Scottish & Southern Electricity Networks

RIIO T2 East Coast Onshore Transmission Investment Case

Contents

1 Executive Summary

This paper sets out the strong technical, economic and urgent need for coordinated reinforcement on the eastern side of the GB Transmission network from the north of Scotland to the north of England. It also explains how the Scottish onshore transmission works fit into the overall reinforcement strategy and explains the clear need and economic justification to progress with the Scottish onshore reinforcement to meet their earliest possible delivery dates.

This has been demonstrated by assessing boundary congestion on the existing network as the counterfactual and analysing the potential reduction in constraints that can be achieved by implementing the different reinforcement options across a range of generation scenarios including Future Energy Scenarios (FES) and local generation sensitivities.

We use this report to support the justification of onshore transmission projects in our RIIO-T2 Certain View as set out in our paper, Planning for Net Zero: Scenarios, Certain View and Likely Outturn[1]. Each of the following projects is supported by a separate RIIO-T2 Engineering Justification Paper;

- East Coast 275kV Onshore Upgrade, 2023
- East Coast 400kV Incremental Upgrade, 2026
- North East 400kV Upgrade, 2023

National Grid Electricity System Operator (ESO) prepared a Cost Benefit Assessment (CBA) Report in collaboration with the three onshore Transmission Owners, Scottish Hydro Electric Transmission (SHE Transmission), Scottish Power Transmission (SPT) and National Grid Electricity Transmission (NGET).

The Net Present Value (NPV) for the East Coast 275kV Onshore Upgrade ranges from £2.5bn - £4.2bn across the scenarios and sensitivities assessed. When in combination with the East Coast 400kV incremental Upgrade, the NPVs increase ranging from £2.9bn - £6.0bn. The optimal combination of onshore plus offshore reinforcements gives positive net present values ranging from £11.6bn to £18.4bn.

The bundling of the Scottish onshore projects in our RIIO T2 submission differs from that presented to date in the Network Options Assessment (NOA) and ESO CBA Report. This is based on the requirement to coordinate the scope and timing of wider system capability works with those required to accommodate regional connections.

The optimal reinforcement pathway comprises several discrete projects with different costs and capacities, at different levels of maturity and spanning a horizon of around ten years that combine to give the optimal investment strategy across the three TO areas. The development of such a large programme of works is therefore challenging, requiring all three TOs to work together to deliver the most economic, efficient and coordinated reinforcement strategy.

[1] T2BP-PAP-0008 - Planning for Net Zero: Scenarios, Certain View and Likely Outturn

The first projects to be delivered as part of the eastern reinforcement strategy are the Scottish incremental 275kV and 400kV onshore transmission upgrade works, utilising predominantly existing assets. The ESO's cost benefit analysis indicates these projects have strong economic benefits, are robust against a variety of sensitivities and would not be regretted even if the later reinforcements were delayed or not carried out. These works are therefore included in our RIIO T2 plan based on the certainty of need demonstrated through the NOA, the ESOs CBA Report and the design and development of these projects being well advanced.

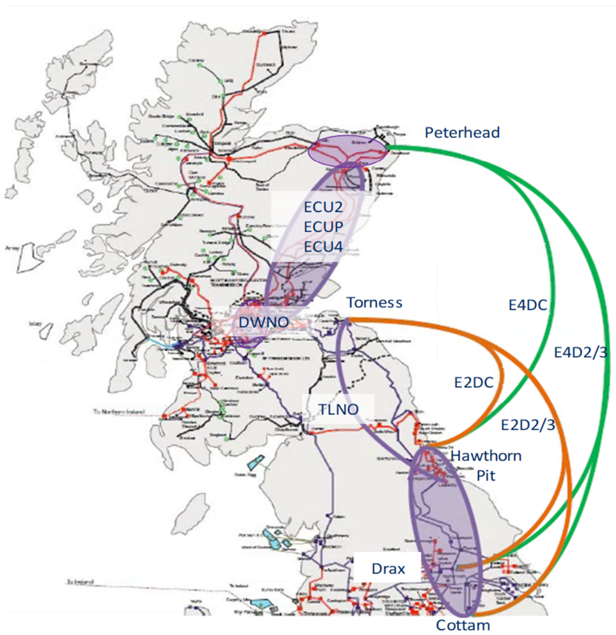
The other projects in the optimal reinforcement pathway shown in Figure 1 are;

- AC reinforcement across B5 in SPT's area due in 2028, NOA ref: DWNO
- An HVDC link between Peterhead and North of England due in 2028/29
- An HVDC link between Torness and North of England due in 2027/28

These projects are less well advanced in their design and development than the onshore works in the North of Scotland and therefore it is proposed that these projects will follow the strategic wider works process, starting with the preparation of an Initial Needs Case to be submitted to Ofgem in 2020. However, the pre-construction funding for these projects will be included within the RIIO-T2 submission.

Figure 1: East Coast Optimal Reinforcement Projects

Onshore and offshore options



Optimal Reinforcement Pathway

Onshore:

- **ECU2** - East Coast onshore 275kV upgrade - 2023
- **ECUP** - East Coast onshore 400kV- 2026 incremental reinforcement (builds on ECU2).
- **DWNO** – Denny Wishaw 400kV reinforcement - 2028

Offshore:

- HVDC link between Peterhead and North of England - 2028/29
- HVDC link between Torness and North of England 2027/28

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2 Introduction

This Investment Case details the need, sequence, interface and timing of the East Coast onshore transmission projects in the context of the wider GB Network reinforcement plans. This includes the onshore work on the East Coast of Scotland as shown on the map in Figure 2 and the proposed two Eastern HVDC links from Peterhead and Torness to the North of England.

The East Coast Onshore Investment Case is structured as follows:

Section 3: Need

This section provides an explanation of the "need" for the planned works. It provides evidence of the primary and, where applicable, secondary drivers for undertaking the planned works. Where appropriate it provides background information and/or process outputs that generate or support the "need".

Section 4: Network Options Assessment

This section sets out the Network Options Assessment (NOA) methodology, introduces the East Coast Wider System reinforcement options and the NOA recommendations.

Section 5: ESO East Coast Cost Benefit Analysis (CBA) Report

This section sets out the ESO East Cast CBA Report, the Joint TO inputs, East Coast options, option combinations and ESO recommendations for the optimal East Coast reinforcement pathway.

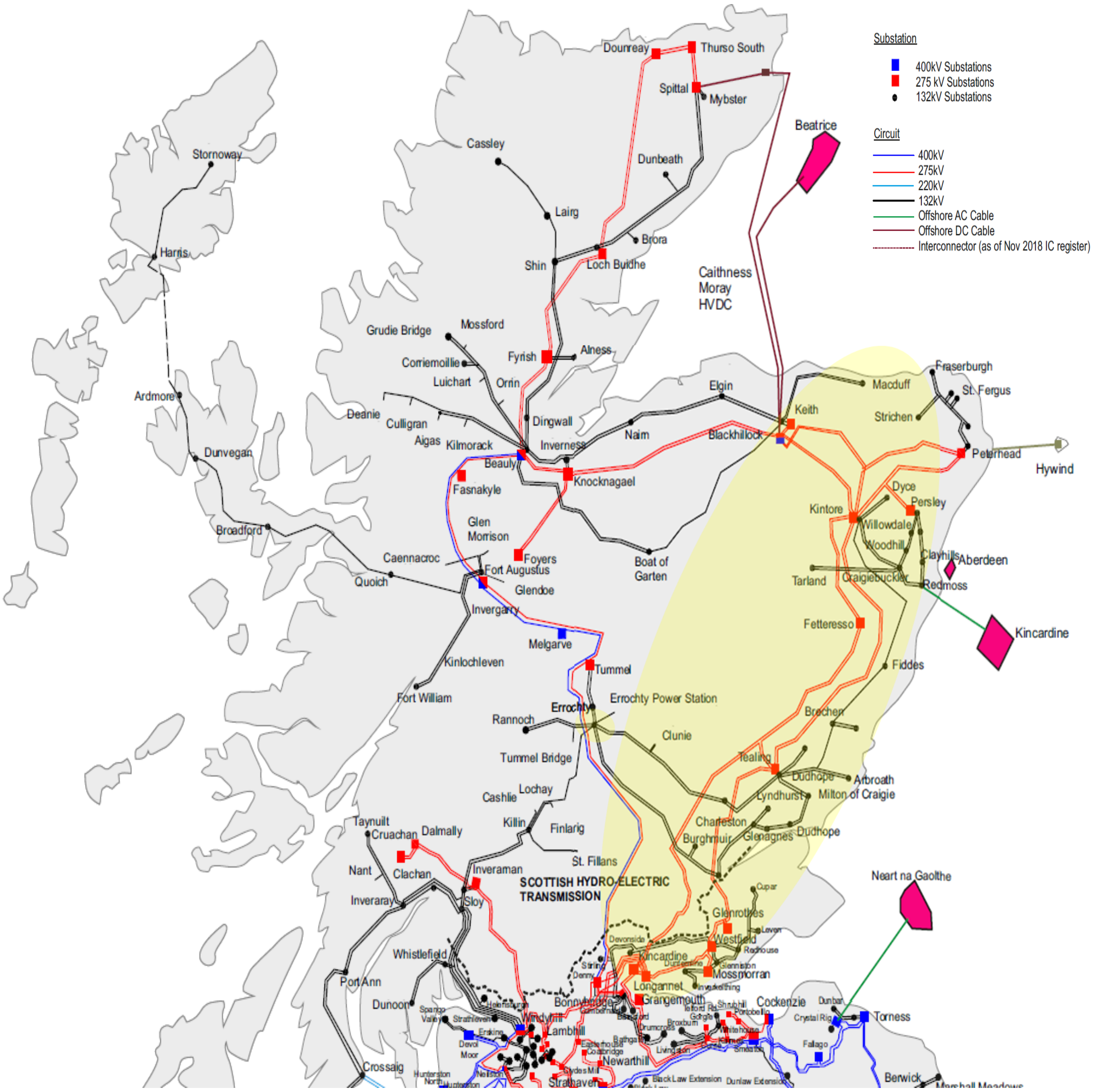
Section 6: RIIO T2 East Coast Onshore Upgrades

This section provides summary of how the ESO recommendations for Wider System reinforcement are coordinated with both Regional and Asset Condition based factors. This explains the sequencing and bundling of works included in our RIIO T2 Business Plan.

Section 7: Conclusion

This section summarises the justification for the proposed works planned to be undertaken in the RIIO-T2 period and the next steps for the East Coast HVDC links.

Figure 2: Existing SHE Transmission Network Map[2]

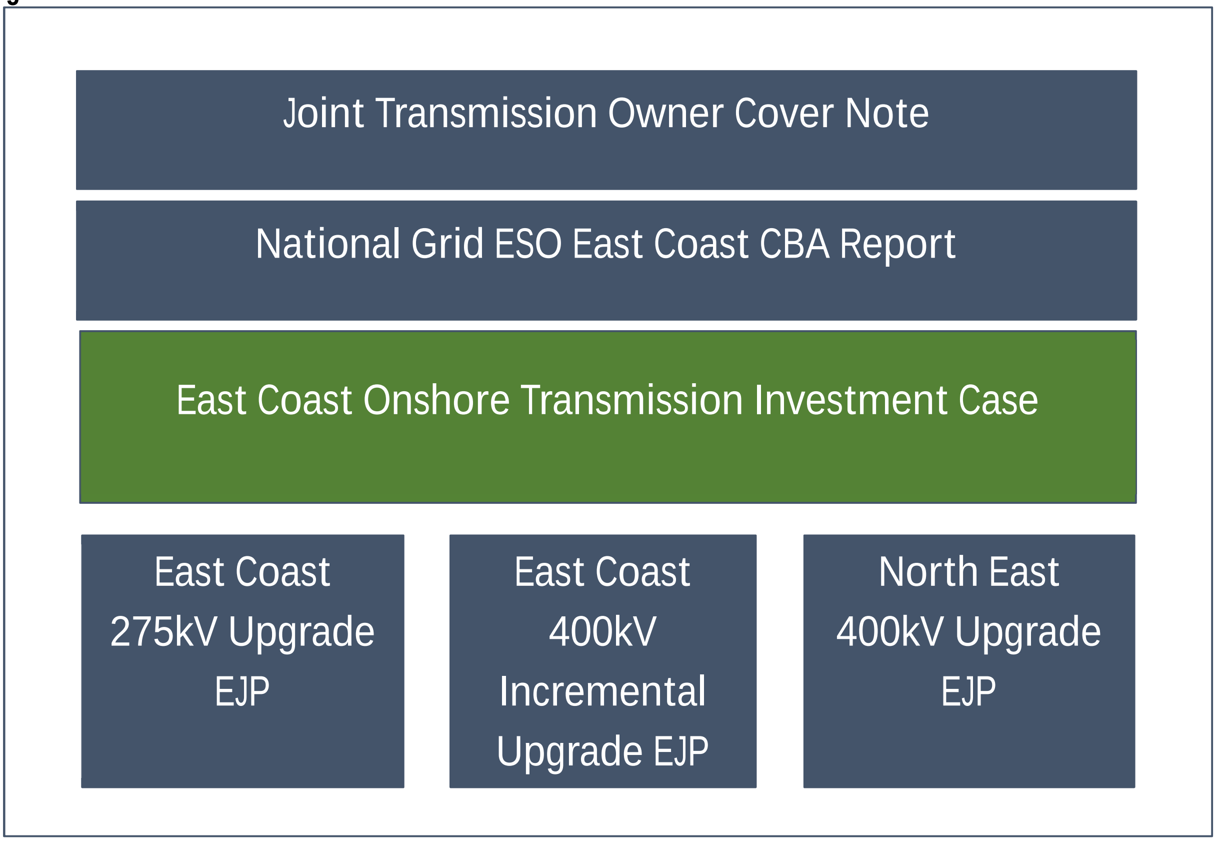


2 Electricity Ten Year Statement, November 2018, Appendix A, Figure A2

This paper is one of a suite of documents setting out our RIIO-T2 East and North East Transmission Reinforcement Plans. The hierarchy of the East and North East suite of documents is shown in Figure 3 and the purpose of each document is as follows;

- **Joint Transmission Owner Cover Note:** A one-page note detailing the coordinated, TO led Eastern Cost Benefit Analysis (CBA) undertaken by the Electricity System Operator (ESO).
- **National Grid ESO CBA Report**: Presents the detailed CBA and Least Worst Regret Analysis undertaken to economically justify the optimal coordinated reinforcement path for the transmission network from the North of Scotland to the North of England.
- **RIIO-T2 East Coast Onshore Transmission Investment Case**: This document details the Need, sequence, interface and timing of the East Coast onshore projects in the context of the wider GB Network
- **RIIO T2 Engineering Justification Papers**
  The Individual Engineering Justification Papers detail the background, need, optioneering, delivery strategy, timing and outputs for each project.

Figure 3: RIIO T2 East and North East Suite of Documents



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The scope of the proposed GB Transmission reinforcement works from the north of Scotland to the north of England span across all three onshore transmission owner's licensed areas. It is therefore essential for SHE Transmission, SPT and NGET to work together, in collaboration with the ESO, to develop and evaluate reinforcement proposals.

Governance for joint planning of the GB transmission system comes under the System Operator Transmission Owner Code (STC) which provides the framework for Licensees to plan and develop their respective grid systems in an efficient, coordinated and economic manner. To facilitate this process and to comply with the STC, a Joint Planning Committee (JPC) exists which co-ordinates investment planning, connection and transmission system performance activities.

Under the STC and JPC arrangements, each party carries out the necessary pre-construction works and bears its own costs, except in the case where the parties agree to jointly engage a service provider. Under these circumstances any costs would be shared between TOs as appropriate and as jointly agreed. Such arrangements would allow established costs and reporting arrangements within each company to continue pending establishment of a specific project vehicle for the Eastern HVDC links, at a later date.

