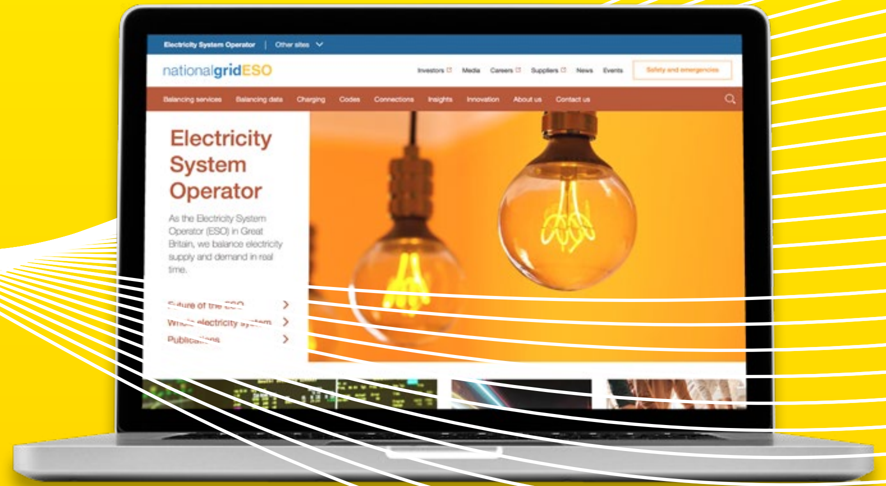
Electricity Ten Year Statement

November 2018



How to use this interactive document

To help you find the information you need quickly and easily we have published the *Electricity Ten Year Statement* as an interactive document.

Home button
This will take you to the contents page. You can click on the titles to navigate to a section.

Arrows
Click on the arrows to move backwards or forwards a page.

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Foreword

Welcome to our *Electricity Ten Year Statement*. This statement puts forward our latest view of the future requirements of GB's electricity transmission system. It also highlights the areas that show future uncertain flows and requirements. Such areas provide opportunities for system development and innovative management solutions.

Our *Electricity Ten Year Statement (ETYS)*, along with our other System Operator (SO) publications, aims to encourage and inform debate, leading to changes that ensure a secure, sustainable and affordable energy future. It is also a key input into the *Network Options Assessment (NOA)* process that makes recommendations as to which investments and solutions should be taken forward. It is important to note that the *ETYS* and the *NOA* only focus on the key major transmission boundaries across GB and that there will be many other system requirements and transmission investments required that are not currently considered in these documents.

Thank you for your continued feedback as to what and how you would like to see the *ETYS* process develop, it is really important that we are sharing the right data in the right way that makes this a useful document for your needs. You will see some changes in this document which are as a result of the direct feedback from you.

As we all know, the electricity industry is changing at an unprecedented pace and scale as we move to a more decarbonised and decentralised nation. This is demonstrated through our 2018 *Future Energy Scenarios (FES)*, which we've developed with stakeholder and industry input, and it is these scenarios that are at the heart of the *ETYS* process in determining the future transmission network needs.

The themes in this year's *FES* are continued closure of fossil-fuelled generation, an influx of wind generation, rising electric vehicle and heat pump demand, and increasing import and export via interconnectors. These changes are leading to high north-to-south transmission flows across Scotland and much of the north of England to meet demand in the Midlands and the South. The number of interconnectors that are predicted to connect towards the south east of England also create stresses on the existing network and is a key focus area to ensure that we can meet the needs of the interconnector connections.

One of the most important transmission developments this year has been the commissioning of the Western HVDC project to link south-west Scotland to north Wales. This adds a significant increase to the capability (circa 2 GW) across the northern part of the network to help manage the high flows of mainly wind generation.

From the results of the work in this document the Transmission Owners (TO) have provided asset solutions to meet the required capability needs. These asset options, alongside reduced or no-build options will be assessed through our *Network Options Assessment (NOA)*. The *NOA* aims to make sure that the transmission system is continuously developed in a timely, economic and efficient way, providing value for our customers. The *NOA 2017/18*, using the assessment results from *ETYS 2017*, recommended £21.6 million of development spend on future network reinforcements in 2018 to provide the required transmission capabilities.

