75m/km
Voltage Source Technology HVDC	£300m (£150m at each end)	£1.75m/km

Table D.7 - HVDC Technology Capital Costs for 2GW installations

Notes: -

1. Costs are updated to median of prices published in Appendix 4 of National Grid's September 2011 Offshore Development Information Statement (ODIS). http://www.nationalgrid.com/NR/rdonlyres/0CFEBA62-0986-408D-8154-E9E73123D4CA/49326/2011_Appendix_Protected.pdf
2. 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.
3. Where a single HVDC Link is proposed as an option, to maintain compliance with the NETS SQSS, there may be a requirement to install an additional "Earth Return" DC cable. For example a 2 GW link must be capable of operating at half its capacity i.e. 1 GW during maintenance or following a cable fault. To allow this operation the additional cable known as an "Earth Return" must be installed, this increases cable costs by a further 50% to £2.6m/km.
4. Capital Costs for HVDC cable installations are based upon subsea or rural/arable land installation with no major obstacles (examples of major obstacles would be subsea pipelines, roads, rivers, railways etc…)

D.24 Costs can be adjusted from this table to achieve equivalent circuit ratings where required. For example a "Lo" rating 3,190 MW would require two HVDC links of (1.6 GW capacity each), while "Med" and "Hi" rating 6,380 MW-6,930 MW would require three links with technology stretch of (2.1-2.3 GW each).

D.25 Converter costs at each end can also be adjusted, by linear scaling, from the cost information in Table D.7, to reflect the size of the HVDC link being appraised. HVDC cable costs are normally left unaltered, as operating at the higher load does not have a large impact on the cable costs per km.

D.26 The capacity of HVDC circuits assessed for this report is not always exactly equivalent to capacity of AC circuits assessed. However, Table D.8 illustrates how comparisons may be drawn using scaling methodology outlined above.

IET, PB/CCI Report short-form label	Converters (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 (3,190 MW)	£3.5m/km (2 x £1.75/km)	£463m (4 x £115.7m [4 converters 2 each end])	£479m (4 x £119.7m [4 converters 2 each end])
Med	3 x 2.1 GW (6,380 MW)	£5.25m/km (3 x £1.75/km)	£925m (6 x £154.2m [6 converters 3 each end])	£957m (6 x £159.5m [6 converters 3 each end])
Hi	3 x 2.3 GW (6,930 MW)	£5.25m/km (3 x £1.75/km)	£1005m (6 x £167.5m [6 converters 3 each end])	£1040m (6 x £173.3m [6 converter 3 each end])

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

Notes: -

1. Costs based on 2 GW costs shown in table C.4 and table shows how HVDC costs are estimated based upon HVDC capacity required for each option.
2. Scaling can be used to estimate costs for any size of HVDC link required.

Indication of Technology end of design life replacement impact

D.27 It is unusual for a part of the 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.

D.28 National Grid does not take account of replacement costs in the lifetime cost assessment.

D.29 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.

D.30 The following provides a high level summary of common replacement requirements applicable to specific technology options.

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

Net Present Value Cost Estimates

D.31 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, and

- electrical losses

D.32 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.

D.33 The design life for all technology equipment is outlined in the technology description in Appendix C. The majority of expected design lives are of the order of 40 years, which is used to assess the following NPV cost estimates below.

D.34 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 discount rate of 3.5% for the reasons set out below [43]

"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."

D.35 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.

D.36 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.

Annual Operations and Maintenance cost

D.37 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

[43] http://www.hm-treasury.gov.uk/d/green_book_complete.pdf Paragraph 5.49 on page 26 recommends a discount rate of 3.5%. The mathematical expressions used to calculate the discount factor for a cost in year n is $Dn = 1/(1 + r)^n$ where r is the discount rate. The net present value is the sum of the annual discounted cash flows over the period 0 to n, in this case 40 years.

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

	Overhead Line	**AC Underground Cable**	**Gas Insulated Line (GIL)**	**High Voltage Direct Current (HVDC)**
Annual maintenance cost per two circuit km (AC) **Annual maintenance cost per circuit km (AC)**	£1,980/km £999/km	£4,200/km £2,100/km	£2,000/km £1,000/km	£100/km Subsea Cables
Associated equipment Annual Maintenance cost per item	N/A	£5,000 per reactor £31,000 per switching station	N/A	£968,000 per converter station
Additional costs for 275 kV circuits requiring connection to the 400 kV system				
275/400 kV SGT 1,100 MVA annual maintenance cost per SGT	£5,000	£5,000	£5,000	N/A

Table D.9 – Annual maintenance costs by Technology

D.38 As an example, annual maintenance costs for two 40 km circuits would be assessed as:

- For overhead line: 1,980 x 40 = £79k
- For underground cable: 4,200 x 40+(6x5,000) = £198k
- For Gas Insulated line: 2,000 x 40 = £80k
- For CSC HVDC (3 x 2.1 GW): (3 x 100 x 40) + (6 x 968,000) = £5.82m
- For CSC HVDC (3 x 2.1 GW): (3 x 100 x 40) + (6 x 968,000) = £5.82m

Annual Electrical Losses and Cost

D.39 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 I^2R losses (the electrical current flowing through the circuit, squared, multiplied by the resistance). As the load (the amount of power each circuit is carrying) increases, the current in the circuit is larger.

D.40 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.

D.41 This level of circuit utilisation is required because if a fault occurs there needs to be an alternative route to carry power to prevent wide scale loss of electricity for homes, business, towns and cities. Such events would represent a very small part of a circuit's 40 year life, but this availability of alternative routes is an essential requirement at all times to provide secure electricity supplies to the nation.

D.42 In all AC technologies the power losses are calculated directly from the electrical resistance properties of each technology and associated equipment. Table D.10 provides a summary of circuit resistance data for each AC technology and capacity options considered in this report.

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 2,500 mm^2 (0.013 Ω/km)	Single Tube per phase (0.0086 Ω/km)
Med	2 x 850 mm^2 (0.0184 Ω/km)	2 x 2,500 mm^2 (0.0065 Ω/km)	Single Tube per phase (0.0086 Ω/km)
Hi	3 x 700 mm^2 (0.014 Ω/km)	2 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	0.4MW per reactor	N/A
Additional losses for 275kV circuits requiring connection to the 400 kV system			
275 kV options only **275/400 kV SGT losses**	0.2576 Ω (plus 83 kW of iron losses) per SGT	0.2576 Ω (plus 83 kW of iron losses) per SGT	0.2576 Ω (plus 83 kW of iron losses) per SGT

Table D.10 – AC circuit technologies and associated resistance.

D.43 The process of converting AC power to DC is not 100% efficient. Power losses occur in all elements of the converter station: the valves, transformers, reactive compensation/filtering and auxiliary plant. Manufacturers typically represent these losses in the form of an overall percentage. Table D.11 shows the typical percentage losses encountered in the conversion process, ignoring losses in the DC cable circuits themselves.

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	Negligible	1% per HVDC Link
Voltage Source (VSC) Technology HVDC	1.0% per converter	Negligible	2% per HVDC Link

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

D.44 The example calculation explained in detail is for "Med" category circuits and has been selected to demonstrate the principles of the mathematics set out in this section. This example does not describe specific options set out within this report. A detailed example explanation of the calculations used to calculate AC losses is included in Appendix E.

D.45 The circuit category, for options contained within this report, is set out within each option. The example below demonstrates the mathematics and principles, which is equally applicable to "Lo", "Med" and "Hi" category circuits, over any distance.

D.46 The example calculations (using calculation methodology described in Appendix E) of instantaneous losses for each technology option for an example circuit of 40 km "Med" capacity 6,380 MVA (two x 3,190 MVA).

- Overhead lines = (2 x 3) x $1,565.5^2$ x (40 x 0.0184) = 10.8 MW
- Underground cable = (2 x 3) x $1,565.5^2$ x (40 x 0.0065) + (6 x 0.4) = 6.2 MW
- Gas Insulated Lines = (2 x 3) x $1,565.5^2$ x (40 x 0.0086) = 5.1 MW
- CSC HVDC = 34% x 6,380 x 1% = 21.7 MW
- VSC HVDC = 34% x 6,380 x 2% = 43.4 MW

D.47 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 which is the cost of energy derived in the Ofgem "project discovery" document. [44]

D.48 The following is a summary of National Grid's example calculations of Annual Losses and Maintenance costs for each technology option for an example circuit of 40 km "Med" capacity 6,380 MVA (two x 3,190 MVA).