Coordination between the three TOs is critical to delivering the eastern reinforcement projects, particularly in determining a strong technical and economic Needs Case in conjunction with the ESO, but also in coordinating pre-construction works.

Given the scale of the potential projects involved and the requirement for specific pre-construction development tasks, SHE Transmission, SPT and NGET have established a project structure comprising a project supervisory board, a project management committee and three working groups (see Figure 4). Future workstream groups have been identified as Commercial and Procurement, Land and Consents and a Project Management Office.

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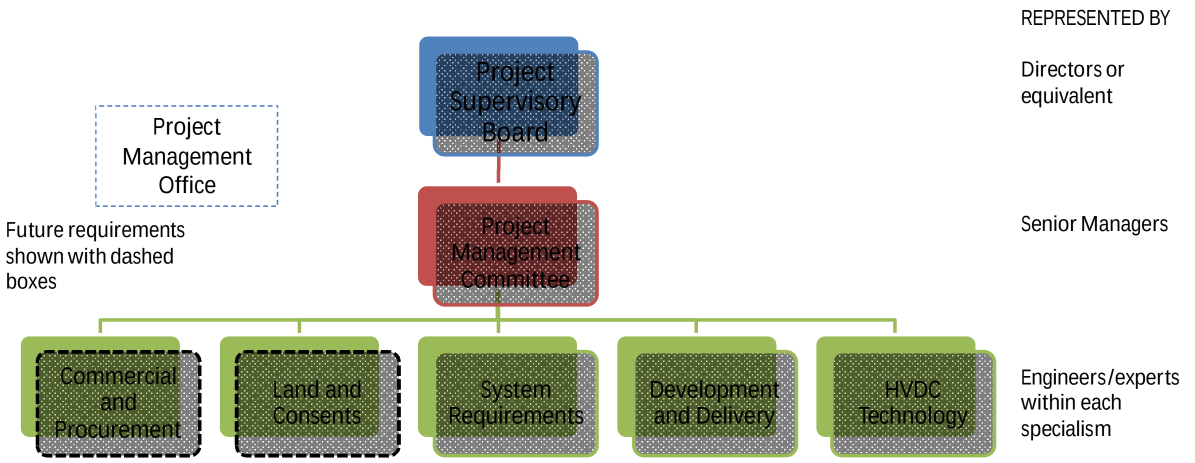
Figure 4: Project Structure



The roles and responsibilities of these groups are;

Project Supervisory Board (PSB)

The PSB membership is at an appropriate senior level (Director or equivalent) within each company, where decisions and commitment can be made on behalf of that company.

Project Management Committee (PMC)

The PMC membership is at an appropriate senior managerial level within each company with in depth knowledge of the projects in scope. The PMC reports to the PSB and meets at least monthly to manage the project within the envelope outlined by the PSB. It also coordinates activities between NGET, SPT, SHE Transmission and the ESO, and discusses any issues related to the work programme.

Systems Requirements Workstream

The systems requirements workstream membership is at an appropriate specialist level (Transmission System Planning Engineer) within each company with in depth knowledge in the relevant disciplines. The system requirements workstream reports to the PMC and meets as often as required to fulfil their duties. They are responsible for all system studies, NOA inputs and to confirm the project need through technical and economic analysis.

Development and Delivery Workstream

The development and delivery workstream membership is at an appropriate specialist project management level within each company with in depth knowledge in the relevant disciplines. The development and delivery workstream reports to the PMC and meets as often as required to fulfil their duties. They are responsible for preparing project programmes and activities to progress the project up to delivery, including consents and seabed surveys.

HVDC Technology Workstream

The HVDC Technology workstream membership is at an appropriate specialist engineering level within each company with in depth knowledge of HVDC technology. The HVDC technology workstream reports to the PMC and meets as often as required to fulfil their duties. While, in the main, the onshore options comprise of tried and proven transmission technologies, the offshore HVDC options all have a degree of technology risk. The remit for the HVDC technology workstream is to define assumptions and essential recommendations into the offshore option appraisal process. This includes information on HVDC link ratings, market capability and delivery and construction timescales for a variety of HVDC plant items.

3 Need

This section provides an explanation of the "need" for the planned works. It provides evidence of the primary and, where applicable, secondary drivers for undertaking the planned works. Where appropriate it provides background information and/or process outputs that generate or support the "need".

To articulate the sequencing of onshore works in the north of Scotland in the context of the GB network; growth and asset driven needs for transmission investment are set out in this paper as Wider System, Regional Connections and Asset Condition;

- Wider System – The industry process for assessing the capability and requirements of the transmission system against an uncertain future.
- Regional Connections – The industry standards and codes used to determine the works required to accommodate the connection of generation and demand to the transmission system.
- Asset Condition – As set out in our paper 'A Risk Based Approach to Asset Management[3]'

3.1 Wider System

3.1.1 Transmission Investment Planning Scenarios

As set out in our Paper, Planning for Net Zero: Scenarios, Certain View and Likely Outturn, the renewable generation connected to the north of Scotland transmission system will reach nearly 10 GW by March 2026 and the total generation will be 11.2 GW.

The SHE Transmission system must continue to adapt and be developed so power can be transported from source to demand, reliably and efficiently. To do this we must continually assess the balance between the cost of investing in the network against the cost of constraints to ensure we invest at the right time and in the right place.

To make sure this happens, we must understand its capabilities and the future requirements that may be placed upon it. We use the Future Energy Scenarios (FES) to help us decide on credible range of future transmission capabilities and requirements. These future transmission capabilities and requirements are published in the ESO's annual Electricity Ten Year Statement report.

In June 2019 we published our draft Business Plan for the RIIO-T2 price control period from 1 April 2021 to 31 March 2026. Our Plan is what we call the Certain View where all of the activities and investments we propose have a strong, evidence-based need to be done. Our Paper, Planning for Net

[3] T2BP-PAP-0009 - A Risk Based Approach to Asset Management

Zero: Scenarios, Certain View and Likely Outturn sets out our Certain View and how this compares with FES.

Scenarios have continued to play an important role in the assessment of network investments during the RIIO-T1 period, for example:

- Prior to 2015, FES described within the Electricity Ten Year Statement (ETYS) were used to assess the Main Interconnected Transmission System (MITS) network boundary capability requirement based on the required power transfers determined using the industry standard deterministic methodology;
- Major SWW reinforcements developed and delivered within RIIO-T1 have used generation and demand scenarios to underpin value for money aspects through Cost Benefit Analysis (CBA) methodology. This has involved detailed studies undertaken by both us (and our external consultants) and the Electricity System Operator (ESO). These assessments used least worst regret in order to identify the optimum solution; and
- The Network Options Assessment (NOA) process introduced in 2015 incorporated this scenario and CBA based approach to make recommendations for wider network reinforcements. NOA takes total GB constraints into account when assessing the consumer value delivered by reinforcement options under alternative FES.

The first step in identifying the need for reinforcement is to establish the capability of the existing network across a range of generation and demand scenarios. The network can then be analysed to check its capability against the requirements of the the National Electricity Transmission System Security and Quality of Supply Standard (NETS SQSS) and to determine the levels of network congestion across relevant transmission boundaries.

3.1.2 Criteria for the Design of the Main Integrated Transmission System (NETS SQSS Section 4)

Our Licence conditions require us to plan and develop our transmission system in accordance with the NETS SQSS.

The NETS SQSS sets out a coordinated set of criteria and methodologies that the transmission licensees shall use in the planning and operation of the National Electricity Transmission System (NETS). The standard sets out both planning and operational criteria which determine the need for services provided by the transmission licensee, including transmission equipment. The planning criteria set out the requirements for the transmission capacity for the NETS and also require consideration to be given to ensure the satisfactory operation and maintenance of the NETS.

NETS SQSS Section 4, Design of the Main Integrated Transmission System, sets out minimum deterministic planning criteria for the Main Interconnected Transmission System ("MITS") to ensure demand security and allow efficient market access for generation. The SQSS Security criterion is

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intended to ensure that demand can be supplied securely, without reliance on intermittent generators or imports from interconnectors in accordance with the NETS SQSS. The SQSS Economy criterion is a pseudo cost-benefit designed to ensure sufficient network capability is built to allow the efficient transmission of generation to main load centres.

The GB MITS is planned in accordance with criteria of Section 4 of the SQSS. Limiting factors on transmission capacity include thermal circuit ratings, voltage constraints and dynamic stability. From network studies, the lowest known limitation is used to determine the network boundary capability.

3.1.3 Network Boundaries

The transfer of energy across network boundaries occurs because generation and demand are typically in different locations. When the power transfer across a transmission system boundary is above that boundary's capability, the ESO must reduce the power transfer to ensure operation of the transmission system in accordance with NETS SQSS, Section 5. This is referred to as 'constraining' the network. When this happens, the ESO generally asks generators on the exporting side of the stressed boundaries to limit their output (other actions could include instruction to demand customers). To maintain energy balance, the curtailed energy is replaced with generation on the importing side. Balancing the network by re-dispatching generation this way costs money, and if the ESO is regularly constraining the network by large amounts, costs begin to accumulate. The existing transmission network and boundaries are illustrated on the GB transmission map shown in Figure .

The parts of the existing GB transmission network that are most relevant to this document are the north and east of Scotland characterised by boundaries B1, B1a, B2, B4 and B5, the Anglo-Scottish region characterised by boundary B6 and the north east of England comprising the transmission network across and north of the Midlands to South boundary. This region is characterised by boundaries B7, 7a and B8. Further detailed background information on the existing GB transmission network can be obtained from the published ETYS and NOA documents. This region is known as the northern region within the NOA report.

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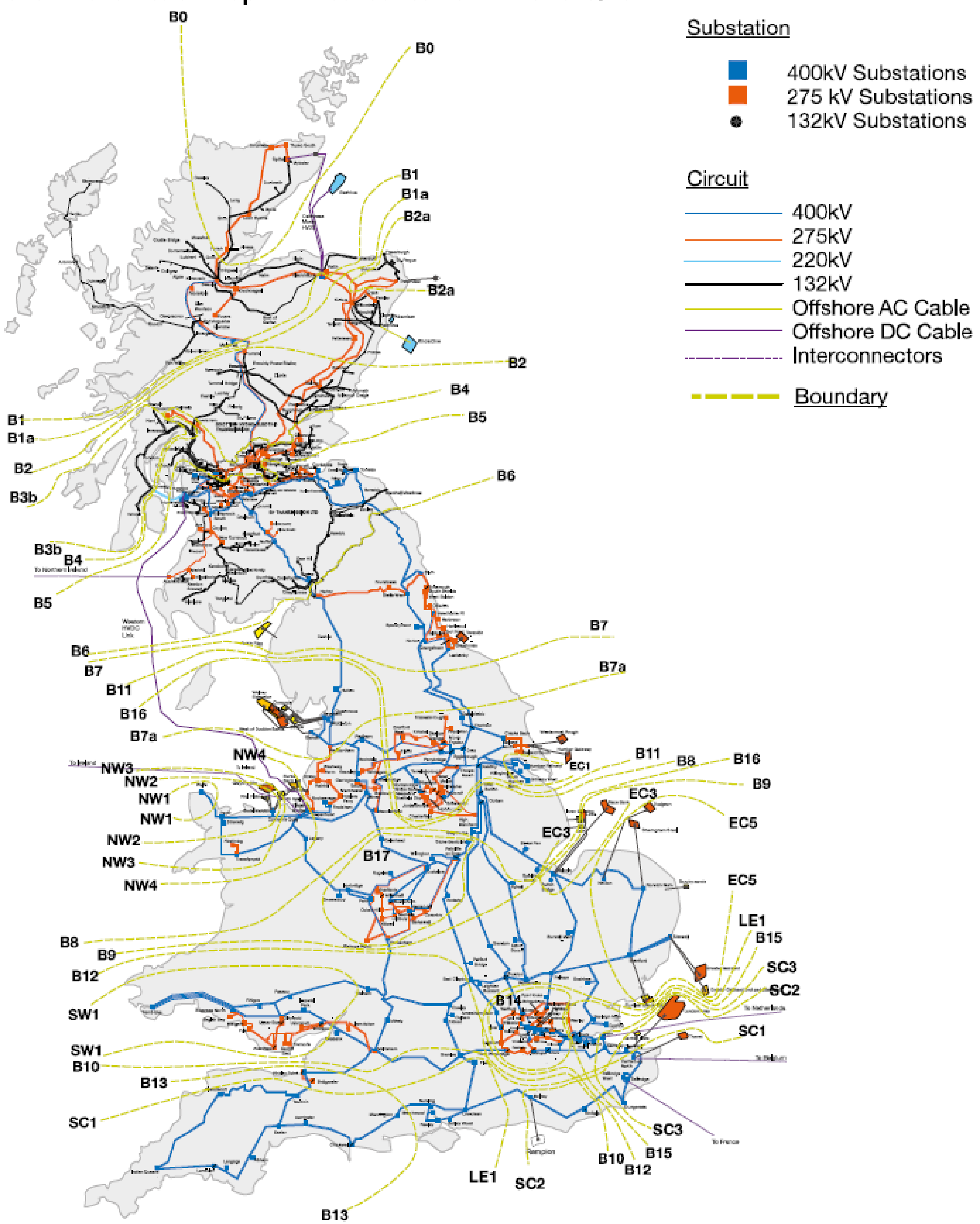
Figure 5: GB Transmission Map with Boundaries from ETYS 2018/19[4]



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[4] Electricity Ten Year Statement November 2018, Appendix A, Figure A3

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3.1.4 Base Capability and Network Requirements

Taken from the ESO's 2018 ETYS publication the 2018/19 the boundary capabilities are plotted alongside anticipated boundary power transfers for the next 20 years, and the economy and security required transfers as calculated according to criteria in the NETS SQSS.

The SQSS sets the methodology to determine the wider boundary planning requirements, i.e. the Economy and Security criteria discussed above. These are shown in the graphs as a solid coloured line for Economy required transfer (Economy RT) and a dashed coloured line for Security required transfer (Security RT).

Two shaded areas are shown on each boundary graph which represents the distribution of annual power flow. The darker shaded area shows an area in which 50% of the annual power flows lie. The lighter and darker shaded areas together show an area in which 90% of the annual power flows lie.

The calculations of the annual boundary flow are based on unconstrained market operation, meaning network restrictions are not applied. This way, the minimum cost generation output profile can be found. By looking at these free market power flows in comparison with boundary capability, it can be seen where future network reinforcement needs can be expected.

3.1.4.1 Boundaries B2 and B4 in SHE Transmission's Area

The key boundaries in SHE Transmission's area are B2 and B4 (see Single Line Diagram in Appendix A) and the boundary flows, current capability and SQSS transfer requirements are illustrated in Figure below.

For B2 the boundary capability is thermally limited to 2.9GW whereas the economy required transfers and a large proportion of the projected MW flows from 2023 onwards and across all FES scenarios significantly exceed this (See Appendix B for Boundary Flow and Base capability plot).

The ESO has communicated that B4 is the constrained boundary and will therefore be used to define the output measures for the East Coast projects. The B4 boundary separates the transmission network at the SHE Transmission and SPT interface running from the Firth of Tay in the east to the north of the Isle of Arran in the west. The B4 boundary cuts across two 132kV double circuit OHLs, two 275/132kV auto-transformer circuits, two 220kV subsea cables (between Crossaig and Hunterston), and the Beauly – Denny 400/275kV double circuit OHL on the west coast, and a 275kV double circuit OHL between Kintore, Fetteresso and Kincardine (in SPT's area) as well as a 275kV double circuit OHL between Tealing and Glenrothes/Westfield (in SPT's area) on the east coast.