As the Electricity System Operator (ESO), we are always looking to find ways to reduce the costs to the consumer whilst meeting the needs of the transmission network. This year, following the commitments made in the ESO Forward Plan and the Network Development Roadmap consultation, we are looking to encourage and assess a broader range of solutions to meet transmission needs. This range of solutions ranges from smart grid management systems to Distribution Network Operator (DNO) assets that provide transmission support and market solutions. This will help improve our investment recommendations for the benefit of customers and consumers. In this document, we present case studies that demonstrate how we are taking steps towards enhanced tools and analysis to improve our network planning. You can find further details about our enhanced role in network planning in the ESO Forward Plan. You can also find further details about the changes we are making to our methods in the Network Development Roadmap.

I hope that you find this document, along with our other SO publications, useful as a catalyst for wider debate.

Please share your views with us; you can find details of how to contact us on our website https://www.nationalgrideso.com/insights/electricity-ten-year-statement-etys/.

Julian Leslie
Head of Networks, ESO

Key messages

We have assessed the capability of the National Electricity Transmission System (NETS) against the requirements derived from the *Future Energy Scenarios (FES)*, using boundary analysis techniques.

Below is a summary of the main findings, together with how these findings will be used in the *NOA* and the future development of the *ETYS*.

1. The NETS will face future growing needs in a number of regions due to the following factors:
   - Increasing quantities of wind generation connected across the Scottish networks is likely to double north-to-south transfer requirements within ten years. For example, the flow through the Scotland–England boundary is expected to reach 15.7 GW in *FES* **Two Degrees** scenario by 2028, almost three times the current 5.7 GW boundary capability with the Western HVDC reinforcement operational.
   - A potential growth of more than 6 GW in low carbon generation and interconnectors in the north of England, combined with increased Scottish generation, will increase transfer requirements into the English Midlands.
   - Potentially high growth in the next decade of up to 9 GW in generation coming from offshore wind on the east coast connecting to East Anglia risks stressing this region of the network.
   - New interconnectors with Europe will place increased stress on the transmission network, especially southern and eastern regions of the network.

2. The *NOA* process will evaluate options for NETS development and condense them to a set of ESO preferred options and investment recommendations. These results will be shown in the *NOA 2018/19* report to be published in January 2019.
   - For *NOA 2018/19*, we expect to assess around a hundred NETS reinforcement options and, at the time of writing, eight have been initiated by the ESO. Following our cost-benefit analysis (CBA), we will recommend the options requiring expenditure in 2019, as well as those worth delaying.

3. The NETS will see growing impact from new technologies such as electric vehicles, battery storage and heat pumps. As a result, the requirements of NETS are becoming increasingly complex. System requirements are more frequently being driven by conditions other than winter peak demand. We are taking this evolution in requirements into account and are developing analysis tools and processes to assess this future transition. We publish in this year's document the description and the preliminary results of two case studies addressing voltage and thermal year round requirements. We will publish full separate reports about the voltage and thermal year round case studies by March 2019.

4. In April 2019, the ESO will become legally separate from the rest of National Grid. This will shape the future development of the *ETYS* and *NOA* publications, as we work to facilitate competition and improve our reinforcement recommendations for the benefit of our customers and consumers. Furthermore, the ESO is promoting more whole system thinking to facilitate network and market access.

Chapter 1
Introduction

The *Electricity Ten Year Statement (ETYS)* presents the National Grid Electricity System Operator's (ESO) view of future transmission requirements and the capability of Great Britain's (GB) National Electricity Transmission System (NETS). This is a significant part of our annual network planning process. Through it, we identify requirements that may lead to network development, which are then assessed through the *Network Options Assessment (NOA)*[1] process.

This is our seventh *ETYS*, which we produce in our role as the ESO, with help from the TOs in Scotland (Scottish Hydro Electric Transmission and SP Transmission) and in England and Wales (National Grid Electricity Transmission).

Our aim is to build on the *Future Energy Scenarios (FES)*[2] and provide you an overview of the NETS, its power transfer capability and its potential future capability requirements.

Since the first *ETYS*, published in 2012, and the Seven Year Statement that preceded it, our publications have continuously evolved. As a result, some of the information you used to find in *ETYS* is now published in separate, more focused documents, which we describe below.