(a) Overhead line annual loss = 10.8 x 24 x 365 x 60 = £5.7m.

(b) Underground cable annual loss = 6.2 x 24 x 365 x 60 = £3.3m.

(c) Gas Insulated lines annual loss = 5.1 x 24 x 365 x 60 = £2.7m

(d) CSC HVDC annual loss = 21.7 x 24 x 365 x 60 = £11.4m

(e) VSC HVDC annual loss = 43.4 x 24 x 365 x 60 = £22.8m

[44] http://www.ofgem.gov.uk/Markets/WhlMkts/monitoring-energy-security/Discovery/Documents1/Discovery_Scenarios_ConDoc_FINAL.pdf 2012 figure from figure 3.19 Wholesale Electricity Prices Graph "Dash for Energy" Cost £60/MWhr including marginal cost of carbon.

Example Lifetime costs and NPV Cost Estimate

D.49 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.

D.50 Table D.12 shows an example for a "Med" capacity 6,380 MVA (2 x 3,190 MVA) 400 kV circuit over 40 years.

Example 400 kV "Med" Capacity over 40 km	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	£64m	£738m	£640m	£1,135m	£1,167m
NPV Loss Cost over 40 years at 3.5% discount rate	£125m	£72m	£58m	£250m	£501m
NPV Maintenance Cost over 40 years at 3.5% discount rate	£2m	£4m	£2m	£128m	£128m
Lifetime Cost	**£191m**	**£814m**	**£700m**	**£1,513m**	**£1,796m**

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

Appendix E – Detailed Mathematical Principles used for AC Loss Calculation

E.1 This Appendix provides a detailed description of the mathematical formulae and principles that National Grid applies when calculating losses on the Transmission System. The calculations use recognised mathematical equations which can be found in power system analysis text books.

E.2 The example calculation explained in detail below is for "Med" category circuits and has been selected to demonstrate the principles of the mathematics set out in this section. This example does not describe specific options set out within this report.

E.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.

<u>Example Loss Calculation (1) - 40 km 400 kV "Med" Category Circuits</u>

E.4 The following is an example loss calculation for a 40 km 400 kV "Med" category (capacity of 6,380 MVA made up of two 3,190 MVA circuits).

E.5 Firstly, the current flowing in each of the two circuits is calculated from the three phase power equation of,

$$P = \sqrt{3} \times V_{LL} \times I_{LL} \times cos\theta$$

Assuming a unity power factor (cos θ = 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,

$$I = I_{LL} = I_{LN}$$

$$I = \frac{P}{\sqrt{3} \times V_{LL}}$$

where, P is the circuit utilisation power, which is 34% of circuit rating as set out in D.40 of Appendix D, which for the each of the two circuits in the "Med" category example is calculated as:

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

And, 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

$$I = \frac{1{,}084.6 \times 10^6}{\sqrt{3} \times 400 \times 10^3} = 1{,}565.5\ A$$

E.6 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.

E.7 For this "Med" category example, the total resistance for each technology option is calculated (from information in Appendix D, Table D.10) as follows:

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

$$Cable\ Circuit\ ^{45} = \frac{0.0065\Omega}{km} \times 40km = 0.26\ \Omega$$

$$Gas\ Insulated\ Line = \frac{0.0086\Omega}{km} \times 40km = 0.344\ \Omega$$

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

E.8 The following is a total instantaneous loss calculation for the underground cable technology option for the "Med" category example:

Losses per phase are calculated by,

$$P = I^2R$$

$$= 1{,}565.5^2 \times 0.26 = 0.64\ MW$$

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

Losses per circuit are calculated using by,

$$P = 3 \times I^2 \times R$$

$$= 3 \times 1{,}565.5^2 \times 0.26 = 1.91\ MW$$

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

$$Losses\ for\ two\ circuits = 2 \times 1.91 = 3.8\ MW$$

E.9 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:

$$3.8 + (6 \times 0.4) = 6.2\ MW$$

E.10 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:

$$Overhead\ Line = (2 \times 3) \times 1{,}565.5^2 \times 0.736 = 10.8\ MW$$

$$Cable\ Circuit = (2 \times 3) \times 1{,}565.5^2 \times 0.26 + (6 \times 0.4) = 6.2\ MW$$

$$Gas\ Insulated\ Line = (2 \times 3) \times 1{,}565.5^2 \times 0.344 = 5.1\ MW$$

Example Loss Calculation (2) - 40 km 275 kV "Lo" Category Circuits Connecting to a 400 kV part of the Transmission System

E.11 The following is an example loss calculation for a 40 km 275 kV "Lo" category (capacity of 3,190 MVA made up of two 1,595 MVA circuits) and includes details of how losses of the supergrid transformer ("SGT") connections to 400 kV circuits are assessed. This example assesses the losses associated with the GIL technology option up to a connection point to the 400 kV system.

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

$$P = 34\% \times 1.595.5 = 542.3\ MVA$$

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

$$I = \frac{542.3 \times 10^6}{\sqrt{3} \times 275 \times 10^3} = 1,138.5\ A$$

E.12 For this "Lo" category example, the total resistance for the GIL technology option is calculated (from information in Appendix D, Table D.10) as follows:

$$0.0086\ \Omega/km \times 40\ km\ = 0.344\ \Omega$$

E.13 The following is a total instantaneous loss calculation for the GIL technology option for this "Lo" category example:

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

$$P = 3 \times 1,138.5 \times 0.344 = 1.35\ MW$$

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

$$P = 2 \times 1.35\ MW = 2.7\ MW$$

E.14 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 [46] is calculated (from information in Appendix D, Table D.10) as 0.2576 Ω.

E.15 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 windings is calculated as:

$$I_{HV} = \frac{542.3 \times 10^6}{\sqrt{3} \times 400 \times 10^3} = 782.7\ A$$

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

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

$$SGT\ Losses = 3 \times 782.7 \times 0.2576 = 0.475\ MW$$

Iron Losses in each SGT = 84 kW

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

E.16 For this example, the total "Lo" category loss is the sum of the calculated GIL and SGT total loss figures:

$$\text{"Lo"}category\ loss = 2.7 + 1.1 = 3.8\ MW$$

Appendix F – Environmental and Socio-Economic Appraisal

F.1 At this strategic level of appraisal, where consideration is being given to options for network reinforcement, constraints or features largely of international and national importance in environmental and socio-economic terms are used as differentiators. A summary of these potential constraints and their data sources, derived from desk-based assessment at this stage, is presented in Table F.1 at the end of this Appendix.

F.2 Prior to conducting the environmental and socio-economic appraisals for this project, discussions were held with key stakeholders about the options to be appraised and the scope of those appraisals. The following sections explain the resultant scope of the environmental and socio-economic topic appraisals and the method by which they have been undertaken.

F.3 In certain circumstances, and through consultation with key stakeholders, consideration will be given to the inclusion of additional constraints or features which are not necessarily of international or national importance in environmental and socio-economic terms.

F.4 In general terms, consultants gather baseline environmental and socio-economic information about receptors, constraints and features for the various sub-topics and then assess the likely significant effects of options on those receptors, constraints and features. The findings of that appraisal are then used to inform further consultation with key statutory stakeholders about the options.

F.5 Thereafter, in considering which one or more preferred strategic option(s) to take forward to the next stage of development, National Grid will have regard to the issues identified through the appraisal, key stakeholder feedback, the Company's statutory duties and licence obligations, the standards to which the Company is required to design and operate the network (the NETS SQSS) and the relevant National Policy Statements.

Environmental Appraisal

F.6 There are a number of sub-topics within the environmental appraisal, which are set out in the paragraphs below.