The 2018/19, B4 boundary capability shown in Figure 6 and published in ETYS 2018/19 is 3.3GW with the limiting contingency being the outage of the Melgarve – Denny North 400kV and Braco West – Denny North 275kV double circuit overhead line. The thermal constraint is present on both the Errochty-Killin 132kV circuit and the 275kV circuit between Fetteresso and Kincardine. This is in line with the NETS SQSS, Section 4.6.3; The minimum transmission capacity of the MITS shall be planned for the secured event of a double circuit overhead line fault outage on the supergrid.

Figure 6 : Boundary flows and base capability for boundary B4[6]

3.1.4.2 Boundaries B5 in SPT's Area and B6 between SP Transmission and NGET

The boundary internal to SP Transmission's area is B5. The B5 boundary capability 3.7GW whereas the economy required transfers and a large proportion of the projected power flows across all FES scenarios significantly exceed this.

For B6, the interface between SP Transmission and NGET, the boundary capability of 5.7GW . This has increased due to the addition of the new Western HVDC circuit and the upgrade of underground cables at Torness. Even with this increase in B6 capability, the economy required transfers and a large proportion of the projected power flows across all FES scenarios significantly exceed the actual boundary capability. The B5 and B6 boundary flows and base capability plots are shown in Appendix C.

3.1.4.3 Boundaries B7, B7a and B8 in NGET Transmission's Area

The key boundaries in NGET's area are B7, B7a and B8 (See Figure).

For B7, the boundary capability is 6.5GW. In future years the requirements exceed this capability. The limit to the boundary capability now is post-fault voltage depression close to the Scottish border. The 2018/19 boundary capability is expected to satisfy the NETS SQSS requirements but, for all the FES, the SQSS Economy required transfer and expected power flows quickly grow to beyond the present boundary capability.

The B7a boundary capability has increased to 8.7GW with the addition of the new Western HVDC circuit. The limit to the boundary capability now is the load rating of the 400kV circuits from Penwortham. For all the FES, the SQSS Economy required transfer and expected power flows grow to well beyond the present boundary capability.

The B8 boundary capability is limited to 10GW by loading limits of a Cellarhead–Drakelow 400kV circuit. Across all the FES, the SQSS Economy required transfer and expected power flows grow to beyond the present boundary capability. The B7, B7a and B8 boundary flows and base capability plots are shown in Appendix D.

3.2 Regional Connections

In addition to the wider system network investment plans, we must facilitate effective competition in the generation and supply of electricity through the timely delivery of local works to accommodate connections. This is in line with our licence obligations and our goal to provide network connections to meet our customer needs, on time and on budget.

We are required at all times to plan and develop our transmission system in accordance with the National Electricity Transmission SQSS and the STC. Furthermore, we are obliged to provide adequate transmission capacity to facilitate connections to customers in the north of Scotland who wish to connect to, and use, the transmission system in order to participate in the national wholesale electricity market.

The Connection and Use of System Code (CUSC) is the contractual framework for connection to, and use of, the NETS. CUSC section 13 deals with the identification of Enabling Works to be included in an Offer made under the Connect and Manage Arrangements. Enabling works as a minimum will include those Transmission Reinforcement works required to meet among other technical criteria; the Pre-fault Criteria' set out in Section 2 of the NETS SQSS and enable the ESO to operate the NETS in a safe manner.

The Connect and Manage (C&M) transmission access regime allows generators to connect in advance of the completion of the wider transmission reinforcement works but not before completion of the identified Enabling Works. Connection of generators ahead of the completion of Wider Works means that parts of the Transmission System will not be compliant with the NETS SQSS until these works are completed. Under this transmission access regime, C&M derogations from the planning criteria of NETS SQSS are required to allow these generators to connect ahead of the completion of the Wider Works. The TO submits a C&M derogation report as part of an associated TO Connection Offer. These C&M derogations are subject to the ESO approval. The Enabling, Wider and Derogated Wider works are entered into the developers' connection agreements with the ESO.

The transmission network in the north east of Scotland is due to see a significant increase in the generation capacity in the period leading up to 2024. Our North East 400kV Upgrade Engineering Justification Paper sets out the need to advance the Enabling Works for connections in the North East of Scotland where these Enabling Works form a subset of the NOA East Coast 400kV Onshore Incremental reinforcement.

3.3 Asset Condition

As set out in our paper, A risk Based Approach to Asset Management, we strive to meet the expectations of our stakeholders and deliver on our legislative requirements. In order to deliver these key requirements, we continually monitor and assess the condition of our assets to maintain the reliable and resilient network that is expected by our stakeholders.

Where asset condition deteriorates, we undertake a programme of cost-effective, risk-based interventions to maintain the longevity and performance of the transmission network. Our paper provides insight into the key strategies and decision-making processes that underpin our risk-based approach to Asset Management and how we identify and select the asset interventions we believe are essential to meet the ongoing requirement to deliver a safe and secure network throughout the RIIO-T2 period and beyond and achieve our ambitious goal of a Network for Net Zero.

Our East Coast 400kV incremental Upgrade and North East 400kV Upgrade Engineering Justification Papers set out the benefits of concurrently reconductoring and reinsulating the overhead line circuits being uprated to 400kV between Peterhead, Blackhillock and the B4 boundary.

4 Network Options Assessment

This section sets out the Network Options Assessment (NOA) methodology, introduces the East Coast Wider System reinforcement options and summaries the NOA recommendations.

4.1 Network Options Assessment Methodology

The base transmission network for each TO, against which the need for reinforcement is assessed, is a combination of the TO's existing network plus any infrastructure works that have already been authorised for construction or Enabling Works that have been committed as a result of connection contracts with developers.

The ESO's NOA is used to help us develop an efficient, coordinated and economic transmission system, in line with our licence obligations and the technical criteria of the NETS SQSS. We use NOA to test the economics and timing of major transmission reinforcement options proposed to meet the future network requirements, as defined in the ETYS. The NOA report is underpinned by the data in the FES. This means that the NOA and the ETYS have a consistent base for assessing the potential development of the electricity transmission networks. Taken together, the ETYS and the NOA give a full picture of requirements and potential reinforcement options to meet those requirements on the wider system.

SHE Transmission respond to the requirements defined in the ETYS by providing the ESO with reinforcement options that build up over time to meet these requirements. The proposed options are submitted to NOA with details including; Option Scope, Earliest In-Service Date (EISD), Cost, Outage requirements and boundary capabilities.

The ESO determines the optimum year of delivery for an option to achieve the best value for GB consumers. The optimum year is determined based on the net benefit that an option brings over its lifetime when comparing the total capital cost of the option and the savings in network constraint costs – this is to ensure that we don't invest too early unnecessarily or incur potentially high constraint costs by investing too late. If an option's optimum year of delivery is later than its Earliest In Service Date (EISD), the ESO does not need to make a recommendation on whether to 'Proceed' yet. However, if an option's optimum year is the same as it's EISD then the option is considered 'critical' and the ESO needs to make a recommendation to ensure the risk of missing the optimum year is minimised. All critical options are then included in a least regret analysis, which for NOA is based on single year regret, where a recommendation is made to either 'Proceed' or 'Delay' for the next financial year.

The single year least regret analysis involves the investigation of all possible courses of action presented by the critical options, and the associated economic regrets calculated to identify and quantify the maximum risk associated with a one year delay to the project. Selecting the investment strategy with the lowest maximum regret leaves consumers exposed to the least amount of risk.

A critical part of the need assessment is the cost benefit analysis undertaken by the ESO to examine the existing transmission network and forecast the potential congestion under a range of future generation scenarios. This is the counterfactual reference against which the reinforcement options proposed by the TOs are examined to determine the economic benefit provided by individual projects and also in combination to find the optimal development path.

4.2 East Coast Reinforcement Options

The options presented annually to NOA are a combination of; short-lead time, medium cost options that utilise/upgrade existing assets to increase the north to south power transfer capability of the SHE Transmission network and long lead time, high cost options that increase the capability of multiple GB boundaries (refer to Figure for GB Boundary Map). These options are assessed on an individual basis and as combinations against the base ‘do nothing’ case to determine the optimum network investment strategy. The options included in the NOA are selected from a more extensive list of conceptual options that could achieve increased north to south power transfers. These included a range of major and incremental onshore and offshore reinforcement options covering a variety of different technologies with variations in capital costs and offering different boundary capacity uplifts:

- New overhead line routes and reconfiguration of the network.
- Voltage uprating of existing overhead lines with related substation changes.
- Re-profiling and reconductoring of existing overhead lines with related substation changes.
- New substations.
- Non-build solutions including operational inter-trips.
- Reactive compensation.
- HVDC/HV Alternating Current (HVAC) links.

The full list of the Scottish Onshore options considered is presented in Appendix E. An initial desktop assessment of these options filtered out the non-credible or unsuitable options which left a short list of suitable options to be further developed as outlined below. These options were carried forward to the detailed cost benefit analysis to determine the optimal economic combination of reinforcements to progress. Combinations of reinforcement options can result in different boundary capacities compared to the individual options by themselves.

A number of reinforcement options have been developed for the eastern network in the northern region to improve boundary capability across boundaries B1 to B8. These options consider onshore and offshore solutions. The notable options and Transmission Owner involvement shown in

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Figure 7 are;

SHE Transmission & ScottishPower Transmission

- East coast onshore 275kV upgrade (ECU2)
- East coast onshore 400kV incremental reinforcement (ECUP)
- East coast onshore 400kV reinforcement (ECU4)

SHE Transmission & National Grid TO

- Eastern Scotland to England link: Peterhead to Hawthorn Pit offshore HVDC (E4DC)
- Eastern Scotland to England link: Peterhead to Cottam offshore HVDC (E4D2)
- Eastern Scotland to England link: Peterhead to Drax offshore HVDC (E4D3)

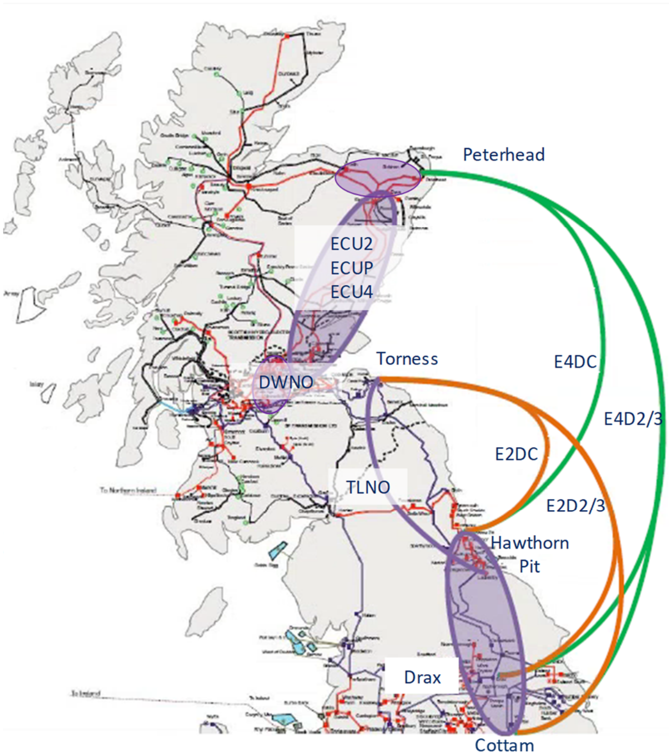
ScottishPower Transmission

- Denny–Wishaw 400kV reinforcement (DWNO)

ScottishPower Transmission & National Grid Electricity Transmission

- Eastern Scotland to England link: Torness to Hawthorn Pit offshore HVDC (E2DC)
- Eastern Scotland to England link: Torness to Cottam offshore HVDC (E2D2)
- Eastern Scotland to England link: Torness to Drax offshore HVDC (E2D3)
- Eastern Scotland to England link: Torness to north east England double circuit (TLNO)

Figure 7 : Onshore and Offshore Reinforcement Options



Onshore:

- **ECU2 -** East Coast onshore 275kV upgrade - 2023
- **ECUP -** East Coast onshore 400kV- 2026 incremental reinforcement (builds on ECU2).
- **ECU4 –** East Coast onshore 400kV – 2025 direct reinforcement to 400kV
- **DWNO** – Denny Wishaw 400kV reinforcement - 2028
- **TLNO -** Torness to northeast England AC reinforcement – 2030

Offshore:

- **E4DC:** Peterhead – Hawthorn Pit
- **E4D2:** Peterhead – Cottam
- **E4D3:** Peterhead – Drax
- **E2DC:** Torness – Hawthorn Pit
- **E2D2:** Torness – Cottam
- **E2D3:** Torness – Drax

These reinforcement projects increase capability on one or multiple of the MITS boundaries B1, B1a, B2, B4, B5, B6, B7, B7a and possibly B8 depending on HVDC southern landing point. The objective is to increase the north to south transfer capability on the east coast of the Scottish and northern England Transmission system between boundaries B1 in the SHE Transmission area and B8 in the NGET area in the north of England. This includes key boundaries between SHE Transmission and SPT (B4) and between SPSPT and NGET (B6). The requirement to reinforce the transmission network is driven fundamentally by the growth of predominantly renewable generation in the SHE Transmission, SPT and north of NGET transmission area, including offshore windfarms situated in Scotland and the north east of England.

The NOA recommendations are based on the economic assessment of options to deliver boundary benefits. Some options or a subset of works within an option may be listed as enabling works in users connection agreements. This may require the subset or full scope of works to proceed in line with the users contracted timescales in advance of the NOA options EISD. This is the case for our Kinardochy Reactive Compensation Project and the East Coast onshore works set out in our RIIO T2 business plan Where a subset of a NOA option is being delivered under a separate driver, the NOA four letter code should no longer be used to describe that project. To reinforce this, we have limited the use of NOA four letter codes when referencing our East Coast projects included in our RIIO T2 submission. This is further explained in the context of our RIIO T2 Business Plan for the East Coast Projects in Section 6 of this Paper.

4.3 Network Options Assessment Recommendations

The need to reinforce the transmission network in the east and north-east of Scotland has been demonstrated through the NOA process. The scope of the reinforcements recommended in the latest NOA, published in January 2019, for the eastern network in the northern region includes offshore HVDC links as well as onshore reinforcement. The NOA proceed recommendations for reinforcement in SHE Transmission are consistent in the 2017/18 and 2018/19 NOA reports.

The recommendation from the NOA 2018/19 process is to progress the following reinforcements for the eastern network in the northern region in this year to maintain the earliest in-service date (EISD):

- East Coast onshore 275kV upgrade (ECU2) – EISD of 2023
- East coast onshore 400kV incremental reinforcement (ECUP) – EISD of 2026
- Denny – Wishaw New Overhead line, DWNO, EISD of 2028
- Eastern Scotland to England link: Peterhead to Drax offshore HVDC (E4D3), EISD of 2028
- Eastern Scotland to England link: Torness to Hawthorn Pit offshore HVDC (E2DC), EISD of 2027

The NOA considered two paths for the east coast onshore upgrade to 400kV namely; (a) ECU2 followed by ECUP and (b) ECU4. The NOA CBA results indicated that the combination of ECU2 and ECUP outperforms ECU4 in all 2018 FES.

The benefit of the incremental approach is that early boundary constraint relief can be achieved by delivering East Coast 275kV Upgrade in 2023 as opposed to going straight to 400kV and not relieving the B4 boundary until 2025. Factored into the assessment was the recognition that the boundary uplift that is achieved from completing East Coast 275kV Upgrade in 2023 will in fact be limited during the 2024/25/26 outage seasons as significant construction outages will be required to deliver the incremental 400kV Upgrade in 2026. The outcome remained in favor of the two-stage approach.