We welcome your feedback, which helps us to improve our publications. We are interested in knowing how you use *ETYS* and how we can make it more useful for you. You can find details of how to contact us at the end of this document.

[1] https://www.nationalgrideso.com/insights/network-options-assessment-noa

[2] http://fes.nationalgrid.com/

1.1 *ETYS* and the ESO publications

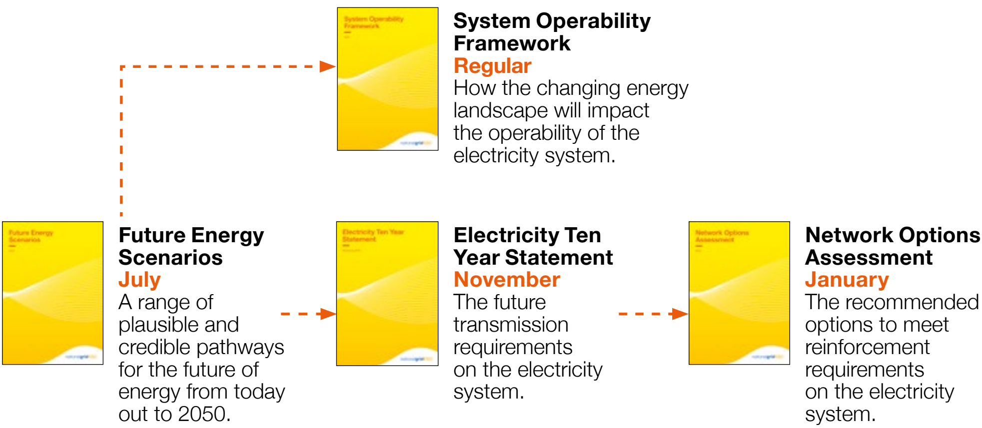
Part of the ESO's role is to assess and make appropriate recommendations about reinforcing the NETS to meet our customers' requirements in an economic and efficient way.

We do this in three stages. The first stage establishes the *Future Energy Scenarios (FES)*, described further in the next chapter. The second stage is determining the NETS's requirements, which we describe in *ETYS*. And finally, we evaluate network development options, and publish investment recommendations in the *NOA* report.

The *ETYS* complements the *NOA* report, because information about NETS capability and future requirements it contains feed into the analysis used to produce the *NOA* report. By updating the future requirements based on the updated scenarios, the *NOA* recommendation can also change. Based on last year's *ETYS*, the *NOA 2017/18* recommended investing £21.6m this year to potentially deliver 22 projects worth almost £3.2bn.

The *System Operability Framework*[3] *(SOF)* takes a holistic view of the changing energy landscape to assess the future operation of Britain's electricity networks. It combines the change in generation and demand from the *FES* with network capability from *ETYS* to assess future system requirements. The assessments in the *SOF* and the *ETYS* complement each other to ensure the future NETS is both operable and can transmit power from suppliers to consumers. While the *SOF* focuses on the operability challenges of the NETS, the *ETYS* evaluates its capability to transmit power. We recently moved from one annual *SOF* publication to reports on a range of topics. Figure 1.1 shows the connection between *ETYS* and the relevant ESO documents.

Figure 1.1
ETYS and ESO documents



[3] https://www.nationalgrideso.com/insights/system-operability-framework-sof

1.2 *ETYS-NOA* and *TYNDP*

The *ETYS* and *NOA* also consider arrangements for developing cross-border electricity transmission networks (including interconnections with mainland Europe).

So, we need to consider the relationship between the *ETYS-NOA* and European transmission developments described in the *Ten Year Network Development Plan (TYNDP)*. The *TYNDP* is produced by the European Network of Transmission System Operators for Electricity (ENTSO-E). It is similar to the *ETYS* and *NOA* but covers all the European Transmission System Operators (TSOs). It is published every two years with input from TSOs in accordance with Regulation (EC) 714/2009. The next publication is due in December 2018.