Ecology

F.7 The guiding principles pertaining to the consideration of likely ecology and biodiversity effects, is to seek to avoid or minimise the effects of new infrastructure on valuable species, habitats, ecological networks and ecosystem functionality.

F.8 While not an exhaustive list of considerations, the strategic options appraisal has paid particular attention to the objectives of the following international and national ecological and biodiversity designations:

(a) Ramsar sites, listed under the Convention on Wetlands of International Importance, 1971

(b) Special Protection Areas (SPAs), classified under the EC Directive on the Conservation of Wild Birds, 1979

(c) Special Areas of Conservation (SACs), classified under the EC Directive on the Conservation of Natural Habitats and of Wild Fauna and Flora, 1992 (the Habitats Directive)

(d) National Nature Reserves (NNRs), declared under Section 19 of the National Parks and Access to the Countryside Act 1949 & Section 35 of the Wildlife and Countryside Act 1981

(e) Sites of Special Scientific Interest (SSSI), notified under Section 28 of the Wildlife and Countryside Act 1981 (as amended)

(f) Marine Nature Reserves under the Wildlife and Countryside Act 1981, and

(g) Marine Conservation Zones under the Marine and Coastal Access Act 2009 (MACA)

F.9 The strategic options appraisal has also considered the wider habitat resource and ecological functionality at a strategic level. This has included consideration of sites designated as having national or international value as well as some particular habitats which may fall outside these designated areas or which are not designated as having such value.

F.10 Given the scale of habitats designated at less than a national level, it was considered appropriate through consultation with key stakeholders that some such sites should also be considered in the strategic options appraisal for the North Wales Connections Project. The list of interests includes:

(a) areas of, ancient and semi-natural woodland;

(b) Local Nature Reserves (LNRs)

(c) RSPB Reserves, and

(d) Important Bird Areas.

F.11 Under Article 6(4) of the Habitats Directive 92/43/EEC, an appropriate assessment by a competent authority is required where a plan or project is likely to have a significant effect upon a Natura 2000 site (also known as 'European wildlife sites'), alone or in combination with other planned projects. Natura 2000 is a network of sites that includes SACs and SPAs. In addition, it is UK policy that sites designated under the Ramsar convention are included in this process.

F.12 Given the importance of these sites, consideration has been given to the potential for each of the strategic options to affect the integrity of European wildlife sites, including effects in combination with other plans or projects. Information regarding associated energy projects has been included in this appraisal together with other third party projects advised by CCW. However, the list of projects considered is not exhaustive and will need to be subject to review as the project develops. A screening assessment under the Habitat Regulations would be undertaken for the strategic option finally selected, and an appropriate assessment completed if necessary, prior to submission of any consent application.

Historic Environment

F.13 The guiding principles pertaining to the consideration of likely effects upon the historic environment is to seek to avoid or minimise the effects of new infrastructure on cultural heritage features, including historic buildings and archaeological features.

F.14 While not an exhaustive list of considerations, the strategic options appraisal has paid particular attention to areas subject to international and national archaeological and cultural heritage designations as follows:

(a) World Heritage Sites- as designated by UNESCO's World Heritage Committee to be of Outstanding Universal Value for their contribution to universal cultural heritage

(b) Scheduled Monuments as designated under the Ancient Monuments and Archaeological Areas Act 1979

(c) Protected Wreck Sites as designated under the Protection of Wrecks Act 1973

(d) Historic Battlefields- as defined in the English Heritage register of historic battlefields (England only)

(e) Historic Parks and Gardens- at Grade I and Grade II* as defined by English Heritage's 'Register of Parks and Gardens of Special Historic Interest in England' and by Cadw in the 'Register of Parks and Gardens of Special Historic Interest in Wales', and

(f) Historic Landscape Areas as recorded in Cadw's 'Register of Landscapes of Historic Interest in Wales'.

F.15 Although Listed Buildings are designated at national level they have not been considered at the Level 1 strategic options appraisal stage due to their small site area and the difficulty of assessing the potential for impacts to occur to the setting of the building or feature at this strategic level.

Landscape and Visual

F.16 The guiding principles pertaining to the consideration of likely landscape and visual effects is to seek to avoid or minimise the effects of new infrastructure on the landscape/townscape and visual amenity.

F.17 The strategic options appraisal has paid particular attention to national landscape, and world heritage site designations, and their settings, as follows:

(a) National Parks and any future extension areas which are currently under consideration

(b) Areas of Outstanding Natural Beauty

(c) Designated and proposed World Heritage sites

(d) Areas defined as Heritage Coast

(e) Recreational Trails and Sustrans routes

(f) The value of the visual and sensory aspect of the landscape as assessed by CCW and reported in LandMap

(g) Principal settlement areas, and

(h) The designated cultural heritage features referred to above.

Local Air Quality

F.18 At this strategic level of appraisal the effects of any of the options upon local air quality is not likely to be material to the selection of a preferred option and therefore this aspect was scoped out for this level of appraisal.

Noise and Vibration

F.19 At this strategic level of appraisal the noise and vibration effects associated with any of the options was not considered likely to be material in the selection of a preferred option. It was therefore proposed that this topic be scoped out of the appraisal. However, a number of core statutory consultees suggested that it may differentiate between options, and while not material in itself, may be material in combination with other topic areas. It was therefore considered as part of the appraisal but was found not to be material at this strategic level.

Water

F.20 The guiding principles pertaining to the consideration of likely hydrological effects is to seek to avoid or minimise the effects of new infrastructure on water quality and to minimise flood risk and erosion.

Soils and Geology

F.21 The guiding principles pertaining to the consideration of likely effects on soils and geology is to seek to avoid or minimise the effects of new infrastructure on important geological features or on soils of the highest quality.

F.22 The strategic options appraisal has paid particular attention to:

(a) Nationally important sites of geological or geomorphological interest classified as Sites of Special Scientific Interest (SSSI), and

(b) Areas of extensive geological interest designated as European Geoparks by UNESCO.

(c) Land classified as 'best and most versatile' (i.e. Agricultural land classification Grades 1, 2 and 3a).

Resource Use and Waste

F.23 The guiding principles pertaining to the consideration of likely effects in terms of resource use and waste is to optimise the use of material resources in construction and minimise waste sent to landfill.

Greenhouse Gases and Energy Efficiency

F.24 The guiding principles pertaining to the consideration of likely greenhouse gases and energy efficiency effects is to improve the carbon / energy efficiency of National Grid's network, minimise climate change impacts and optimise resilience with respect to likely changes in future weather patterns.

Socio-Economic Appraisal

F.25 There are three sub-topics within the socio-economic appraisal, which are set out in the paragraphs below.

Local Economic Activity

F.26 The guiding principles pertaining to the consideration of effects on local economic activity are to seek to avoid or minimise the effects of new infrastructure on economic activities and, so far as reasonably practicable, provide economic benefits at a strategic level.

F.27 Existing areas of strategic economic activity have been identified, including key tourist attractions, ports and airports.

People and Communities

F.28 The guiding principles pertaining to the consideration of likely effects on people and communities is to seek to avoid or minimise the negative economic impacts of new infrastructure on people and communities and, so far as reasonably practicable, provide wider economic benefits for the local community.

F.29 At Level 1 Options Appraisal, major centres of population and community facilities of strategic importance are identified. Such community facilities include major healthcare, educational, sports/leisure and transport facilities.

Traffic and Transport

F.30 The guiding principles pertaining to the consideration of likely traffic and transport effects is to seek to avoid or minimise disruption to local communities during construction.

Aviation and Defence

F.31 The guiding principles pertaining to the consideration of likely effects on aviation and defence is to seek to avoid or minimise the effects of new infrastructure on civil aviation or defence interests.