Figure 8 below shows the B4 boundary Economy Planned transfer requirements using the FES2018 scenarios and the boundary uplift provided by the three recommended projects – East Coast 275kV Upgrade, East Coast 400kV Incremental Upgrade and the Eastern High Voltage Direct Current (HVDC) link from Peterhead to the north of England.

These reinforcements are required to be delivered as soon as is practically possible ; this has been confirmed by the ESO through CBA (these options are critical in all scenarios). The ESO has specifically requested that the TOs investigate the accelerated delivery of the HVDC links. Even after the Eastern HVDC from Peterhead is complete, there remains a significant need for more capacity. We have submitted further options to the ESO in this year's NOA and we await results in January 2020. The plot in Figure 8 shows the strength of the need to progress with these onshore and offshore reinforcement works in the north of Scotland.

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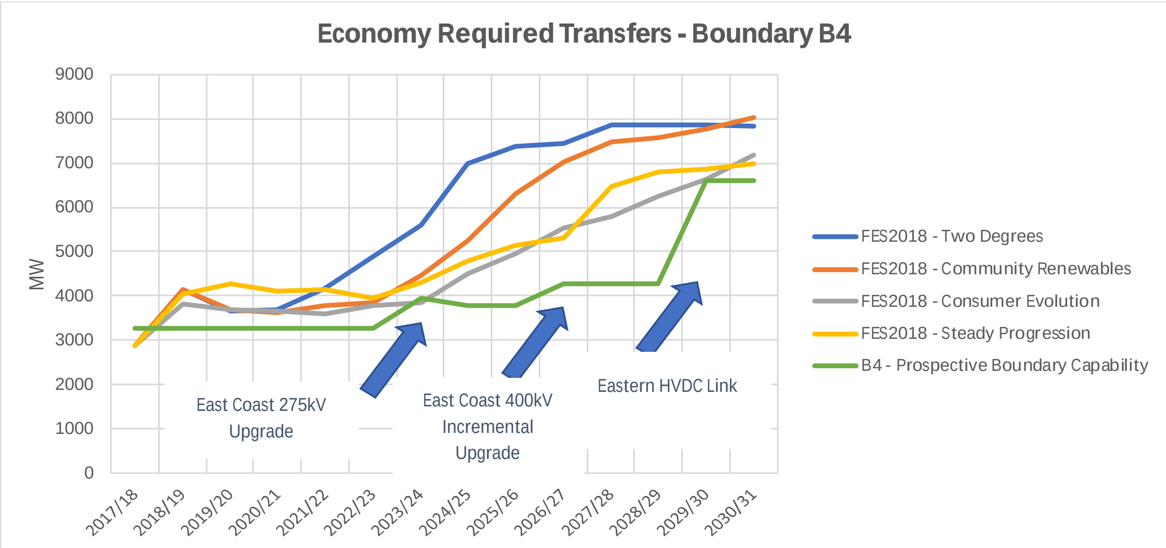
Figure 8: Economy Required Transfers and B4 Capability Uplift



5 National Grid East Coast CBA Report

This section sets out the ESO East Coast CBA Report, the Joint TO inputs, East Coast options, option combinations and ESO recommendations for the optimal East Coast reinforcement pathway.

A joint team among the three onshore TOs was established in spring 2017 and have continued to assess the East Coast options, examining them in more detail. The TOs have continued to work with the ESO who provide a cost-benefit analysis of the reinforcement options in more detail to help identify the optimum sequence and delivery dates for the reinforcements. The CBA and Least Worst Regret (LWR) methodology and results are summarised in this section and described in detail in the National Grid ESO East Coast CBA Report (reference Figure 3).

5.1 TO Inputs

The options included in the ESO East Coast CBA Report aim to cover a wide range of reinforcement options with varying degrees of investment, delivery dates and boundary capacity uplift. The purpose of this is to fully assess the level and combinations of reinforcement required in order to develop an economic, efficient and coordinated transmission network that allows a more optimal economic dispatch of generation in GB.

Given the strong recommendations from the NOA for large reinforcements across multiple boundaries, the CBA was carried out in order to be able to firstly assess the benefits of each of the proposed reinforcements in turn, and then in combination to determine the benefits of each potential 'package' of options, resulting in comparable levels of uplift across each boundary.

All options are assessed against a base network of the currently authorised system. This gives a comparison of reinforcement investments against a 'do nothing' approach. This allows the CBA to determine the net benefit that the consumer would receive as a direct result of the reinforcement.

The TOs jointly prepared the inputs for the ESO East Coast CBA Report. For the options (and combination of options) the TOs provided; seasonal boundary capabilities, spend profiles, Earliest in Service Dates, indicative construction outages and timing sensitivities.

5.2 Options and Option Combinations

The reinforcement options for the CBA are summarised below. They are categorised into groups with the East Coast onshore and offshore works studied separately so that the economic impact of each option can be captured. The categories are labelled as Option sets A – D.

Option set A - Scottish onshore options in isolation to provide a view of how the Scottish onshore reinforcement options alone perform. This allows for the benefit and any regret associated with completing the onshore works and no further eastern reinforcement.

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Table 1: Option Set A - East Coast Onshore Options in Isolation

Option	Reinforcement	Option in detail	Boundary impact	EISD
1	ECU2	Eastern Onshore 275kV Reinforcement	B1,B1a,B2,B4	2023
2	ECU2 + ECUP	Eastern Onshore 400kV Upgrade	B1,B1a,B2,B4	2023/2026
3	ECU4	Eastern Onshore 400kV Reinforcement	B1,B1a,B2,B4	2025
4	ECU4 + DWNO	Eastern Onshore 400kV Reinforcement + Denny Wishaw new OHL	B1,B1a,B2,B4, B5	2025/2028
5	ECU2 + ECUP+DWNO	Eastern Onshore 400kV Upgrade+ Denny Wishaw new OHL	B1,B1a,B2,B4, B5	2023/2026/2028

Option set B – Single major reinforcement options in isolation to provide a view of how the individual longer options perform in comparison to each other in the absence of any onshore network reinforcement.

Table 2: Option Set B - East Coast HVDC / B6 Onshore Options in Isolation

Option	Reinforcement	Option in detail	Boundary impact	EISD
B. **East Coast HVDC / B6 Onshore Options in Isolation**				
6	E4DC	2GW HVDC Peterhead to Hawthorn Pit	B2, B4, B5, B6	2028
7	E4D2	2GW HVDC Peterhead to Cottam	B2, B4, B5, B6, B7, B7a, B8	2029
8	E4D3	2GW HVDC Peterhead to Drax	B2, B4, B5, B6, B7, B7a	2029
9	E2DC	2GW HVDC Torness to Hawthorn Pit	B6	2027
10	E2D2	2GW HVDC Torness to Cottam	B6, B7, B7a, B8	2028
11	E2D3	2GW HVDC Torness to Drax	B6, B7, B7a	2028
12	TLNO	New OHL from Torness to Lackenby	B6	2031

Option set C – Single major reinforcement options with onshore incremental works to provide a view of how individual longer options perform alongside combinations of the Scottish onshore network reinforcements as well as NGET onshore incremental reinforcement works (See table in Appendix F).

Option set D – Multiple major reinforcement options with onshore incremental works expanding on 'Option set C' by exploring the benefit in having multiple major reinforcements at different connection points. Evaluating the impact of offshore versus onshore reinforcements for the southern connection points and testing these alongside both Scottish onshore works and NGET onshore works (See table in Appendix F).

The studied as Option Set D in the CBA analysis assume two major reinforcements do not start or end at the same location. This is due to the level of onshore reinforcement that would be required to accommodate the power flows from the connection of more than one link in one location.

5.3 Future Energy Scenarios Sensitivities

The ESO East Coast CBA Assessment was completed using the FES2017. To demonstrate that these scenarios remain credible for demonstrating the need, a comparison with FES2018 for generation north of B4 is shown in Figure 9.

Key comparison findings are;

- Two Degrees, Consumer Power/Consumer Evolution and Slow progression/Steady Progression in FES2017 are in the range of FES2018 generation forecast;
- Steady State in FES2017 is pessimistic and not in trend of any of the other scenarios in FES2017 and FES2018. NG ESO take the view that Steady State is outside the credible pathway and decided not to include it in the main decision making least worst regret analysis. Instead, the Steady State scenario will be discussed in the sensitivity analysis.

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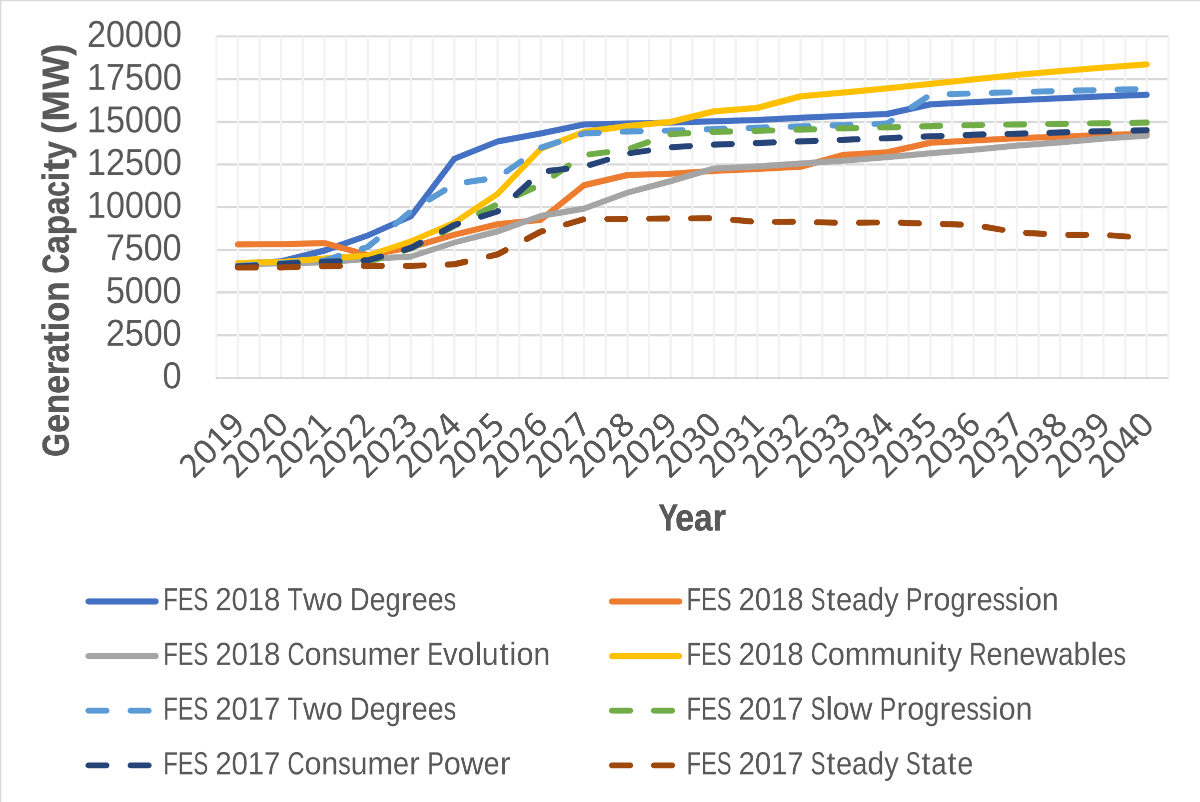
Figure 9: North of B4 Overall Generation Capacity FES2017 vs FES 2018



In addition to the FES, two sensitivity scenarios were included to further test the robustness of the investment signal. The sensitivities applied to the Slow Progression scenario are;

- No Firth of Forth Offshore Windfarm, 1075MW connecting at Tealing 275kV and no North Connect, 1400MW Interconnector connecting at Peterhead 400kV
- No Firth of Forth Offshore Windfarm, 1075MW connecting at Tealing 275kV and Inch Cape, 600MW connecting at Cockenzie

5.4 ESO East Coast CBA Results and Recommendation

Given the range of uncertainty assessed by various scenarios, option combinations and local generation sensitivities specific to Scotland and Northern England, a robust cost benefit assessment has been carried out to determine the preferred options to be taken forward.

The ESO's CBA analysis provides an overwhelmingly positive economic case for reinforcement of the eastern side of the GB transmission network.

The recommendation from the ESO East Coast CBA Report is to progress the following reinforcements for the eastern network in the northern region:

- East Coast onshore 275kV upgrade (ECU2) – EISD of 2023
- East coast onshore 400kV incremental reinforcement (ECUP) – EISD of 2026
- Denny – Wishaw New Overhead line, DWNO, EISD of 2028
- Eastern Scotland to England link: Peterhead to North of England, EISD of 2028/29
- Eastern Scotland to England link: Torness to North of England, EISD of 2027/28

The NPV for the East Coast 275kV Upgrade ranges from £2,515m - £4,174m (Appendix G) across the scenarios and sensitivities assessed. These NPVs assume no further reinforcement beyond East Coast 275kV Upgrade.

The NPVs for the East coast onshore 400kV incremental reinforcement following the East Coast Onshore 275kV Upgrade, range from £2,962m - £6,004m (Appendix G) across the scenarios and sensitivities assessed.

The optimal combination of onshore plus offshore reinforcements gives positive net present values (NPV) ranging from £11,530million to £18,292million (See NPV Table in Appendix H).

It should be noted that ESO CBA report results differs from the NOA 2018/19 results in that the southern connection sites are flipped. The East Coast Offshore two HVDC links Peterhead to Hawthorn Pit (E4DC) and Torness to Drax (E2D3) is the best solution with marginally better least worst regret compared to the second best combination Peterhead to Drax (E4D3) and Torness to Hawthorn Pit (E2DC). Based on all the available analysis, NG ESO recommends TOs to consider both combinations and that NOA 2019/20 is used to further refine the investment decision ahead of Initial Needs Case submission in 2020. To that effect we have worked with the other TOs to provide all combinations for the offshore options to the 2019 NOA process, from which we await results in January 2020.

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6 RIIO T2 East Coast Onshore Upgrades

As confirmed by both NOA and the ESO East Coast CBA Report; the optimal solution for the east coast onshore network is a two-stage approach, stage one – upgrade at 275kV completing by 2023 and stage 2 – incremental upgrade to 400kV operation by 2026.

SHE Transmission and SP Transmission have included the scope of two East Coast 275kV and 400kV projects in their respective RIIO T2 business plans. This is based on the certainty of need demonstrated through the NOA, the ESOs CBA Report and the design and development of these projects being well advanced.

The projects that remain in the optimal reinforcement pathway and will be subject to approval of the Initial and Final Needs Cases include;

- Denny – Wishaw New Overhead line, DWNO, EISD of 2028
- HVDC link between Peterhead and North of England, EISD of 2028/29
- HVDC link between Torness and North of England, EISD of 2027/28

These projects are less well advanced in their design and development and therefore it is proposed that these projects will follow the strategic wider works process, starting with the submission of an Initial Needs Case to Ofgem in 2020. However, it is anticipated that pre-construction funding for these projects will be included within the RIIO-T2 submission.

6.1 East Coast Onshore Coordination of Wider System, Reginal Connections and Asset Condition

As set out in this paper, the need for Wider System reinforcement is based on the economic benefit associated with increasing the north to south capability of our network and reducing constraint costs. In addition to this objective, we must also coordinate the local works required to accommodate Regional Connections and our Asset Condition based plans as set out in our paper– A Risk Based Approach to Asset Management.

The assessment of non-load works is out with the scope of NOA as these works would need to be planned and undertaken based on asset condition, irrespective of the NOA recommendations. The opportunities and efficiencies of coordinating load and non-load works concurrently are considered when developing our network.

Figure 10 shows the timing and sequencing of the recommended wider system reinforcements without consideration of Regional Connections. Also shown in Figure 10 are the opportunities to coordinate asset condition based intervention with the growth driven projects.