Although *TYNDP*, *ETYS* and *NOA* all highlight future network developments, there are important differences:

- The *TYNDP* is produced every two years, whereas the *ETYS* and *NOA* are produced annually. So information included in the *TYNDP* usually lags the *ETYS* and *NOA*.
- A different set of energy visions are used for the *TYNDP* compared to the *FES* we use for *ETYS* and *NOA*.
- The *TYNDP* focuses mainly on pan-European projects that satisfy European Union objectives, such as facilitation of cross-border trade and European environmental targets.
- Analysis for the *TYNDP* is conducted by European regional groups. GB participates in the North Sea group.

You can find more information about the *TYNDP* at **http://tyndp.entsoe.eu/**

1.3 *ETYS* and the Network Development Roadmap

We published our Network Development Roadmap in July, following consultation in May[4]. The roadmap sets out ambitious commitments to develop our network planning tools and deliver greater value for consumers. Some of these changes inform the development of the *ETYS*, others will be incorporated in the *NOA* process.

The changing nature of the electricity system means it is increasingly important we study the transmission network needs across more of the year than our current primary focus of winter peak.

We are applying a *NOA*-type approach to regional voltage challenges which are becoming more costly to manage. We are carrying out practical pathfinding projects in three regions of the country, to develop the tools and processes we need to include in next year's *ETYS* and *NOA*. We include the preliminary results of a case study of voltage year-round assessment in a high-priority region.

The level of uncertainty in the conditions of a year of operation has increased because of high penetration of intermittent renewable resources and interconnectors. We are carrying out a case study to explore the use of probabilistic techniques to one region of the GB network, and we include preliminary results.

These pathfinding projects should help improve the value the *ETYS* and *NOA* drive for consumers by providing more informative data and therefore helping ensure the right balance between operational and network investment solutions. We will publish full reports on the pathfinding projects before *ETYS 2019*.

The roadmap also highlights that our analysis is considering more complex conditions at the same time as expanding the *NOA* process to allow network and non-network solution providers across distribution and transmission to submit options to meet transmission network needs. We therefore are taking steps to communicate our analysis and transmission network needs as clearly as possible to the new audience. We have taken initial steps in this document but would welcome feedback on how else we could make this document and the way we set out transmission network needs more accessible.

[4] https://www.nationalgrideso.com/insights/network-options-assessment-noa

1.4 Improving your experience

We hope you will benefit from the 2018 *ETYS* and our other ESO publications, the *NOA*, *FES* and *SOF*.

We are keen to hear your views as we continue developing the *ETYS*. This year, we received feedback through consultation survey, face-to-face at our electricity customer seminars, as well as from correspondence sent to our *ETYS* email address.

Based on your feedback, we have increased the size of the maps in Chapter 3, adding more information in the graphs where possible. We have also explained more about the naming convention for some of the boundaries.

We have investigated extending our winter peak demand analysis with year-round voltage and thermal analysis and have added two case studies in Chapter 3. We have also improved the way we present the future required transfer graphs to represent each scenario in a separate graph and include the range of expected boundary flows based on market data.

We have created a new appendix, Appendix H, to explain further some of the inputs and methodologies we use in the analysis. In this appendix, you can find descriptions of the *FES* inputs and further details about the thermal case study.

Chapter 2
Network Development Inputs

To identify the future transmission requirements of the NETS we must first understand what power demand and generation the network may need to handle. We do this by using the *FES*.

We engage with our customers and stakeholders in a variety of ways, including workshops, webinars and meetings. The feedback we receive through our engagement is fundamental to the development of the *FES* scenarios. The scenarios help to inform our network planning.

2.1 *Future Energy Scenarios (FES)*

Following extensive analysis and consultation, we have created a new framework for our scenarios this year. We continue to use our 2x2 matrix, however, the scenarios are now aligned to two new axes:

- speed of decarbonisation
- level of decentralisation.

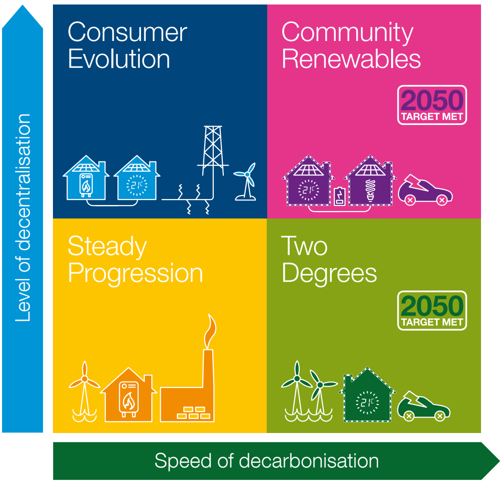
The speed of decarbonisation axis is driven by policy, economics and consumer attitudes. All scenarios show progress towards decarbonisation, with Community Renewables and Two Degrees meeting the 2050 target.