Topic / Sub-topic	Potential Constraints and Data Sets	Value	Data Source	Extent of Inclusion
Environment Ecology and Biodiversity	Special Areas of Conservation (SAC)	International	Countryside Council for Wales / Natural England	Included
	Special Protection Areas (SPA)	International	Countryside Council for Wales / Natural England	Included
	Ramsar Site	International	Countryside Council for Wales / Natural England	Included
	Sites of Special Scientific Interest (SSSI)	National	Countryside Council for Wales / Natural England	Included
	National Nature Reserve (NNR)	National	Countryside Council for Wales / Natural England	Included
	Biospheres Reserves	International	Countryside Council for Wales / Natural England	Included
	Marine Nature Reserves	National	Countryside Council for Wales / Natural England	Marine Reserves are identified as either a SSSI, SPA or SACs
	Local Nature Reserve (LNR)	Local up to Regional	Countryside Council for Wales / Natural England	Included
	RSPB Reserve	National	RSPB	Included
	Important Bird areas (IBA)	International	BirdLife International RSPB	Included
	National Inventory of Woodland	National	gis.naturalengland.org.uk /Forestry Commission	Included
	Ancient and semi natural woodland (ASNW)	Local to National	Countryside Council for Wales / Natural England	Included

Topic / Sub-topic	Potential Constraints and Data Sets	Value	Data Source	Extent of Inclusion
	Plantation on Ancient Woodland (PAW) site	Local to National	Countryside Council for Wales	Included
Environment Cultural Heritage	World Heritage Sites	International	CADW/English Heritage	Included
	Scheduled Monuments	National	CADW/English Heritage	Included
	Designated landscapes or their regional equivalent	National	CADW/English Heritage	Included
	Historic landscape of international value, whether designated or not.	International	CADW/English Heritage	Included
	Scheduled Monuments with standing remains	National	CADW/English Heritage	Included
	Registered Parks and Gardens	National	CADW/English Heritage	Included
	Protected Wreck Sites	National	CADW/English Heritage	Included
	Heritage Coasts	National	Countryside Council for Wales / Natural England	Included
	Historic Landscape Areas (Wales Only)	National	CADW	Included
Environment Landscape and Visual	National Parks	National	Countryside Council for Wales / Natural England	Included
	Areas of Outstanding Natural Beauty (AONB)	National	Countryside Council for Wales / Natural England	Included
	National Character Areas (NCAs)	National	Natural England	Included
	Principal settlement areas	Regional	DCLG	Included
	Woodland Inventory	Regional	Forestry Commission Wales/ Forestry Commission England	Included

Topic / Sub-topic	Potential Constraints and Data Sets	Value	Data Source	Extent of Inclusion
	Registered Parks and Gardens	Regional	CADW/English Heritage	Included
	Visual and Sensory Aspect Areas (LandMap)	Regional	Countryside Council for Wales	Included
	Sustrans Cycle Routes	Regional	SUSTRANS	Included –National and Regional Cycle Routes Only
	Geoparks	International	Countryside Council for Wales/Geoparks/ Natural England	Included
	Recreational Railway	Regional	OS Mapping	Included
Environment Noise	-	-	-	Included
Environment Soil and Geology	Land classified as Best and Most Versatile (BMV; i.e. ALC grades 1, 2 and 3a);	National	Welsh Assembly Government/ Natural England	Included
	Land of lower ALC grades (i.e. 3b, 4 or 5) where other sustainability considerations need to be taken into account.	National	Welsh Assembly Government/ Natural England	Included
Environment Hydrology and Environment	Water courses (rivers) and still waters (lakes, ponds and reservoirs)	Regional	Environment-agency.gov.uk	Aspects relating to Biodiversity, Recreation, Value to economy, Impacts to river courses and water quality and to fishing have been considered

Topic / Sub-topic	Potential Constraints and Data Sets	Value	Data Source	Extent of Inclusion
	Floodplain (EA flood zones 3 and 2)	Regional	Environment-agency.gov.uk	Included
	Marine and estuaries	Regional	Environment-agency.gov.uk	Aspects relating to Biodiversity, Recreation and Value to economy, have been considered
Socio-Economic Aviation and Defence	Military airfield	National	Defence Estates Safeguarding -	Included
	Passenger airport	National	OS Mapping	Included
	Licensed civil airfield	National	OS Mapping / DECC	Included
Socio-Economic Economic Activity	Tourism and Major visitor attractions and destinations	Regional / National	OS Mapping	Included
	National Trust land	Regional / National	National Trust	Included
	Transport infrastructure	National	OS Mapping	Included
Socio-Economic People and Communities	National Planning Policies	National /Regional		Planning Policy Statements and Technical Advice Notes Regional Spatial Strategies and Regional Development Strategies.
	Local settlements / Population Density	Regional	OS Boundary line & Office of National Statistics	Included

Topic / Sub-topic	Potential Constraints and Data Sets	Value	Data Source	Extent of Inclusion
	Welsh Language	Local / Regional	Welsh Government	Appraisal of whether Strategic Options would have a disproportionate effect on welsh-speaking individuals or communities and / or impact negatively on successful achievement of stated Welsh Government and Local Authority legislative and policy aims
	Community land	Regional	OS Mapping	Included
	Land Access (Wales) - Common land	Regional	Countryside Council for Wales / Natural England	Included
	Land Access (Wales) - Open country	National	Countryside Council for Wales / Natural England	Included
	Community facilities(Health, sports and education facilities)	Local	OS Mapping	Included
	National cycle paths	National	SUSTRANS	Included
	Regional cycle paths	Regional / national	SUSTRANS	Included
Socio-Economic Traffic and Transport	Public rights of way	National	Local Authorities	National and long distance routes only
	Rail network	National	OS Mapping	Included
	Primary roads	National	OS Mapping	Included
	Class A roads (including Trunk road network)	National	OS Mapping	Included
	Class B roads	National	OS Mapping	Included

Topic / Sub-topic	Potential Constraints and Data Sets	Value	Data Source	Extent of Inclusion
	Minor roads	Regional	OS Mapping	Included