Figure 10 East Coast Timing and Sequencing uninfluenced by Regional Connections

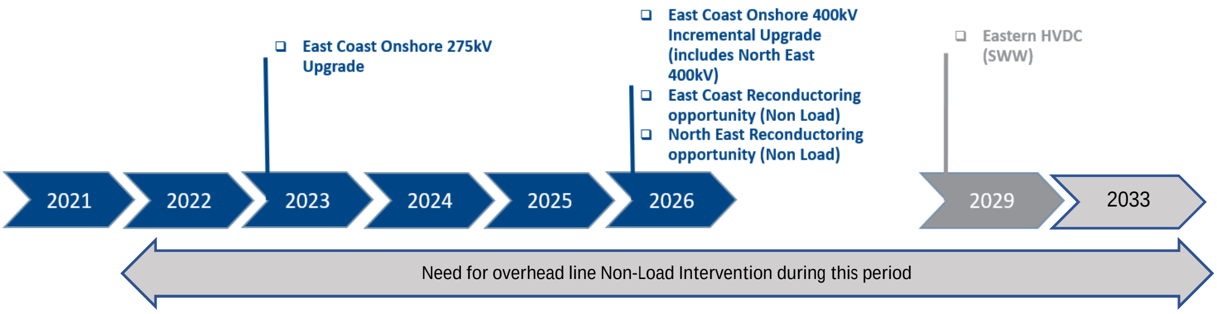
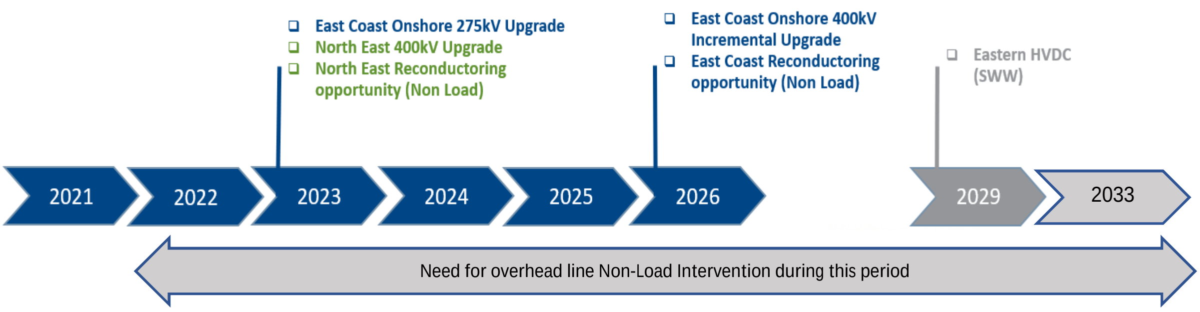


Figure 11 shows the timing and sequence of the recommended Wider System reinforcements with consideration of Regional Connections. A subset of the NOA recommended East Coast Onshore 400kV Incremental Reinforcement scope is required to accommodate contracted connections in the North East; namely the NorthConnect, 1400MW interconnector from Peterhead to Norway, the Moray West Offshore Windfarm, 800MW connecting into Blackhillock and the Clashindarroch onshore windfarm, 77MW connecting at Cairnford. This subset comprises the scope of works required to deliver the North East 400kV Upgrade by 2023, aligning with the contracted connection dates. The opportunity to coordinate load and non-load works in the North East is therefore also advanced to 2023.

The North East 400kV Upgrade interfaces with the East Coast 400kV Incremental Upgrade at Kintore substation. The Enabling Works for the connection of Moray West at Blackhillock and Clashindarroch at Carinford do not extend beyond Kintore. The proposed 400kV upgrade works south of Kintore are classed as Wider Works, allowing Moray West to connect in advance of the completion of the 400kV upgrade south of Kintore. For these connections, Kintore substation is considered the notional point on the network that is sufficiently deep into the MITS at which the system operator has diverse constraint options to manage the system.

Figure 11: East Coast Timing and Sequencing influenced by Regional Connections



The cost benefit assessment and appraisal of concurrently delivering the load and non-load works is pertinent to the East and North East 400kV projects and is addressed in their respective RIIO T2

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Engineering Justification Papers. The concurrent approach offers an undiscounted capex saving attributed to project re-mobilisation costs and a significant reduction of construction outages.

6.2 East and North East Project Scope Summary

The scope of the East Coast 275kV, East Coast 400kV Incremental and the North East 400kV Upgrades is provided in a Table in Appendix I. The RIIO T2 Engineering Justification Papers provide full project details for the three East and North East Upgrades planned within the RIIO T2 period;

- RIIO T2 East Coast 275kV Upgrade Engineering Justification Paper (T2BP-EJP-0018).
- RIIO T2 East Coast 400kV Incremental Upgrade Engineering Justification Paper (T2BP-EJP-0017).
- RIIO T2 North East 400kV Upgrade Engineering Justification Paper (T2BP-EJP-0016).

The RIIO T2, East Coast 275kV Upgrade scope remains as presented in NOA 2018/19; comprising the new Alyth substation constructed to 400kV and reactive compensation scheme, increase maximum operating temperature of 185km of overhead line between Kintore, Fetteresso, Tealing, Alyth and the SHE Transmission/SPT border and 36km of the existing 275kV OHL between Tealing and the SHE Transmission/SPT border by undertaking reprofiling works, phase shifting transformers installed at Tealing on the 275kV circuits from Kintore and the Errochty-Killin Inter-trip scheme.

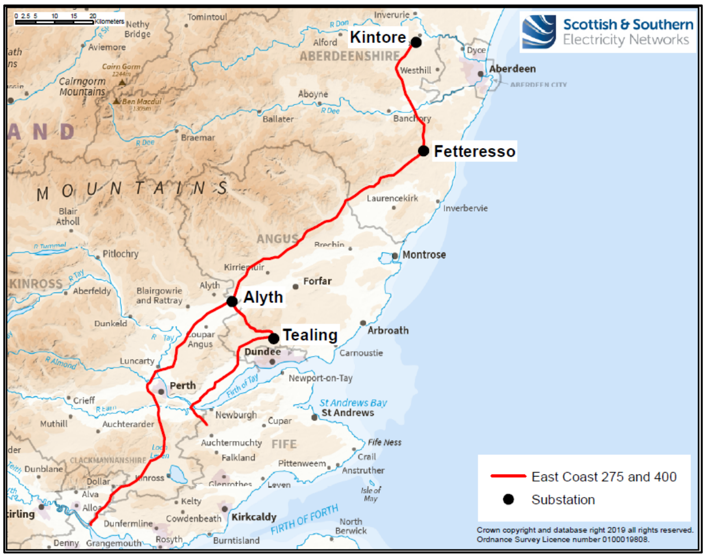
The scope of East Coast Onshore 400kV Incremental Upgrade as presented in NOA 2018/19 comprises the upgrade of the network from Peterhead and Blackhillock in the North East to the SHE Transmission/SPT border to 400kV. Regional contracted generation in the North East requires earlier delivery of elements of this 400kV scope; this subset of works are known for RIIO T2 as the North East 400kV and will be delivered in 2023. The remaining 400kV upgrade scope south of Kintore (and installation of Phase Shifting Transformers (PSTs) at Blackhillock) will be completed in 2026 and is included in RIIO T2 as the East Coast 400kV Incremental Upgrade (see Figure 12).

The condition assessment of the existing conductors between Kintore, Fetteresso, Alyth and the SHE Transmission/SPT border has established that the conductors should be replaced between 2022 and 2033. The benefits of coordinating the load and non-load drivers to reduce project re-mobilisation costs and reduce the impact on constraints during construction outages is demonstrated by Cost Benefit Analysis (CBA). This work concluded that the most coordinated, economic and efficient strategy for delivering the East Coast 400kV Upgrade works is to concurrently reinsulate and reconductor the overhead lines between Kintore, Fetteresso, Alyth and the SHE Transmission/SPT border by 2026.

Figure 12: East Coast 400kV Incremental Upgrade

East Coast 400kV Incremental Upgrade

- Reconductor and Reinsulate 170km overhead line between Kintore-Fetteresso – Alyth – Kincardine for 400kV operation
- Substation works at Kintore, Fetteresso and Alyth to accommodate 400kV
- Install two 275kV Phase shifting transformers at Blackhillock

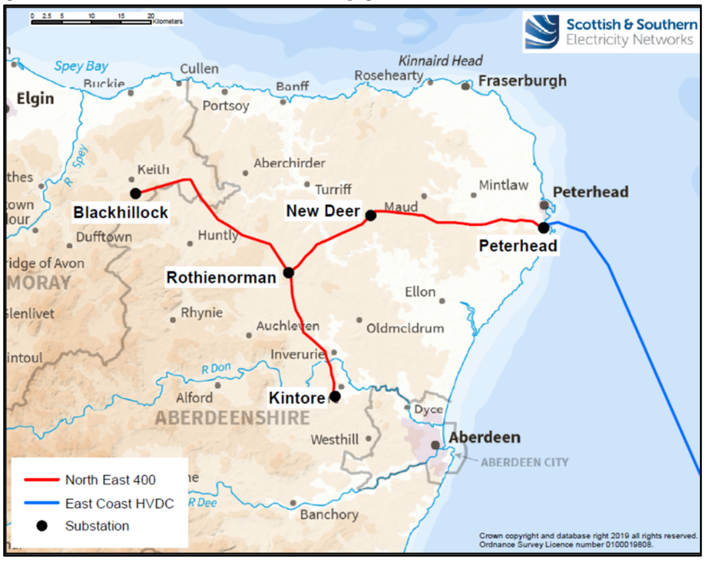


North East 400kV

The local connections driving the North East 400kV reinforcement are contracted connections of the 800MW Moray West Offshore windfarm (2024) at Blackhillock, the 1400MW NorthConnect interconnector to Norway (2023) and the Clashindarroch 2 windfarm, 77MW connection into Cairnford substation. It is therefore planned that the North East 400kV reinforcement would be delivered ahead of the NOA recommended date to accommodate these regional connections.

The condition assessment of the existing conductors between Blackhillock, Rothienorman and Peterhead has established that the conductors should be replaced between 2026 and 2031. The benefits of coordinating the Load and Non-load drivers to reduce abortive and re-mobilisation costs and reduce the constraint impact during construction outages are demonstrated by CBA. This work concluded that the most coordinated, economic and efficient strategy for delivering the North East 400kV reinforcement is to align its delivery with the Peterhead 400kV busbar and the connection of NorthConnect in October 2023 and to concurrently reinsulate and reconductor the overhead lines between Blackhillock, Rothienorman and Peterhead (See Figure 13).

Figure 13: North East 400kV Upgrade



North East 400kV

- Reconductor and Reinsulate 83km overhead line between Blackhillock-Rothienorman and Peterhead for 400kV Operation
- Transition New Deer and Rothienorman to 400kV Operation
- Peterhead 400kV Double Busbar
- Install two 1200MVA Super Grid Transformers (SGTs) at Kintore

6.1 RIIO T2 Outputs

As boundary capabilities are sensitive to generation background, and other network developments and factors such as interconnector dispatch behaviours, we use a fixed background based on FES 2018 background Two Degrees scenario for the purposes of setting/measuring the output.

The B4 boundary capability in 2023 without reinforcement is 3390MW, following completion of the East Coast 275kV Upgrade in 2023 the B4 boundary is thermally limited to 4000MW (based on the FES2018 background). This constitutes a B4 boundary uplift of 610MW. The uplift is calculated based on the capability before and after the reinforcement for the same year (and therefore same network model and background except for the exclusion/inclusion of the reinforcement).

The B4 boundary capability in 2026 without the East Coast 400kV upgrade is 3780MW, following completion of the East Coast 400kV Upgrade in 2026 the B4 boundary is thermally limited to 4260MW (based on the FES 2018 background). This constitutes a B4 boundary uplift of 480MW. All capability values stated are based on the import of 1400MW from NorthConnect, the HVDC interconnector to Norway. The uplift is calculated based on the capability before and after the reinforcement for the same year (and therefore same network model and background except for the exclusion/inclusion of the reinforcement).

The output measure for the North East 400kV reinforcement is 720MVA per circuit based on the increase in overhead line Summer Pre-fault Rating. Of the 720MVA, 350MVA is attributed to the voltage uprating from 275kV to 400kV (based on twin zebra operating at 65°C), the remaining 370MVA uplift is attributed to the replacement of the phase conductors with twin Totora operating at 90°C. The conductors summer pre-fault rating is used for the output measure as it is this that is the system constraint based on the NETS SQSSS, Section 2 assessment criteria and the Connect and Manage guidelines for identifying Enabling works.

Furthermore; the East and North East Upgrades deliver the following benefits:

- Increase the capability of the SHE Transmission Network in line with our goal to transport the renewable electricity that, in total, powers 10 million homes

- Facilitate the efficient, economic and co-ordinated operation of the national electricity transmission system

- Improved operational resilience through timey asset condition-based intervention in line with our goal of 100% network reliability

- Facilitate effective competition in the generation and supply of electricity through the timely delivery of Connect and Manage Derogated Wider Works. This is in line with our licence obligations and our goal to provide network connections to meet our customer needs, on time and on budget.

7 Conclusion

The work undertaken by all three onshore Transmission Owners, SHE Transmission, ScottishPower Transmission and National Grid in collaboration with National Grid Electricity System Operator (ESO) has demonstrated a strong technical, economic and urgent need for coordinated reinforcement on the eastern side of the GB Transmission network.

The ESO's cost benefit and least regret analysis has recommended an economic optimal reinforcement pathway comprising the following works;

- The incremental onshore reinforcement in Scotland, comprising the reinforcement options East Coast 275kV and 400kV Upgrade, to provide early congestion relief across B4. Strongly recommended to proceed to delivery in accordance with their earliest in-service dates (EISD), 2023 and 2026 respectively. These reinforcements would not be regretted even if later subsequent reinforcements were not undertaken.
- Denny – Wishaw New Overhead line, DWNO, EISD of 2028
- HVDC link between Peterhead and North of England, EISD of 2028/29
- HVDC link between Torness and North of England, EISD of 2027/28

The first projects to be delivered as part of the eastern reinforcement strategy are the Scottish incremental onshore transmission upgrade works, utilising predominantly existing assets. The ESO's cost benefit analysis indicates these projects have strong economic benefits, are robust against a variety of sensitivities and would not be regretted even if the later reinforcements were delayed or not carried out.

The incremental Scottish onshore reinforcement projects are sufficiently well proven and mature to be progressed through the RIIO-T2 submission to Ofgem in December 2019. The timing and scope of work to be carried out within the RIIO T2 period is justified based on Wider System, Regional Connections and Asset Condition need.

Completion of the North East 400kV Upgrade in line with Regional Connection timescales in 2023 will accommodate the connection of NorthConnect, 1400MW interconnector, Moray West Offshore Windfarm, 800MW and the Clashindarroch onshore windfarm, 77MW at Cairnford.

The Eastern HVDC link projects have in service dates of 2027 and 2028 and will be progressed through the Strategic Wider Works process in RIIO-T1. The Initial Needs Case for these works is due to be submitted to Ofgem in 2020.

The Net Present Value (NPV) for the East Coast 275kV Onshore Upgrade ranges from £2.5bn - £4.2bn across the scenarios and sensitivities assessed. When in combination with the East Coast 400kV incremental Upgrade, the NPVs increase ranging from £2.9bn - £6.0bn. The optimal combination of onshore plus offshore reinforcements gives positive net present values ranging from £11.6bn to £18.4bn.