The level of decentralisation axis indicates how close the production and management of energy is to the end consumer, moving up the axis from large-scale central to smaller-scale local solutions. All scenarios show an increase in decentralised production of energy compared with today.

You can find more information about the 2018 *FES* on our website[1]. Chapter 3 of the *FES* document discusses the two new axes in more detail.

Figure 2.1 provides a brief overview of each of the scenarios and their relative position on the 2x2 matrix.

Figure 2.1
The 2018 scenario matrix



[1] http://fes.nationalgrid.com/

Community Renewables

The 2050 decarbonisation target is achieved through a more decentralised energy landscape. **Community Renewables** is based on the Consumer Renewables sensitivity[2] from *FES 2017*.

Two Degrees

The decarbonisation target is met using larger and more centralised technologies. This scenario builds on **Two Degrees** from *FES 2017*, combined with hydrogen heating from the Decarbonised Gas sensitivity also from *FES 2017*.

Steady Progression

This scenario is more centralised. It makes progress towards the 2050 decarbonisation target but does not meet it. **Steady Progression** combines elements from **Steady State** and **Slow Progression** from *FES 2017*.

Consumer Evolution

This is a more decentralised scenario which makes progress towards the decarbonisation target, but fails to achieve the 80 per cent reduction by 2050. This scenario builds on a blend of **Consumer Power** and **Slow Progression** from *FES 2017*.

[2] In order to explore uncertainties *FES 2017* contained four sensitivities which considered a broader range of energy pathways (in addition to the four main scenarios).

2.2 Networks

The *FES* data is applied to simulation models of the NETS to analyse their impact on the network and assess its performance.

The Security and Quality of Supply Standards (SQSS)[3] set out the criteria and methodology for planning the NETS. Appendix H provides further details about the standard planning criteria.

It details how the generation, demand and interconnector data are processed and applied to the NETS. Diagrams and details of the network models are provided in Appendices A and B.

[3] https://www.nationalgrideso.com/codes/security-and-quality-supply-standards

Chapter 3
The Electricity Transmission Network

3.1 Introduction

The GB National Electricity Transmission System must continue to adapt and be developed so power can be transported from source to demand, reliably and efficiently.

To make sure this happens, we must understand its capabilities and the future requirements that may be placed upon it. When we assess future requirements, we need to bear in mind that we have a large number of signed contracts for new generation to connect to the NETS. In addition, the development of interconnectors connecting Great Britain to the rest of the Europe will have a big impact on future transmission requirements.

In our experience, it is unlikely that all customers will connect exactly as contracted today. We cannot know exactly how much and when generation will close and new generation will connect, so we use our future energy scenarios to help us decide on credible ranges of future NETS requirements and its present capability.

This is done using the system boundary concept. It helps us to calculate the NETS's boundary capabilities and the future transmission requirements of bulk power transfer capability. The transmission system is split by boundaries[1] that cross important power flow paths where there are limitations to capability or where we expect additional bulk power transfer capability will be needed. We apply the SQSS[2] to work out the NETS boundary requirements.

In this chapter, we describe the NETS characteristics. We also discuss each of the NETS boundaries, grouped together as regions, to help you gain an overview of the total requirements, both regionally and by boundary.

This chapter also provides analysis to show you how, and when in the years to come, the NETS will potentially face growing future network needs on a number of its boundary regions.

We also provide more in depth discussion for some regions in terms of high voltage management and year round thermal analysis. You can find the preliminary results in this chapter. The full reports will be published separately.

The results presented in this chapter will be used in the *NOA 2018/19* to present an assessment of the ESO's preferred reinforcement options, and recommendations to address the potential future NETS boundary needs.

[1] Please note that these boundaries will be reviewed annually and updated as appropriate.