Appendix G – Constraint Maps

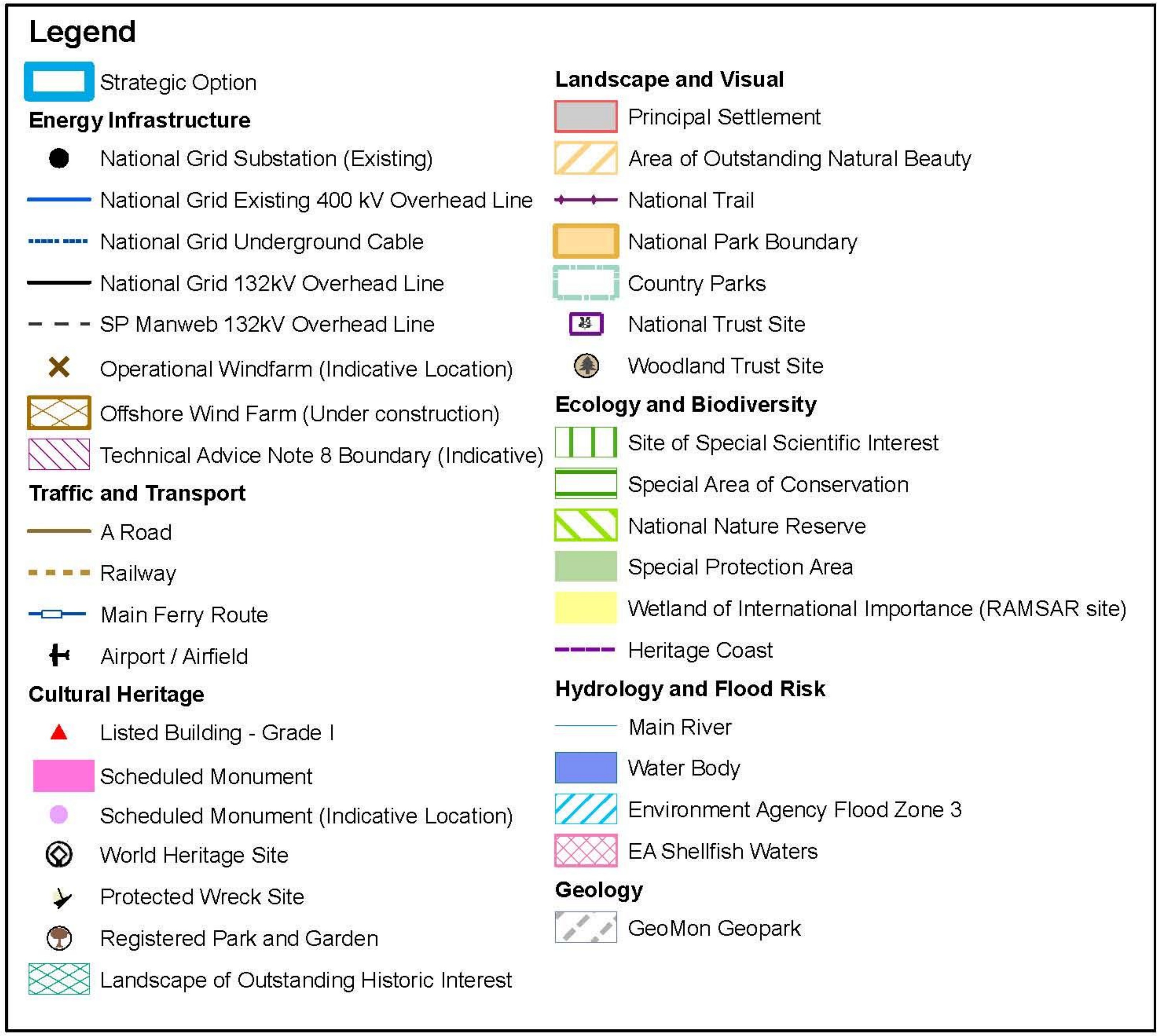

Figure G.1 – Legend for Constraint Maps

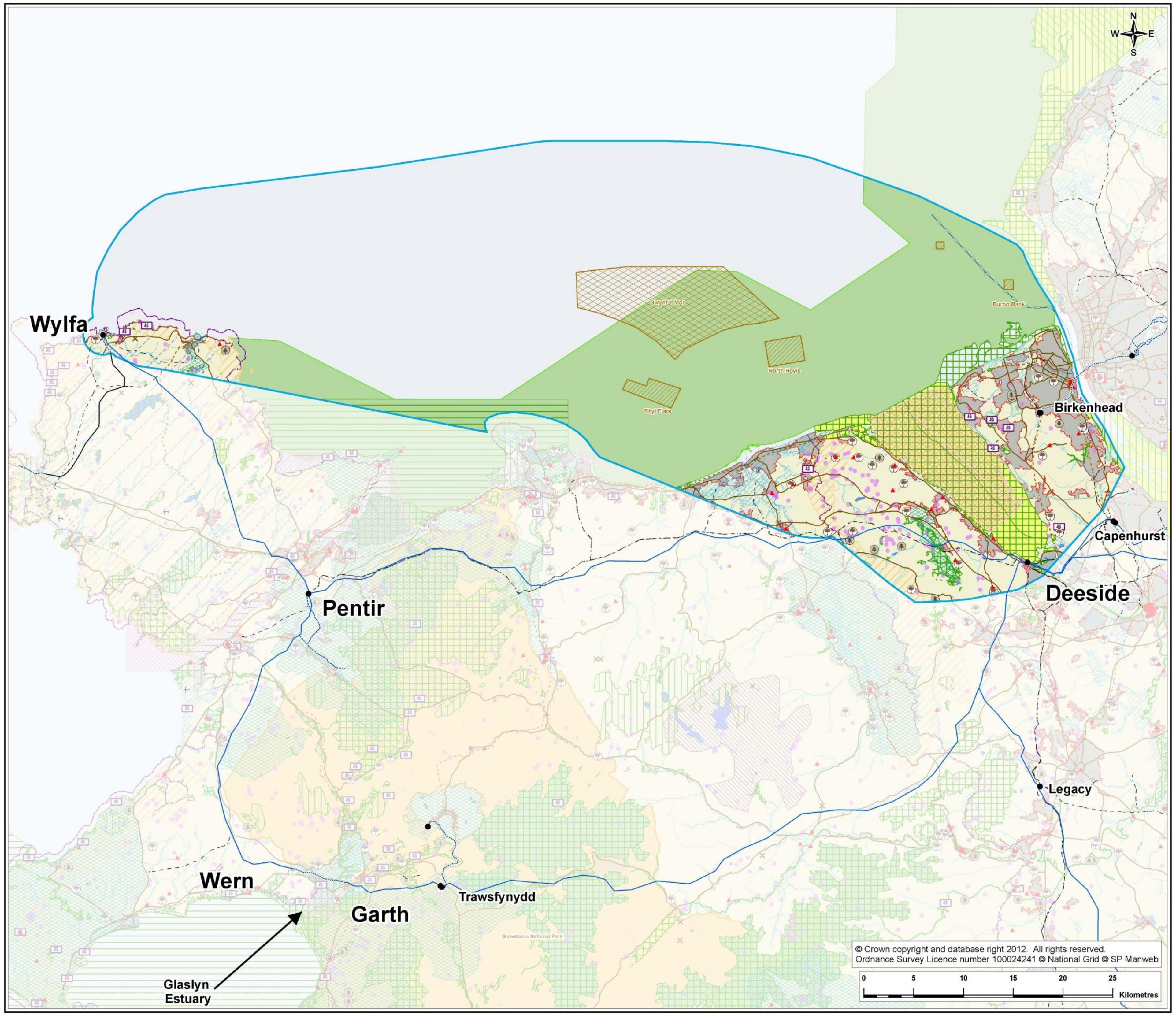

Figure G.2 – The Principal Ecological, Cultural Heritage and Landscape Constraints Affecting Strategic Option 1