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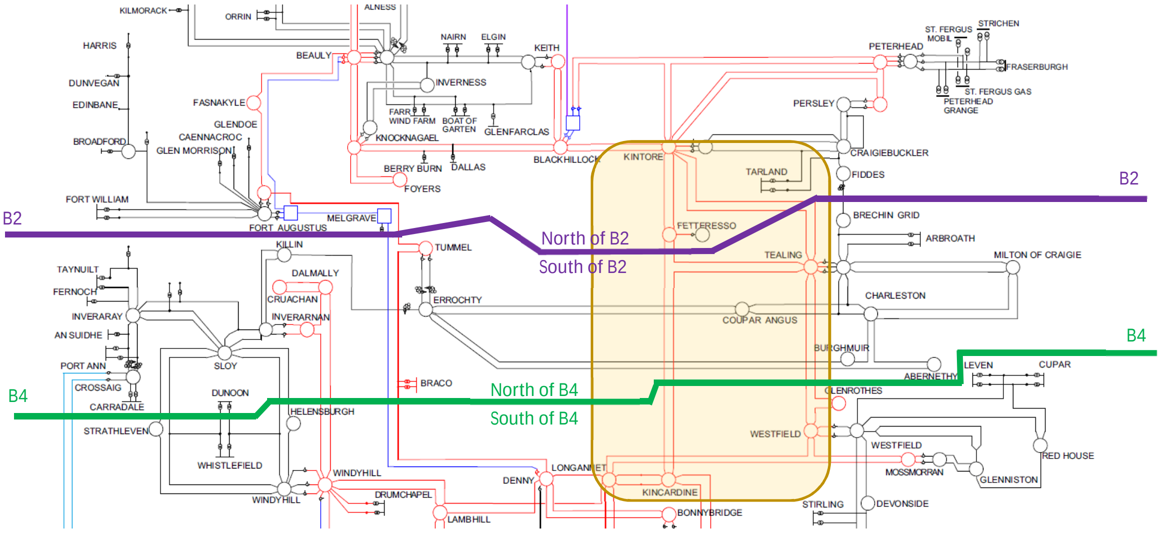
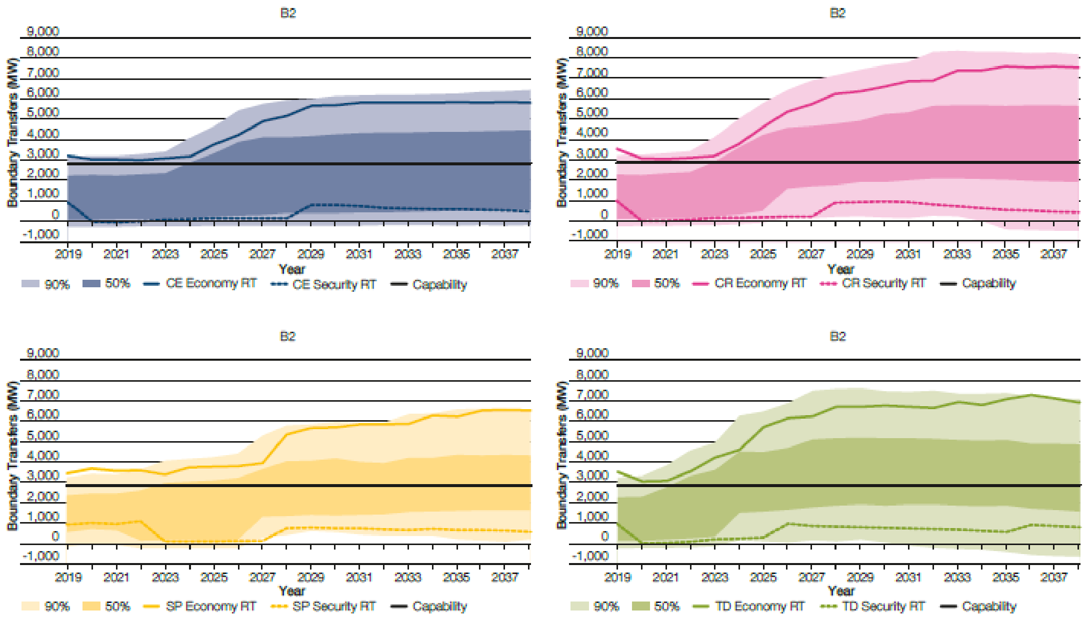
Appendices

Appendix A: SHE Transmission B2 & B4 Single Line Diagram 2018/19[5]



[5] Electricity Ten Year Statement 2018, Appendix A, Figure A4

Appendix B: Boundary flows and base capability for boundary B2[6]



[6] Electricity Ten Year Statement, November 2018

Appendix C: B5 and B6 boundary flows and base capability plots[6]

Figure C1: Boundary flows and base capability for boundary B5

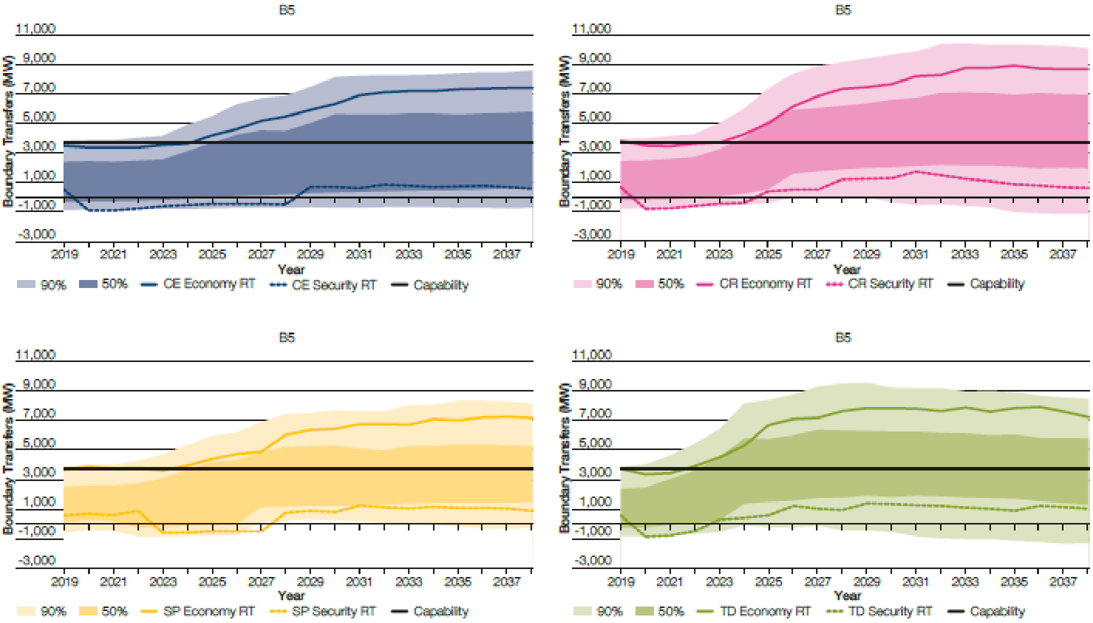
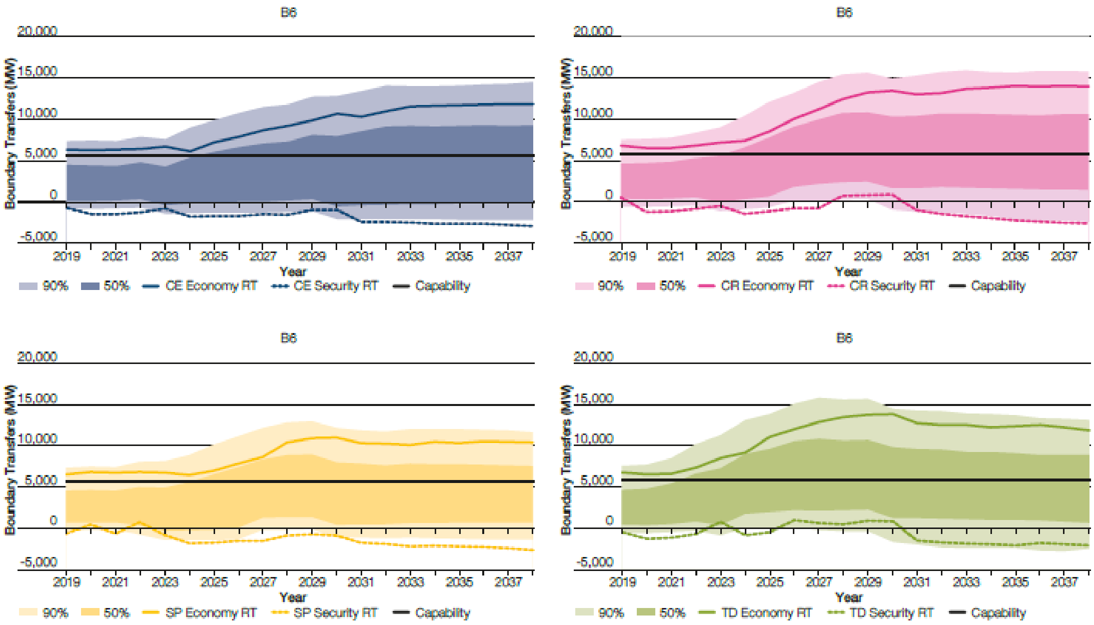


Figure C1: Boundary flows and base capability for boundary B6



Appendix D: B7, B7a and B8 boundary flows and base capability plots [6]

Figure D1: Boundary flows and base capability for boundary B7

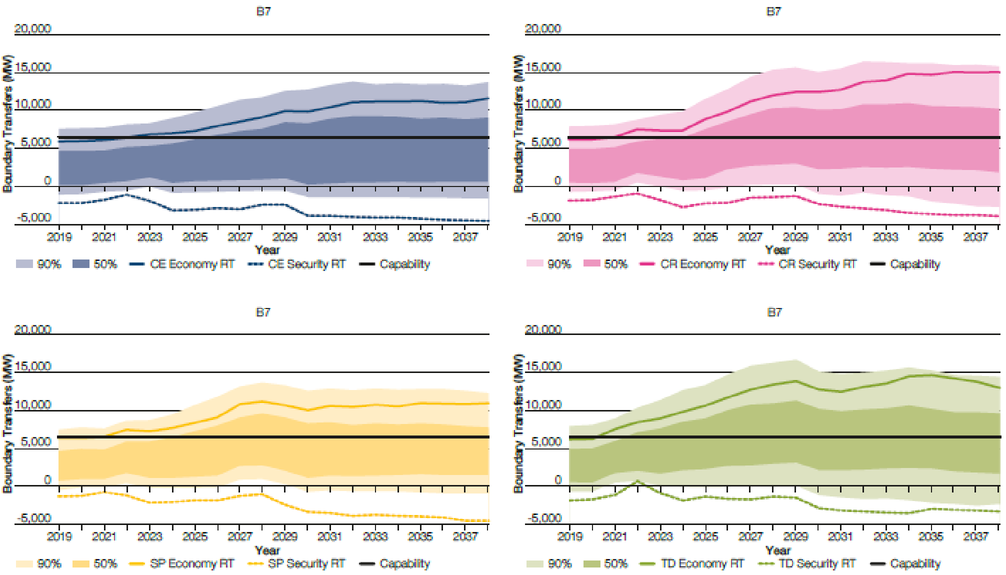


Figure D2: Boundary flows and base capability for boundary B7a

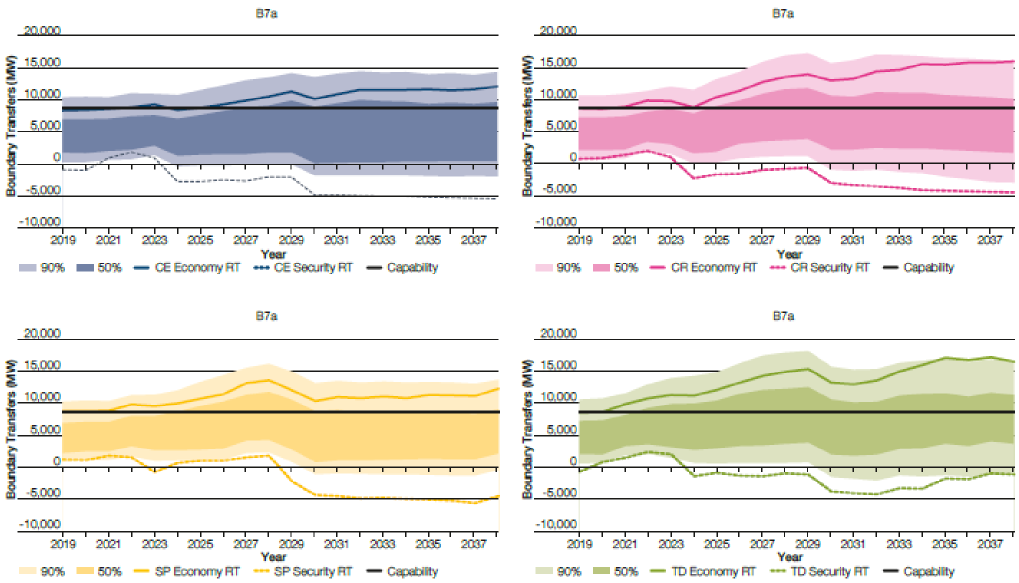


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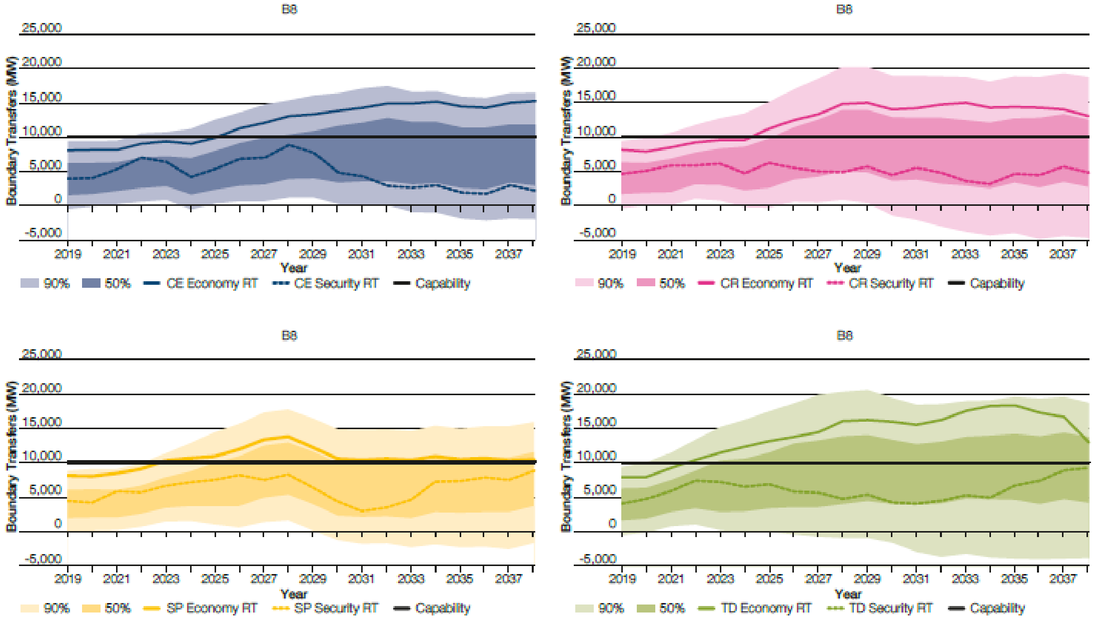
Figure D3: Boundary flows and base capability for boundary B8



Appendix E: B2 & B4 Reinforcement Options

The following Table and option descriptions were considered for reinforcement of the onshore east coast network in NOA 2018 and also those options that were filtered out prior to the CBA assessment.