[2] https://www.nationalgrideso.com/codes/security-and-quality-supply-standards

3.2 NETS background

The NETS is mainly made up of 400kV, 275kV and 132kV assets connecting separately owned generators, interconnectors, large demands and distribution systems.

As the ESO, we are responsible for managing the system operation of the transmission networks in England, Wales, Scotland and offshore. The ‘transmission’ classification applies to assets at 132kV or above in Scotland or offshore. In England and Wales, it relates to assets at 275kV and above.

National Grid Electricity Transmission owns the transmission network in England and Wales. The transmission network in Scotland is owned by two separate transmission companies: Scottish Hydro Electric Transmission in the north of Scotland and SP Transmission in the south of Scotland. The offshore transmission systems are also separately owned. Sixteen licensed offshore transmission owners (OFTOs)[3] have been appointed through the transitional tendering process. They connect operational offshore wind farms that were given Crown Estate seabed leases in allocation rounds.

[3] https://www.ofgem.gov.uk/system/files/docs/2018/08/electricity_registered_or_service_addresses_new.pdf

3.3 NETS boundaries

To provide an overview of existing and future transmission requirements, and report the restrictions we will see on the NETS, we use the concept of boundaries. A boundary splits the system into two parts, crossing critical circuit paths that carry power between the areas where power flow limitations may be encountered.

The transmission network is designed to make sure there is enough transmission capacity to send power from areas of generation to areas of demand.

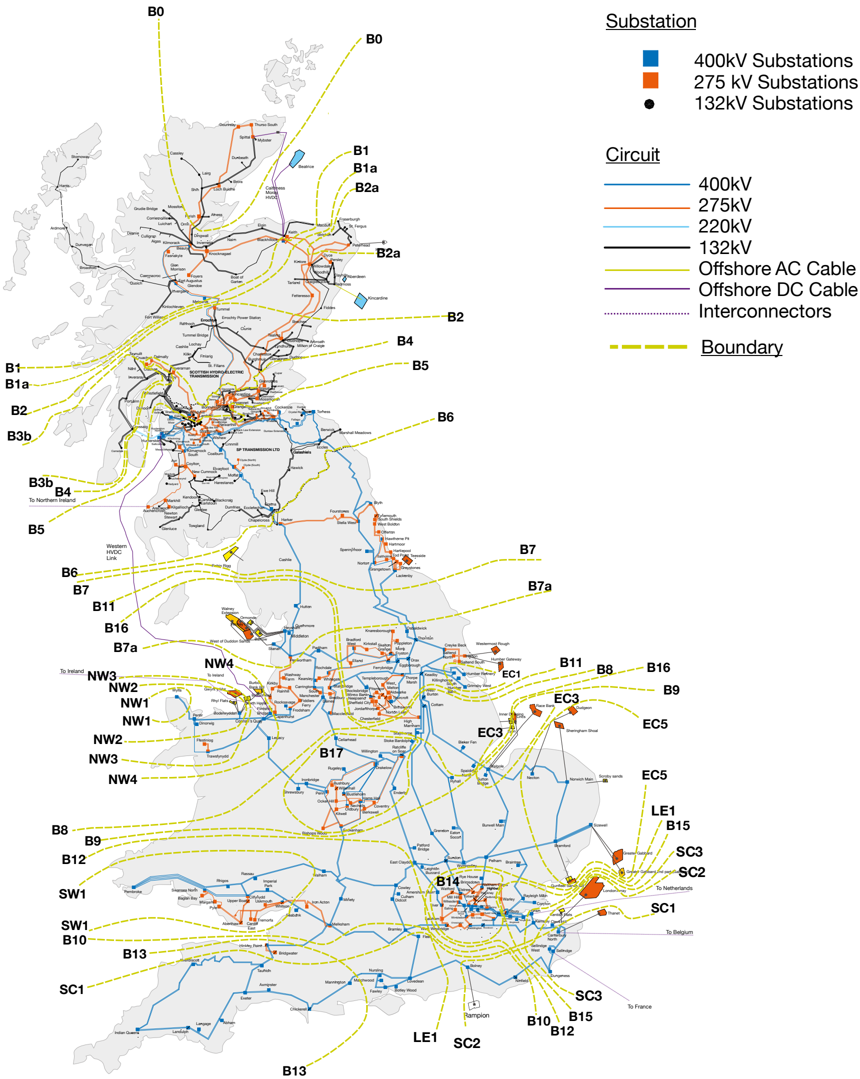
Limiting factors on transmission capacity include thermal circuit rating, voltage constraints and/or dynamic stability. From the network assessment, the lowest known limitation is used to determine the network boundary capability. The base capability of each boundary in this document refers to the capability expected for winter 2018/19.