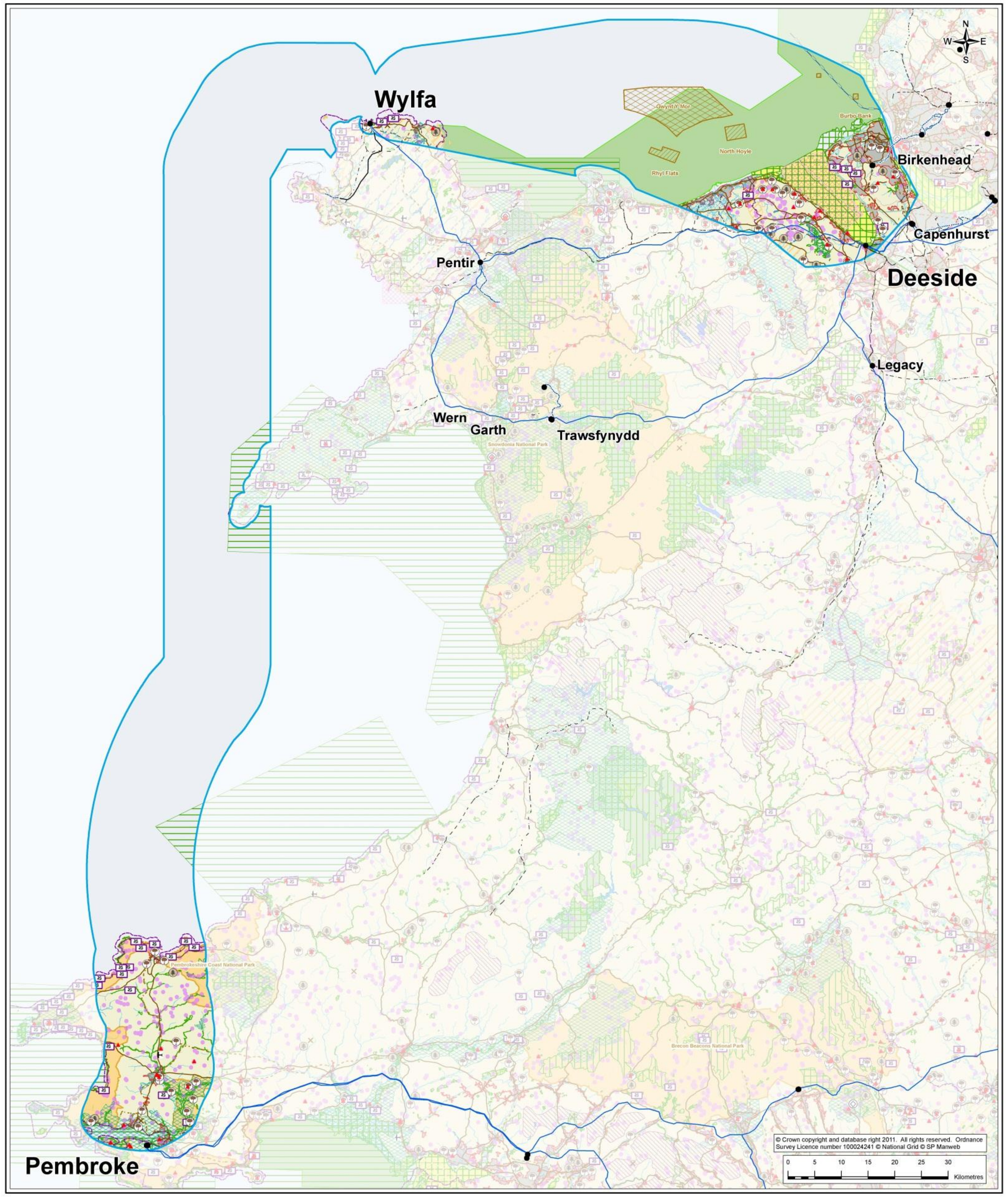

Figure G.3 – The Principal Ecological, Cultural Heritage and Landscape Constraints Affecting Strategic Option 2

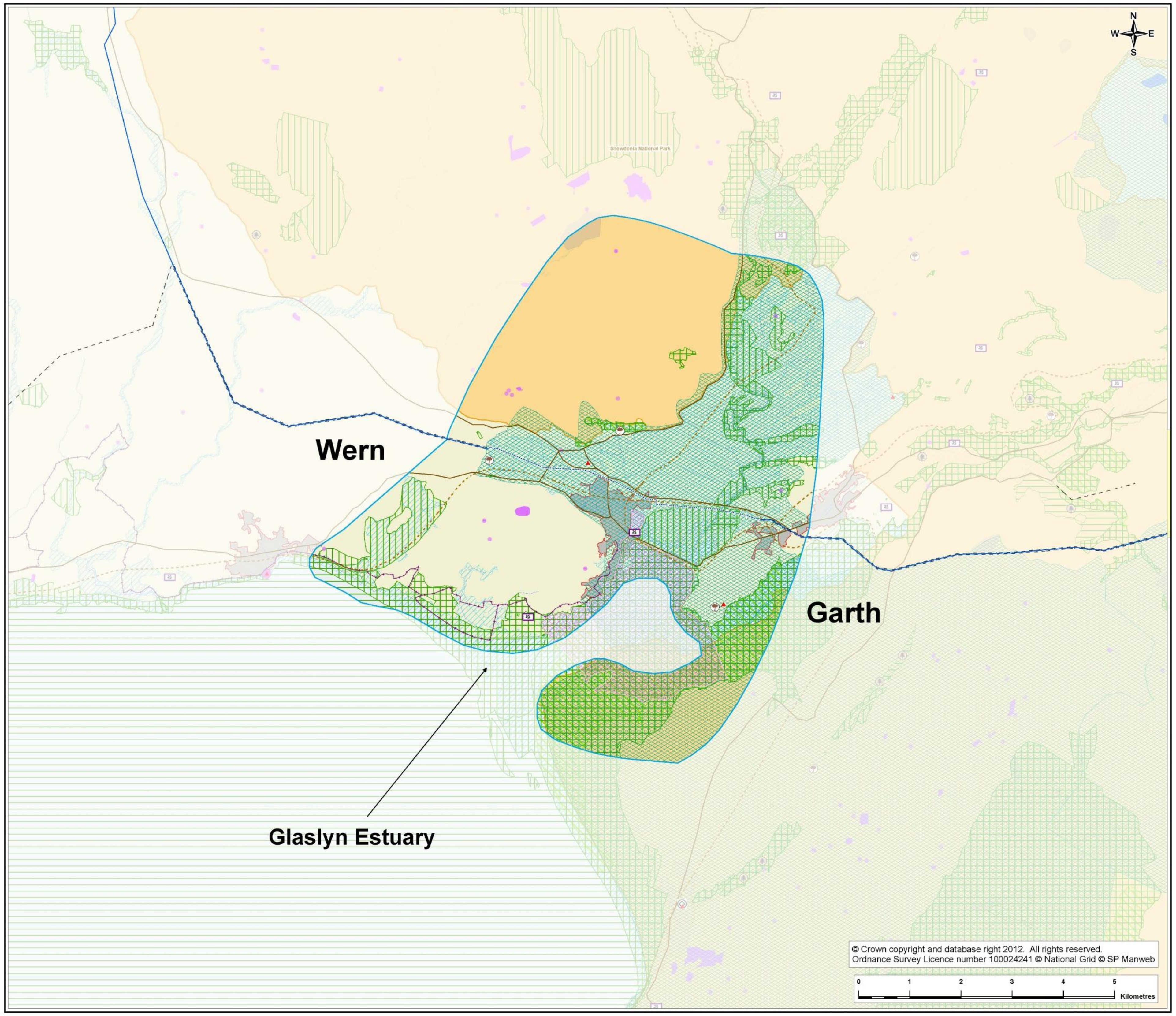

Figure G.4 – The Principal Ecological, Cultural Heritage and Landscape Constraints Affecting Strategic Options 3, 4 and 5 at Glaslyn