Table E1: East Coast SHE Transmission Involved Options

Ref Number	Option Description (consistent with NOA option titles)	Earliest In Service Date (EISD)	Detailed Analysis
1	East Coast Onshore 275kV Upgrade	2023	Progressed
2	East Coast Onshore 400kV Reinforcement	2025	Progressed
3	East Coast Onshore Incremental 400kV Reinforcement	2026	Progressed
4	East Coast HVDC Link	2029	Progressed
5	East Coast Single Circuit 400kV Upgrade	NA	Not Progressed
6	Kintore–Tealing 275kV Rebuild and Tealing–Westfield/Glenrothes 275kV Reconductoring	NA	Not Progressed
7	Kintore – Tealing 275kV Rebuild	NA	Not Progressed
8	Beauly-Denny 400kV Double Circuit Upgrade	NA	Not Progressed

The options are titled in Table E1 are described in this appendix as they were input into the 2017/18 and 2018/19 NOAs. Customer Connections in the north east influence the sequence of how the scope of options are delivered, therefore the East and North East components are separated into sub headers within the detailed descriptions of the 400kV Options 2 & 3.

The North East comprises the transmission overhead lines, cables and substations connecting existing sites at Blackhillock, Kintore and Peterhead. The network south of Kintore is referred to as the East Coast. Kintore is the interface point between the North East and East Coast as it requires enduring transformation of voltage to tie the future 400kV infrastructure to the existing 275kV network.

Option 1 - East Coast Onshore 275kV Upgrade - 2023

- **Alyth:** Establish a new double busbar substation at Alyth, constructed to 400kV but initially operated at 275kV. Reconfigure and terminate all overhead line circuits from Fetteresso,

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Tealing and Kincardine (SPT) on to the new Alyth busbar. Install a reactive compensation scheme at Alyth substation comprising a +225/-225MVar Dynamic and 100MVAr Static.

- **Tealing:** Extend the 275kV substation at Tealing, installing two feeder bays with full busbar selection to connect two PSTs on the Kintore to Tealing 275kV OHL circuits. The PSTs will have a minimum rating of 920MVA and a nominal on-load angle range of +10/-10 degrees.
- **Errochty:** Install an operational intertrip scheme that will trip the feeder breakers on the Errochty to Killin 132kV single circuit OHL in the event of a loss of the Beauly to Denny 400/275kV double circuit OHL south of Tummel (275kV)
- **OHL:** Re-profile the existing 275kV OHL between Kintore, Fetteresso, Tealing and Kincardine and between Tealing and Glenrothes/Westfield up to the SHE Transmission/SPT border, to operate at 65•C, providing an uplift in Winter Post fault thermal capacity of 135MVA from 955MVA to 1090MVA
- **SPT Works** - Re-profile the existing 275kV circuits between the SPT/SHE Transmission border and Kincardine and the SPT/SHE Transmission border and Glenrothes, Westfield, Mossmorran and Longannet to 65°C operation.
- **SPT Works** - Uprate existing cables on the SPT/SHE Transmission border to Kincardine to match future OHL ratings.

PROGRESS TO DETAILED ANALYSIS

Option 2 - East Coast Onshore 400kV Reinforcement (includes North East 400kV scope) - 2025

North East 400kV

- **OHL:** Re-insulate the 275kV OHL circuits to 400kV operation between Blackhillock, Peterhead, New Deer, Rothienorman substations.
- **Peterhead:** Connect the uprated 400kV double circuit OHL from Rothienorman to the Peterhead 400kV double busbar.
- **Rothienorman:** Uprate the existing 275kV double busbar for 400kV operation. Install two new 240MVA 400/132kV SGTs and two new 120MVA 132/33kV GTs to replace the existing 120MVA 275/33kV GTs for the existing GSP connection.
- **New Deer:** Uprate the existing 275kV New Deer double busbar for 400kV operation.
- **Blackhillock:** Remove the 400/275kV line connected SGTs and use the existing 400kV circuit breakers to connect the re-insulated 400kV OHL from Rothienorman Substation.
- **Kintore:** Install two new 1200MVA 400/275kV SGTs with noise enclosures.

East Coast 400kV

- **OHL:** Re-insulate the 275kV OHL circuits to 400kV operation between Kintore, Fetteresso, Alyth and Kincardine (SPT) substations.
- **OHL:** Re-profile the existing 275kV OHL between Glenrothes/Westfield up to the SHE Transmission/SPT border, to operate at 65•C.
- **Kintore:** Establish a new nine bay 400kV AIS double busbar adjacent to the existing 275/132/33kV Kintore Substation. Connect the overhead line circuits from Rothienorman and Fetteresso on to the new Kintore 400kV busbar.
- **Fetteresso:** Replace the existing 240MVA 275/132kV SGT with two 240MVA 400/132kV SGTs and operate the 275kV switchgear at 400kV. Establish an eight bay 400kV double busbar arrangement by installing four new 400kV bays and operating the existing switchgear at 400kV. These works are required to operate the existing substation and the OHLs from Kintore and Alyth at 400kV.
- **Alyth:** Establish a new 400kV double busbar substation at Alyth. Reconfigure and terminate overhead line circuits from Fetteresso, Tealing and Kincardine (SPT) on to the new Alyth busbar. Installing two new 1200MVA, 400/275kV SGTs to terminate the double circuit overhead line from Tealing which remain at 275kV operation. Enclosures will be constructed for each of the two new 1200MVA SGTs to mitigate noise. Install a reactive compensation scheme at Alyth substation comprising a +225/-225MVar Dynamic and 100MVAr Static.
- **Tealing:** Extend the 275kV substation at Tealing, installing two feeder bays with full busbar selection to connect two PSTs on the Kintore to Tealing 275kV OHL circuits. The PSTs will have a minimum rating of 920MVA and a nominal on-load angle range of +10/-10 degrees.
- **Blackhillock:** Install two Phase Shifting Transformers (PSTs) at Blackhillock Substation on the 275kV double circuit OHL to Knocknagael. The PSTs will have a minimum rating of 920MVA and a nominal on-load angle range of +15/-15 degrees.

PROGRESS TO DETAILED ANALYSIS

Option 3 - East Coast Onshore 400kV Incremental Reinforcement (includes North East 400kV scope) – 2026

North East 400kV

- **OHL:** Re-insulate the 275kV OHL circuits to 400kV operation between Blackhillock, Peterhead, New Deer, Rothienorman substations.

- **Peterhead:** Connect the uprated 400kV double circuit OHL from Rothienorman to the Peterhead 400kV double busbar.

- **Rothienorman:** Uprate the existing 275kV double busbar for 400kV operation. Install two new 240MVA 400/132kV SGTs and two new 120MVA 132/33kV GTs to replace the existing 120MVA 275/33kV GTs for the existing GSP connection.

- **New Deer:** Uprate the existing 275kV New Deer double busbar for 400kV operation.

- **Blackhillock:** Remove the 400/275kV line connected SGTs and use the existing 400kV circuit breakers to connect the re-insulated 400kV OHL from Rothienorman Substation.

- **Kintore:** Install two new 1200MVA 400/275kV SGTs.

East Coast 400kV

- **OHL:** Re-insulate the 275kV OHL circuits to 400kV operation between Kintore, Fetteresso, Alyth and Kincardine (SPT) substations.

- **Kintore:** Establish a new 400kV double busbar at Kintore. Connect the overhead line circuits from Rothienorman and Fetteresso on to the new Kintore 400kV busbar.

- **Fetteresso:** Replace the existing 240MVA 275/132kV SGT with two 240MVA, 400/132kV SGTs and operate the 275kV switchgear at 400kV. Establish a eight bay 400kV double busbar arrangement by installing four new 400kV bays and operating the existing switchgear at 400kV. These works are required to operate the existing substation and the OHLs from Kintore and Alyth at 400kV

- **Alyth:** Transition the 275kV double busbar at Alyth substation for 400kV operation and installing two new 1200MVA, 400/275kV SGTs. Enclosures will be constructed for each of the two new 1200MVA SGTs to mitigate noise. Uprate the reactive compensation scheme at Alyth substation to operate at 400kV.

- **Blackhillock:** Install two Phase Shifting Transformers (PSTs) at Blackhillock Substation on the 275kV double circuit OHL to Knocknagael. The PSTs will have a minimum rating of 920MVA and a nominal on-load angle range of +15/-15 degrees.

PROGRESS TO DETAILED ANALYSIS

Option 4 - East Coast HVDC Link - 2029

- **Eastern subsea HVDC link**: establish an indoor 2GW converter station and connect to a dedicated 400kV bay on the existing 400kV double busbar at Peterhead.

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- **Peterhead:** Connect the uprated 400kV double circuit OHL from Rothienorman to the Peterhead 400kV double busbar.
- **Rothienorman:** Uprate the existing 275kV double busbar for 400kV operation. Install two new 240MVA 400/132kV SGTs and two new 120MVA 132/33kV GTs to replace the existing 120MVA 275/33kV GTs for the existing GSP connection.
- **New Deer:** Uprate the existing 275kV New Deer double busbar for 400kV operation.
- **Blackhillock:** Remove the 400/275kV line connected SGTs and use the existing 400kV circuit breakers to connect the re-insulated 400kV OHL from Rothienorman Substation.
- **Kintore:** Install two new 1200MVA 400/275kV line connected SGTs for the 400kV double circuit OHL from Rothienorman to the existing 275kV busbar.
- **Errochty:** In addition to the above, establish an operational intertrip scheme at Errochty to trip the Errochty to Killin 132kV circuit following a double circuit loss (N-D) on the Beauly to Denny 400/275kV line south of Tummel. This prevents unacceptable overloading on the associated 132kV circuit.
- **OHL:** Re-insulate the existing 275kV double circuit OHLs to 400kV operation between Blackhillock, Peterhead, New Deer, Rothienorman substations.

PROGRESS TO DETAILED ANALYSIS

Option 5 - East Coast Single Circuit 400kV upgrade

- Reinsulate one existing 275 kV circuit between Blackhillock and Kincardine (bypassing Kintore and Fetteresso) to allow operation at 400 kV (towers already 400 kV construction).
- Install two Phase Shifting Transformers (PSTs) at Blackhillock Substation on the 275kV double circuit OHL to Knocknagael. The PSTs will have a minimum rating of 920MVA and a nominal on-load angle range of +15/-15 degrees.
- Install 2 x 400/275 kV 1200MVA SGT's at Kincardine. Reconfigure OHLs around Kincardine, Denny North, Longannet, Lambhill

This option has been ruled out due to the technical challenge associated with energising such a long (300km) 400kV OHL with infeasibly high voltage sychronisation angles. Additionally, the thermal capacity of the remaining 275kV circuit would remain the limiting factor due to the sharing of load, thus the boundary uplift for this option would be small.

Not Progressed

Option 6 - New 275kV Kintore–Tealing Double Circuit Overhead Line and Tealing/Westfield Glenrothes 275kV Upgrade

- Construct a new double circuit overhead line between Kintore and Tealing to 400kV construction but initially operate at 275kV. This circuit would replace the existing 275kV Kintore – Tealing construction. Re-insulate and re-conductor to 400kV between Tealing – Westfield / Glenrothes but initially operate at 275kV.

This option has been discounted on the basis that the environmental impact and consenting for the construction of a new double circuit overhead line between Kintore and Tealing would be extremely challenging given that alternative onshore AC and offshore HVDC options exist.

Not Progressed

Option 7– New 400kV Kintore–Tealing Double Circuit Overhead Line and Tealing/Westfield Glenrothes 400kV Upgrade

- Construct a new 400kV overhead line between Kintore and Tealing replacing the existing 275kV construction. Re-insulate and re-conductor Tealing – Westfield / Glenrothes to operate at 400kV.

This option has been discounted on the basis that the environmental impact and consenting for the construction of a new double circuit overhead line between Kintore and Tealing would be extremely challenging given that alternative onshore AC and offshore HVDC options exist.

Not Progressed

Option 8 - Beauly-Denny Double Circuit 400kV

- Upgrade 275kV side of Beauly-Denny OHL to provide a double circuit 400kV line. Associated substation works at Beauly, Ft Augustus, Tummel, Braco, Denny North.

This option has been ruled out on the basis that it is the loss of the double circuit Beauly – Denny overhead line that limits the B4 transfer capability. Therefore, there would be no boundary uplift associated with this reinforcement ahead of reinforcement on the east coast.

Not Progressed

Appendix F: Option Sets C & D

Options grouping	Option in #	Eastern Offshore Reinforcement Options	Connection points	i. No Eastern Onshore	ii. Eastern 275kV Onshore Reinforcement	iii. Eastern 400kV Onshore Reinforcement & Denny Wishaw	iiii. Eastern 400kV Onshore Reinforcement & Denny Wishaw
				-	(ECU2)	(ECU4 + DWNO)	(ECU2+ ECUP + DWNO)
C. Grouping of Options: Onshore Incremental and Single HVDC / B6 Onshore Options In Combination [WITH compensating reinforcement in NGET on B7, B7a and B8]	13	E4DC	Pehe-Hawt	E4DC +NGET B7-8 INC	E4DC + (ECU2) +NGET B7-8 INC	E4DC + (ECU4 + DWNO) +NGET B7-8 INC	E4DC + (ECU2 + ECUP + DWNO) +NGET B7-8 INC
	14	E4D2	Pehe-Cotm	E4D2+NGET B7-8 INC	E4D2 + (ECU2) +NGET B7-8 INC	E4D2 + (ECU4 + DWNO) +NGET B7-8 INC	E4D2 + (ECU2 + ECUP + DWNO) +NGET B7-8 INC
	15	E4D3	Pehe-Drax	E4D3 +NGET B8 INC	E4D3 + (ECU2) +NGET B8 INC	E4D3 + (ECU4+ DWNO) +NGET B8 INC	E4D3 + (ECU2 + ECUP + DWNO) +NGET B8 INC
	16	E2DC	Torn-Hawt	E2DC +NGET B7-8 INC	E2DC + (ECU2) +NGET B7-8 INC	E2DC + (ECU4+ DWNO) +NGET B7-8 INC	E2DC + (ECU2 + ECUP + DWNO) +NGET B7-8 INC
	17	E2D2	Torn-Cotm	E2D2 +NGET B7-8 INC	E2D2 + (ECU2) +NGET B7-8 INC	E2D2 + (ECU4+ DWNO) +NGET B7-8 INC	E2D2 + (ECU2 + ECUP + DWNO) +NGET B7-8 INC
	18	E2D3	Torn-Drax	E2D3 +NGET B8 INC	E2D3 + (ECU2) +NGET B8 INC	E2D3 + (ECU4+ DWNO) +NGET B8 INC	E2D3 + (ECU2 + ECUP + DWNO) +NGET B8 INC
	19	TLNO	Torn-Lack	TLNO +NGET INC	TLNO + (ECU2) +NGET INC	TLNO + (ECU4+ DWNO) +NGET INC	TLNO + (ECU2 + ECUP + DWNO) +NGET INC
D. Grouping of Options: Onshore Incremental and Multiple HVDC / B6 Onshore Options In Combination [WITH compensating reinforcement in NGET on B7, B7a and B8]	20	E4DC + E2D2	Pehe-Haw + Torn-Cotm	E4DC + E2D2 +NGET B7-8 INC	E4DC + E2D2 + (ECU2) +NGET B7-8 INC	E4DC + E2D2 + (ECU4+ DWNO) +NGET B7-8 INC	E4DC + E2D2 + (ECU2 + ECUP + DWNO) +NGET B7-8 INC
	21	E4DC + E2D3	Pehe-Hawt + Torn-Drax	E4DC + E2D3 +NGET B7-8 INC	E4DC + E2D3 + (ECU2) +NGET B7-8 INC	E4DC + E2D3 + (ECU4+ DWNO) +NGET B7-8 INC	E4DC + E2D3 + (ECU2 + ECUP + DWNO) +NGET B7-8 INC
	22	E4D2 + E2DC	Pehe-Cotm + Torn-Hawt	E4D2 + E2DC +NGET B7-8 INC	E4D2 + E2DC + (ECU2) +NGET B7-8 INC	E4D2 + E2DC + (ECU4+ DWNO) +NGET B7-8 INC	E4D2 + E2DC + (ECU2 + ECUP + DWNO) +NGET B7-8 INC
	23	E4D2 + E2D3	Pehe-Cotn + Torn-Drax	E4D2 + E2D3 +NGET B8 INC	E4D2 + E2D3 + (ECU2) +NGET B8 INC	E4D2 + E2D3 + (ECU4+ DWNO) +NGET B8 INC	E4D2 + E2D3 + (ECU2 + ECUP + DWNO) +NGET B8 INC
	24	E4D3 + E2DC	Pehe-Drax + Torn-Cotm	E4D3 + E2DC +NGET B7-8 INC	E4D3 + E2DC + (ECU2) +NGET B7-8 INC	E4D3 + E2DC + (ECU4+ DWNO) +NGET B7-8 INC	E4D3 + E2DC + (ECU2 + ECUP + DWNO) +NGET B7-8 INC
	25	E4D3 + E2D2	Pehe-Drax + Torn-Hawt	E4D3 + E2D2 +NGET B8 INC	E4D3 + E2D2 + (ECU2) +NGET B8 INC	E4D3 + E2D2 + (ECU4+ DWNO) +NGET B8 INC	E4D3 + E2D2 + (ECU2 + ECUP + DWNO) +NGET B8 INC
	26	E4DC + TLNO	Pehe-Hawt + Torn-Lack	E4DC + TLNO +NGET B7-8 INC	E4DC + TLNO + (ECU2) +NGET B7-8 INC	E4DC + TLNO + (ECU4+ DWNO) +NGET B7-8 INC	E4DC + TLNO + (ECU2 + ECUP + DWNO) +NGET B7-8 INC
	27	E4D2 + TLNO	Pehe-Cotm + Torn-Lack	E4D2 + TLNO +NGET INC	E4D2 + TLNO + (ECU2) +NGET INC	E4D2 + TLNO + (ECU4+ DWNO) +NGET INC	E4D2 + TLNO + (ECU2 + ECUP + DWNO) +NGET INC
	28	E4D3 + TLNO	Pehe-Drax + Torn-Lack	E4D3 + TLNO +NGET B8 INC	E4D3 + TLNO + (ECU2) +NGET B8 INC	E4D3 + TLNO + (ECU4+ DWNO) +NGET B8 INC	E4D3 + TLNO + (ECU2 + ECUP + DWNO) +NGET B8 INC