Defining the NETS boundaries has taken many years of operation and planning experience of the transmission system. The NETS's boundaries have developed around major sources of generation, significant route corridors and major demand centres. A number of recognised boundaries are regularly reported for consistency and comparison purposes. When significant transmission system changes occur, new boundaries may be defined and some existing boundaries either removed or amended (an explanation will be given for any changes). Some boundaries are also reviewed but not studied because of no significant changes in the *FES* generation and demand data of the area from the previous years. For such boundaries, the same capability as the previous year is assumed.

GB NETS boundary map

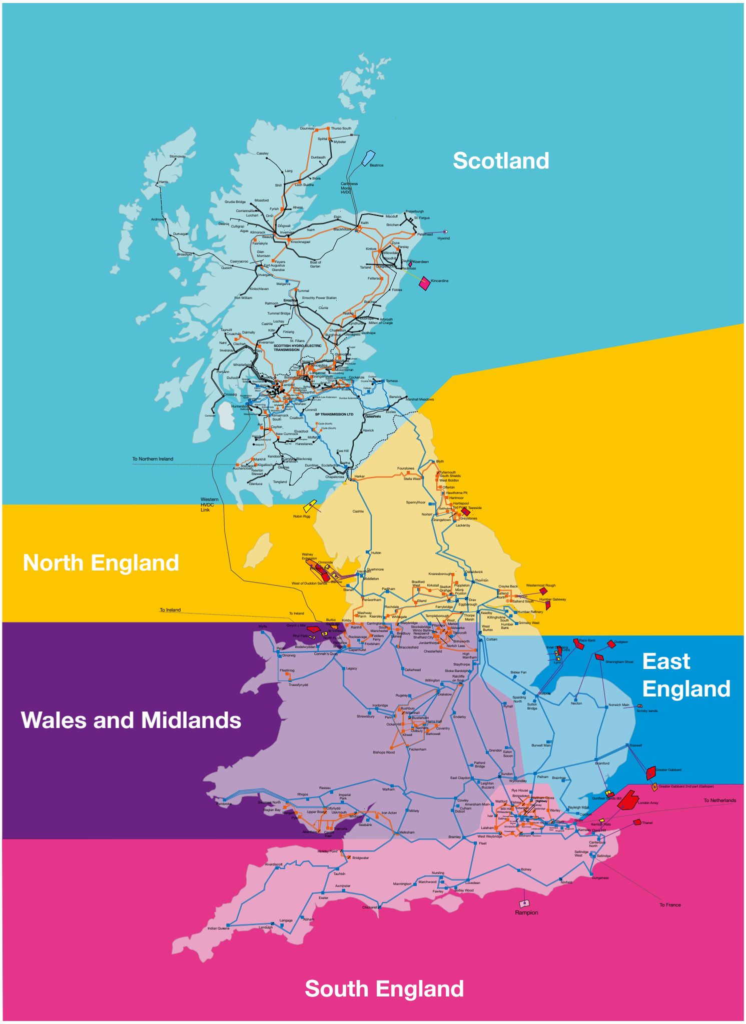
Figure 3.1 shows all the boundaries we have considered for our *ETYS* analysis. Over the years, we have continuously developed the transmission network to ensure there is sufficient transmission capacity to effectively transport power across the country.

Figure 3.1
GB NETS boundaries



To help describe related issues, we have grouped the boundaries into five regions, as shown in Figure 3.2.

Figure 3.2
Regional map



Determining the present capability and future requirements of the NETS boundaries

The boundaries used by *ETYS* and *NOA* can be split into two different types:

Local boundaries – are those which encompass small areas of the NETS with high concentration of generation. These small power export areas can give high probability of stressing the local transmission network due to coincidental generation operation.