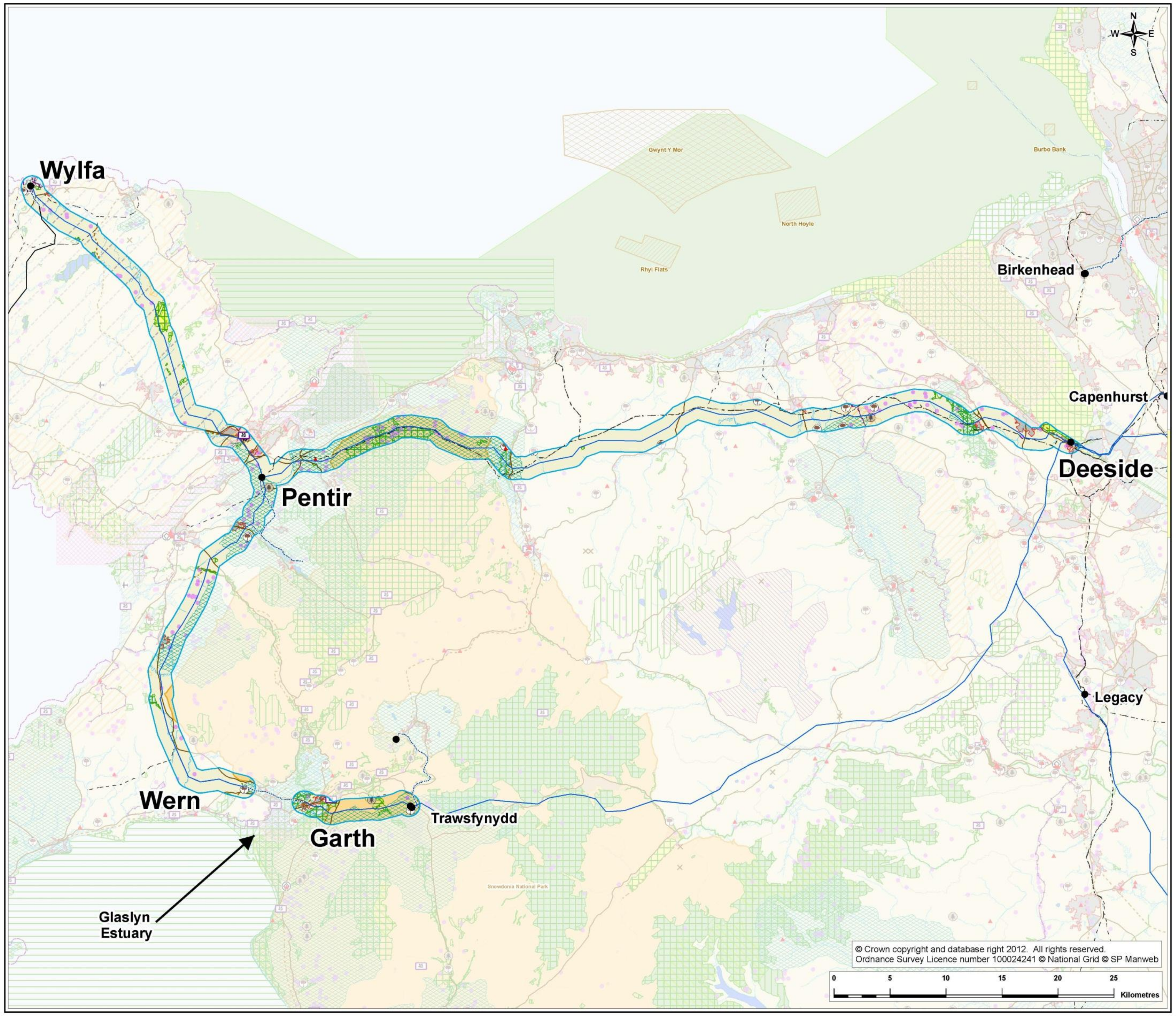

Figure G.5 – The Principal Ecological, Cultural Heritage and Landscape Constraints Affecting the Common Works for Strategic Options 3, 4 and 5

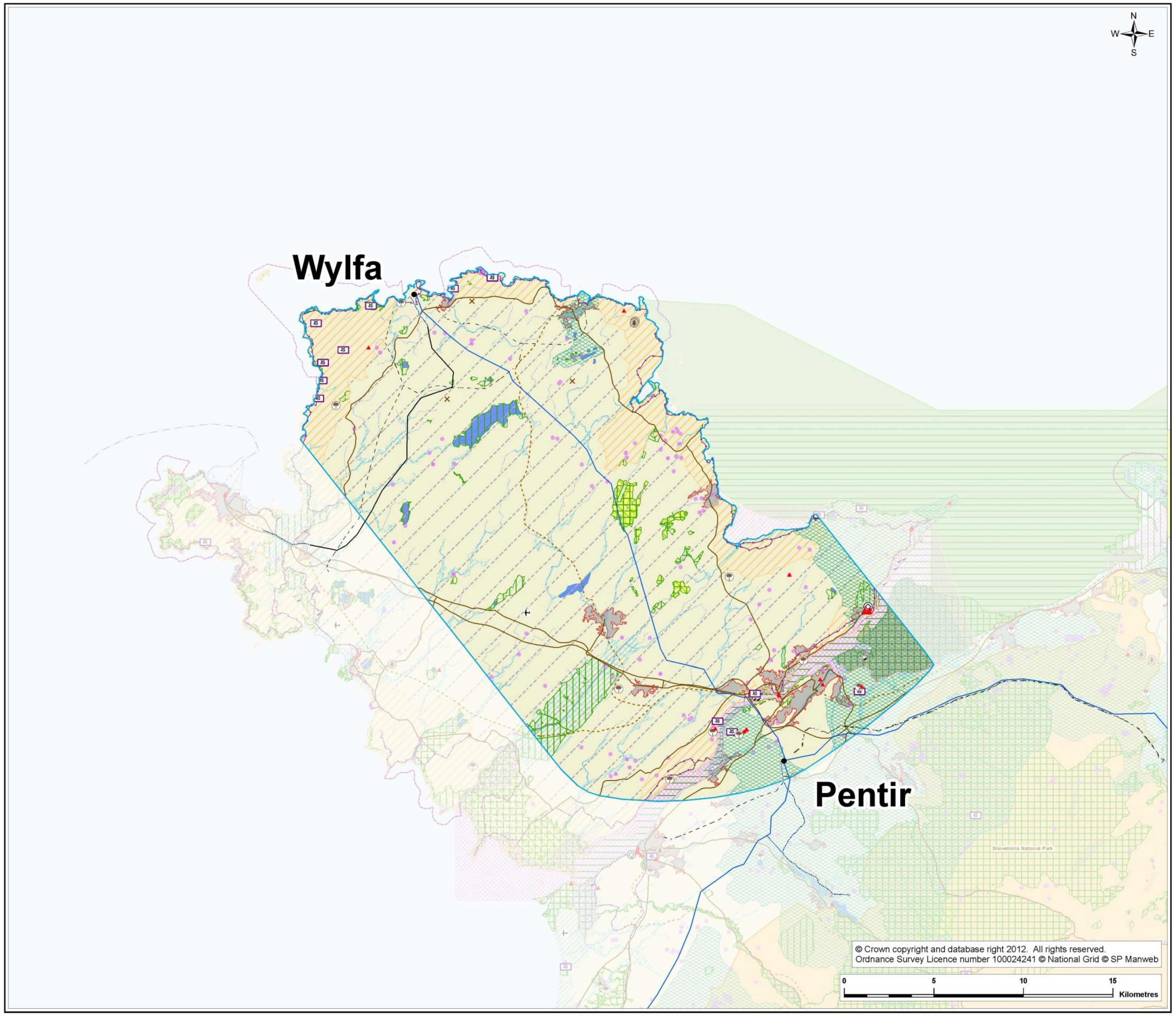

Figure G.6 – The Principal Ecological, Cultural Heritage and Landscape Constraints Between Wylfa and Pentir Affecting Strategic Option 3

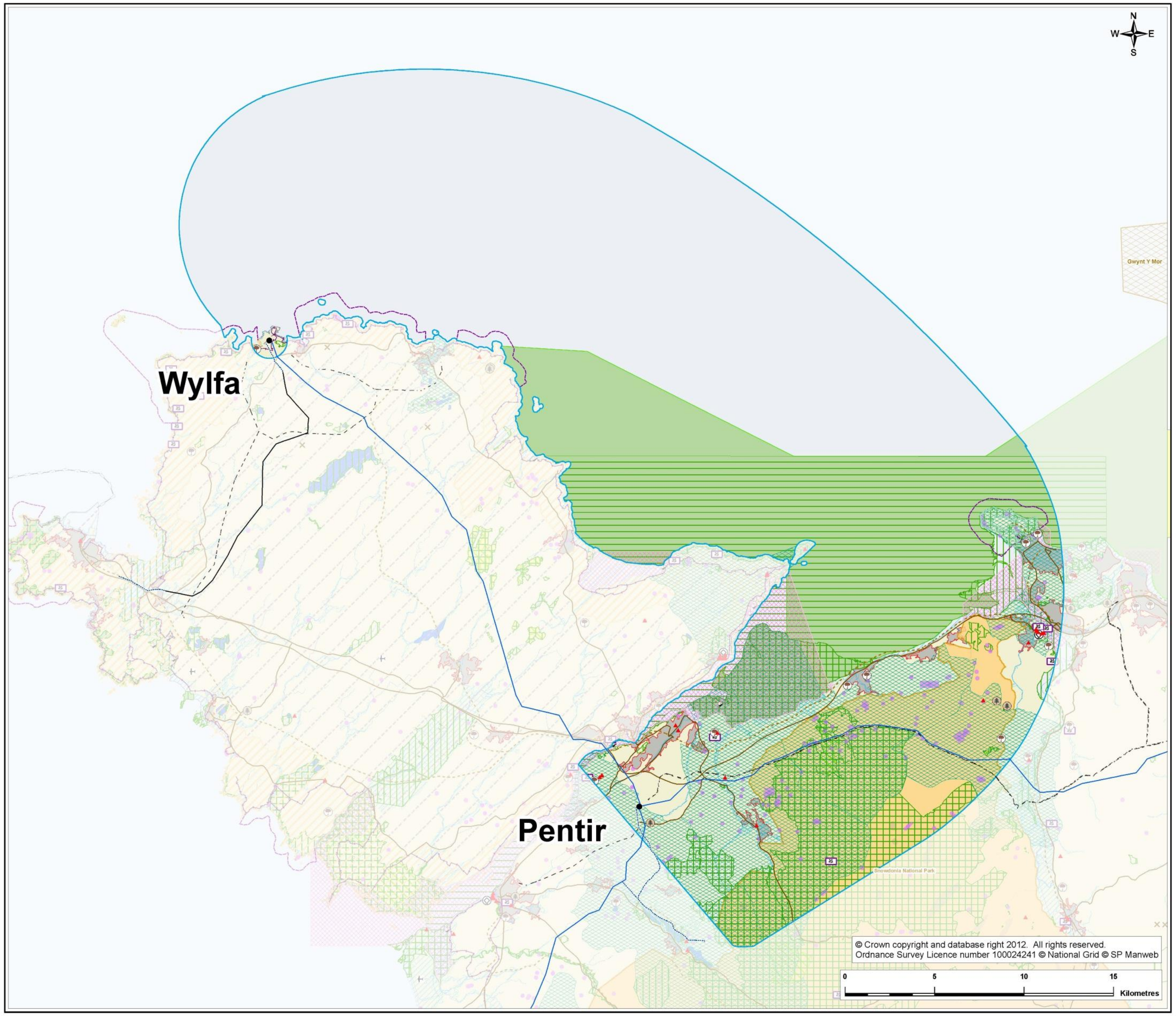

Figure G.7 – The Principal Ecological, Cultural Heritage and Landscape Constraints Between Wylfa and Pentir Affecting Strategic Option 4