Appendix G: NPVs East Coast Onshore Options (£m) Preferred Option from LWR is ECU2 + ECUP

Options in detail	Option	NPV_CP	NPV_SP	NPV_TD	NPV_SPS1	NPV_SPS2
ECU2	Opt_01	2,616	4,059	2,515	3,068	4,174
ECU2 + ECUP	Opt_02	2,962	5,122	3,068	5,179	6,004
ECU4	Opt_03	3,013	5,100	3,030	5,077	5,695
ECU4 + DWNO	Opt_04	2,901	5,013	3,001	4,981	5,598
ECU2 + ECUP + DWNO	Opt_05	2,928	5,077	3,125	5,048	5,685

Note: 1. *conditional formatting applied with higher NPV number in green, low NPV number in red;*
2. *number highlighted in red is the lowest NPV in each scenario;*
3. *number highlighted in green is the highest NPV in each scenario.*

Appendix H: NPVs of options with Both East Coast Onshore AND Offshore Reinforcements (£m) Preferred Option Combination from LWR is 21AAA)

Options in detail	Option	NPV_CP	NPV_SP	NPV_TD	NPV_SPS1	NPV_SPS2
E4DC + (ECU2) +NGET B7-8 INC	Opt_13AA	9,341	14,007	12,384	11,783	12,931
E4D2 + (ECU2) +NGET B8 INC	Opt_14AA	8,534	13,203	12,612	11,005	12,156
E4D3 + (ECU2) +NGET B8 INC	Opt_15AA	8,785	13,481	12,522	11,251	12,405
E2DC + (ECU2) +NGET B7-8 INC	Opt_16AA	3,550	7,805	8,150	4,112	5,874
E2D2 + (ECU2) +NGET B8 INC	Opt_17AA	2,976	7,091	7,611	3,577	5,299
E2D3 + (ECU2) +NGET B8 INC	Opt_18AA	3,139	7,308	8,172	3,741	5,482
TLNO + (ECU2) +NGET B7-8 INC	Opt_19AA	4,797	7,221	8,364	4,189	5,727
E4DC + (ECU4 + DWNO) +NGET B7-8 INC	Opt_13AAA	9,889	15,052	13,166	11,900	14,822
E4D2 + (ECU4 + DWNO) +NGET B8 INC	Opt_14AAA	9,035	14,245	13,444	11,154	14,031
E4D3 + (ECU4+ DWNO) +NGET B8 INC	Opt_15AAA	9,305	14,527	13,317	11,398	14,293
E2DC + (ECU4+ DWNO) +NGET B7-8 INC	Opt_16AAA	6,291	9,997	9,280	6,874	8,232
E2D2 + (ECU4+ DWNO) +NGET B8 INC	Opt_17AAA	5,587	9,186	8,698	6,286	7,638
E2D3 + (ECU4+ DWNO) +NGET B8 INC	Opt_18AAA	5,576	9,421	9,316	6,477	7,834
TLNO + (ECU4+ DWNO) +NGET B7-8 INC	Opt_19AAA	5,829	9,746	9,655	7,132	7,872
E4DC + (ECU2 + ECUP + DWNO) +NGET B7-8 INC	Opt_13AAAA	9,918	15,116	13,289	11,968	14,910
E4D2 + (ECU2 + ECUP + DWNO + DWNO) +NGET B8	Opt_14AAAA	9,061	14,308	13,568	11,222	14,118
E4D3 + (ECU2 + ECUP + DWNO) +NGET B8 INC	Opt_15AAAA	9,331	14,591	13,441	11,465	14,380
E2DC + (ECU2 + ECUP + DWNO) +NGET B7-8 INC	Opt_16AAAA	6,317	10,060	9,404	6,941	8,319
E2D2 + (ECU2 + ECUP + DWNO) +NGET B8 INC	Opt_17AAAA	5,614	9,248	8,821	6,352	7,725
E2D3 + (ECU2 + ECUP + DWNO) +NGET B8 INC	Opt_18AAAA	5,601	9,483	9,438	6,545	7,921
TLNO + (ECU2 + ECUP + DWNO) +NGET B7-8 INC	Opt_19AAAA	5,855	9,808	9,778	7,200	7,959
E4DC + E2D2 + (ECU2) +NGET B7-8 INC	Opt_20AA	10,030	16,101	15,693	11,790	12,134
E4DC + E2D3 + (ECU2) +NGET B7-8 INC	Opt_21AA	10,126	16,225	16,078	11,906	12,249
E4D2 + E2DC + (ECU2) +NGET B7-8 INC	Opt_22AA	9,934	16,032	15,548	11,599	12,016
E4D2 + E2D3 + (ECU2) +NGET B8 INC	Opt_23AA	9,420	15,443	15,492	10,992	11,387
E4D3 + E2DC + (ECU2) +NGET B7-8 INC	Opt_24AA	10,044	16,186	16,015	11,719	12,121
E4D3 + E2D2 + (ECU2) +NGET B8 INC	Opt_25AA	9,410	15,433	14,957	10,983	11,380
E4DC + TLNO + (ECU2) +NGET B7-8 INC	Opt_26AA	10,319	16,230	14,529	12,152	12,640
E4D2 + TLNO + (ECU2) +NGET B8 INC	Opt_27AA	9,428	15,262	14,125	11,218	11,661
E4D3 + TLNO + (ECU2) +NGET B8 INC	Opt_28AA	9,603	15,444	14,345	11,409	11,852
E4DC + E2D2 + (ECU4+ DWNO) +NGET B7-8 INC	Opt_20AAA	11,417	18,166	17,400	12,094	16,128
E4DC + E2D3 + (ECU4+ DWNO) +NGET B7-8 INC	Opt_21AAA	11,530	18,292	17,784	12,219	16,242
E4D2 + E2DC + (ECU4+ DWNO) +NGET B7-8 INC	Opt_22AAA	11,406	18,149	17,248	12,033	15,914
E4D2 + E2D3 + (ECU4+ DWNO) +NGET B8 INC	Opt_23AAA	10,896	17,626	17,023	11,371	15,210
E4D3 + E2DC + (ECU4+ DWNO) +NGET B7-8 INC	Opt_24AAA	11,512	18,256	17,596	12,151	16,034
E4D3 + E2D2 + (ECU4+ DWNO) +NGET B8 INC	Opt_25AAA	10,885	17,615	17,045	11,362	15,202
E4DC + TLNO + (ECU4+ DWNO) +NGET B7-8 INC	Opt_26AAA	11,335	18,245	15,898	12,435	16,152
E4D2 + TLNO + (ECU4+ DWNO) +NGET B8 INC	Opt_27AAA	10,440	17,281	15,502	11,529	15,186
E4D3 + TLNO + (ECU4+ DWNO) +NGET B8 INC	Opt_28AAA	10,615	17,462	15,363	11,717	15,379
E4DC + E2D2 + (ECU2+ECUP+ DWNO) +NGET B7-8	Opt_20AAAA	11,444	18,230	17,524	12,161	16,216
E4DC + E2D3 + (ECU2+ECUP+ DWNO) +NGET B7-8	Opt_21AAAA	11,559	18,354	17,909	12,288	16,330
E4D2 + E2DC + (ECU2+ECUP+ DWNO) +NGET B7-8	Opt_22AAAA	11,432	18,213	17,372	12,101	16,002
E4D2 + E2D3 + (ECU2+ECUP+ DWNO) +NGET B8 IN	Opt_23AAAA	10,922	17,688	17,149	11,438	15,297
E4D3 + E2DC + (ECU2+ECUP+ DWNO) +NGET B7-8	Opt_24AAAA	11,540	18,320	17,718	12,220	16,122
E4D3 + E2D2 + (ECU2+ECUP+ DWNO) +NGET B8 IN	Opt_25AAAA	10,913	17,679	17,168	11,430	15,290
E4DC + TLNO + (ECU2+ECUP+ DWNO) +NGET B7-8	Opt_26AAAA	11,360	18,309	16,022	12,503	16,240
E4D2 + TLNO + (ECU2+ECUP+ DWNO) +NGET B8 IN	Opt_27AAAA	10,468	17,343	15,625	11,595	15,274
E4D3 + TLNO + (ECU2+ECUP+ DWNO) +NGET B8 IN	Opt_28AAAA	10,640	17,523	15,487	11,784	15,466

Note: 1. conditional formatting applied with higher NPV number in green, low NPV number in red;

2. number highlighted in red is the lowest NPV in each scenario;

3. number highlighted in green is the highest NPV in each scenario.

Appendix I: East and North East Table of Scope

East Coast 275kV Upgrade	North East 400kV & Peterhead 400kV Busbar	East Coast 400kV Incremental Upgrade	Description of works:
2023	**2023**	**2026**	**Dates**
P			**Alyth:** Establish a eleven bay new double busbar substation at Alyth, constructed to 400kV but initially operated at 275kV. Reconfigure and terminate all overhead line circuits from Fetteresso, Tealing and Kincardine (SPT) on to the new Alyth busbar. Install a reactive compensation scheme at Alyth substation comprising a +225/-225MVar Dynamic and 100MVAr Static.
P			**Tealing:** Extend the 275kV substation at Tealing, installing two feeder bays with full busbar selection to connect two PSTs on the Kintore to Tealing 275kV OHL circuits. The PSTs will have a minimum rating of 920MVA and a nominal on-load angle range of +10/-10 degrees.
P			**Errochty:** Install an operational intertrip scheme that will trip the feeder breakers on the Errochty to Killin 132kV single circuit OHL in the event of a loss of the Beauly to Denny 400/275kV double circuit OHL south of Tummel (275kV)
P			**OHL:** Re-profile the existing 275kV OHL between Kintore, Fetteresso, Tealing and Kincardine and between Tealing and Glenrothes/Westfield up to the SHE Transmission/SPT border, to operate at 65•C, increasing the winter post-fault rating to 1090MVA.

East Coast 275kV Upgrade	North East 400kV & Peterhead 400kV Busbar	East Coast 400kV Incremental Upgrade	Description of works:
2023	**2023**	**2026**	**Dates**
	P		**Rothienorman:** Uprate the existing 275kV double busbar for 400kV operation. Install two new 240MVA 400/132kV SGTs and two new 120MVA 132/33kV GTs to replace the existing 120MVA 275/33kV GTs for the existing GSP connection.
	P		**New Deer:** Uprate the existing 275kV New Deer double busbar for 400kV operation.
	P		**Blackhillock:** Remove the 400/275kV line connected SGTs and use the existing 400kV circuit breakers to connect the re-insulated 400kV OHL from Rothienorman Substation.
	P		**Kintore**: Install four 400kV Bays and partially construct the 400kV busbar to accommodate two 400/275kV, 1200MVA Super Grid Transformers connecting the uprated 400kV circuits from Rothienorman to the existing Kintore 275kV busbar. Install 8km of 275kV cable and associated sealing ends associated with the diversion of the existing double circuit overhead line from Blackhillock/Cairnford and interconnection between the 275kV SGT terminal and the 275kV busbar.
	P		**OHL:** Reconductor and Reinsulate 170km to 400kV operation between Kintore, Fetteresso and Alyth (established in the East Coast Onshore 275kV Upgrade) as far as the SHE Transmission/SPT border.

East Coast 275kV Upgrade	North East 400kV & Peterhead 400kV Busbar	East Coast 400kV Incremental Upgrade	Description of works:
2023	**2023**	**2026**	**Dates**
	P		**Kintore:** Establish an additional six bays (four bays installed under North East 400kV Upgrade) and complete the construction of the 10 bay (includes bus section and two bus couplers) 400kV AIS double busbar adjacent to the existing 275/132/33kV Kintore Substation.
		P	**OHL:** Reconductor and Reinsulate 170km to 400kV operation between Kintore, Fetteresso and Alyth (established in the East Coast Onshore 275kV Upgrade) as far as the SHE Transmission/SPT border.
		P	**Kintore:** Establish an additional six bays (four bays installed under North East 400kV Upgrade) and complete the construction of the 10 bay (includes bus section and two bus couplers) 400kV AIS double busbar adjacent to the existing 275/132/33kV Kintore Substation.
		P	**Alyth:** Uprate the 275kV (built for 400kV operation) Gas Insulated Switchgear double busbar arrangement established at Alyth via the East Coast Onshore 275kV Upgrade for 400kV operation. Install two new 1200MVA 400/275kV SGTs with piled foundations to connect the existing 275kV OHL from Tealing Substation.
		P	**Blackhillock:** Installation of two Phase Shifting Transformers (PSTs) at Blackhillock Substation on the 275kV double circuit OHL to Knocknagael including installation of associated civils & interconnecting electrical infrastructure. The PSTs will have a minimum rating of 920MVA and a nominal on-load angle range of +15/-15 degrees.

East Coast 275kV Upgrade	North East 400kV & Peterhead 400kV Busbar	East Coast 400kV Incremental Upgrade	Description of works:
2023	**2023**	**2026**	**Dates**
		P	**Fetteresso:** Remove the existing 240MVA 275/132kV SGT and install two new 240MVA 400/132kV SGTs. Utilise existing 400kV equipment at Fetteresso substation to establish a 400kV double busbar. These works are required to operate the existing substation and the OHLs from Kintore and Alyth at 400kV