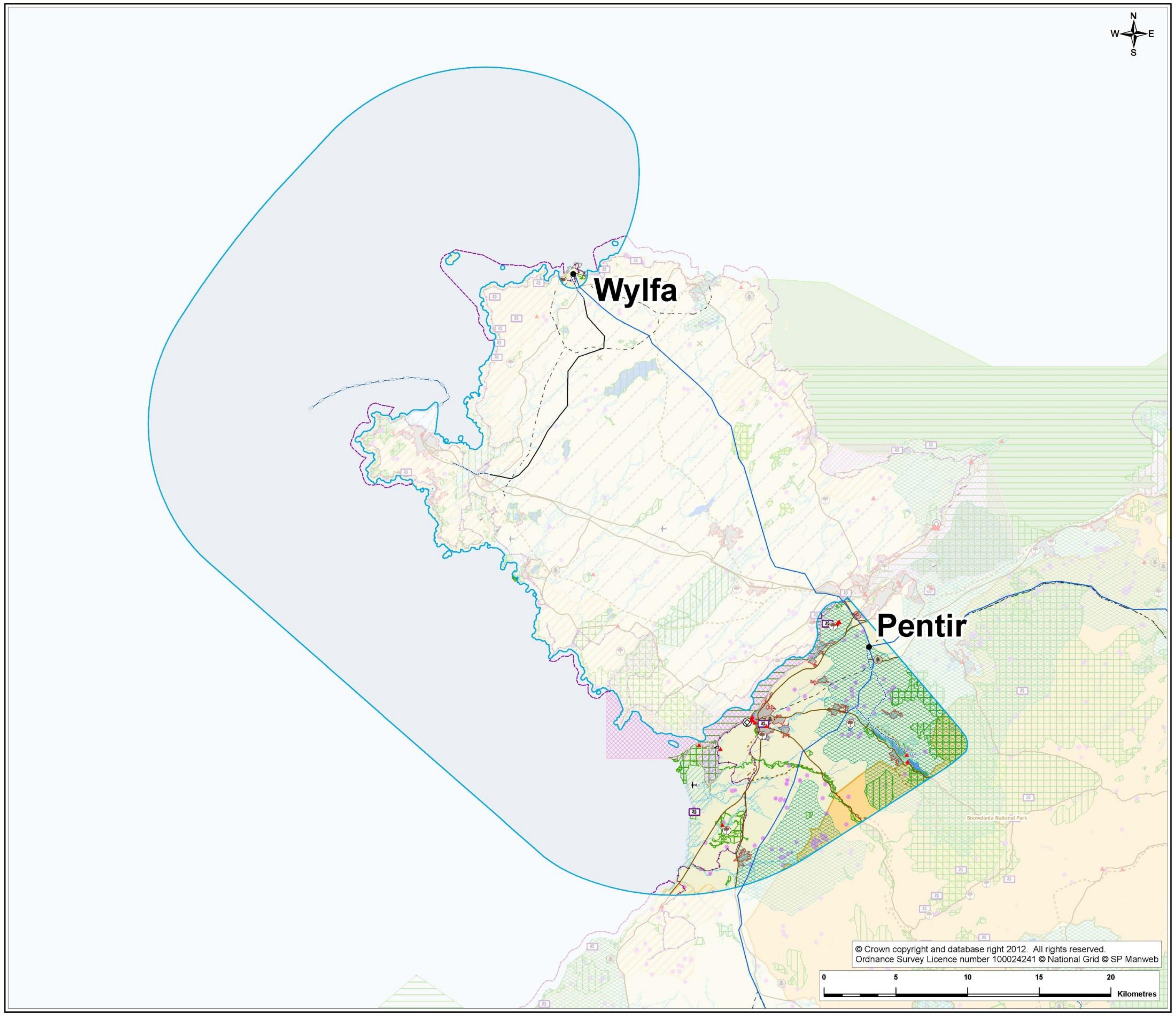

Figure G.8 – The Principal Ecological, Cultural Heritage and Landscape Between Wylfa and Pentir Affecting Strategic Option 5

Glossary of Terms and Acronyms

AC	Alternating Current
AIS	Air Insulated Switchgear - traditional substations with air insulated equipment, usually located away from coastal areas
AONB	Area of Outstanding Natural Beauty
Boundary	Boundaries represent the main weaknesses on the transmission system. Such weaknesses lead to the need to restrict power flows across the system
Converter Station	A converter station connects an AC system to a DC system. It contains electrical equipment that can convert AC to DC (and vice versa)
CSC	Current Source Converter
DC	Direct Current
DCO	Development Consent Order
DNO	Distribution Network Operator
Double Circuit	An overhead line design where two circuits are mounted on a single set of towers.
GIL	Gas Insulated Line
GIS	Gas Insulated Switchgear – compact substations with gas insulated equipment, utilised particularly in coastal areas
HV	High Voltage

HVDC High Voltage Direct Current

HVDC is used where power transmission is necessary over long distances (e.g. greater than 100 km). At such distances, this technology is both highly technically effective and economic. The solution requires the development of at least two converter installations (one at each end) and either a cable or overhead line link between the two. The converter installations are typically the size of a large warehouse.

km Kilometre

NETS SQSS National Electricity Transmission System Security and Quality of Supply Standard. [47]

The NETS SQSS is a document that defines a set of criterion that specifies the robustness of the transmission system, in terms of the transmission faults and combinations of faults that it must be able to withstand without any interruption of electrical supplies, and the maximum interruption to supplies which is permitted under certain more onerous combination of faults. The SQSS is subject updates through industry and regulatory working groups, this periodic review and consultation changes to the NETS SQSS are implemented by changes to the electricity transmission licence Standard Conditions approved by the industry regulator, Ofgem.

The NETS SQSS requires that National Grid must plan for all demand and generation conditions (or "backgrounds") "which ought reasonably to be foreseen to arise in the course of a year of operation … [and] shall include forecast demand cycles, typical power station operating regimes and typical planned outage patterns."

OFGEM Office of Gas and Electricity Markets

The regulatory body that is responsible for electricity and gas supply markets and networks.

OHL Overhead line

[47] The NETS SQSS can be viewed at https://www.nationalgrid.com/uk/Electricity/Codes/gbsqsscode/

Ramsar	A designation covering all aspects of wetland conservation and wise use, recognising wetlands as ecosystems that are extremely important for biodiversity conservation in general and for the well-being of human communities.
SAC	Special Area of Conservation
SF_6	Sulphur Hexafluoride Gas The electrical insulator in GIL and SF_6 switchgear
SOR	Strategic Options Report
SPA	Special Protection Area Gives protection under the Birds Directive to rare and vulnerable birds, and for regularly occurring migratory species.
SSSI	Site of Special Scientific Interest Protect the country's best wildlife and geological sites.
volt (V)	The electrical unit of potential difference. 1 kilovolt (kV) = 1,000 volts
VSC	Voltage Source Converter
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