Wider boundaries – are those that split the NETS into large areas containing significant amounts of both generation and demand. The SQSS boundary scaling methodologies are used to assess the network capability of the wider boundaries. These methodologies take into account both the geographical and technological effects of generation. This allows for a fair and consistent capability and requirements assessment of the NETS.

- **The security criterion –** evaluates the NETS's boundary transfer requirements to satisfy demand without reliance on intermittent generators or imports from interconnectors. The relevant methodology for determining the security needs and capability are from the SQSS Appendices C and D.
- **The economy criterion –** defines the NETS's boundary transfer requirements when demand is met with high output from intermittent and low carbon generators and imports from interconnectors. This is to ensure that transmission capacity is adequate to transmit power from the highly variable generation types without undue constraint. The relevant methodology for determining the economy needs and capability are from the SQSS Appendices E and F.

Interpreting the boundary graphs

The format of the *ETYS* boundary transfer graphs has changed from last year. The graphs now show a distribution of power flow for each scenario, in addition to the boundary power transfer capability and NETS SQSS requirements for the next twenty years. Using the B6 boundary charts as an example (Figure 3.3), it can be seen that a separate chart is provided for each of the four *Future Energy Scenarios*. Each scenario has different generation and demand so produces different boundary power flow expectations.

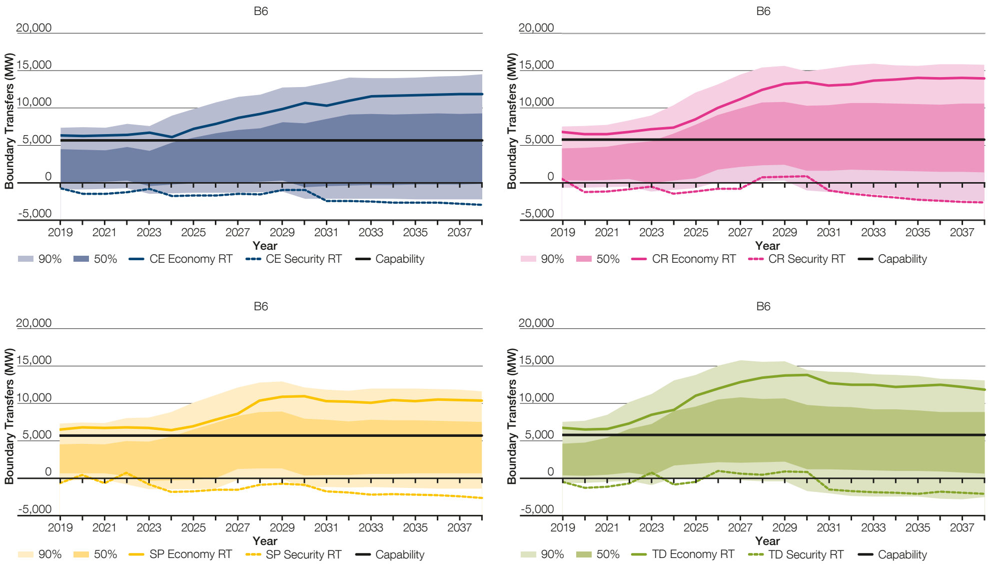
The NETS SQSS sets the methodology to set the wider boundary planning requirements, i.e., the Economy and Security criteria discussed above. These are shown in the graphs as a solid coloured line for Economy required transfer and a dashed coloured line for Security required transfer.

Boundary capability, in accordance with NETS SQSS requirements, is represented as a solid flat line on the graphs. The line position is calculated to represent the expected boundary capability for the coming 2018/19 winter peak. The boundary capability will change over time as the network, generation and demand change, all of which are uncertain. Therefore, to show system future needs and opportunities for each boundary a single straight capability line based on the present conditions is shown.

Two shaded areas are now 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. In percentile terms, 75% of annual power flows are lower than the upper edge of the darker shaded area and 75% are higher than the lower edge. The lighter and darker shaded areas together show an area in which 90% of the annual power flows lie. In percentile terms, 95% of annual power flows are lower than the upper edge of the lighter shaded area and 95% are higher than the lower edge.

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 the free market power flows in comparison with boundary capability, it can be seen where future growing needs can be expected.

Figure 3.3
Example of boundary transfer graphs and base capability for a boundary



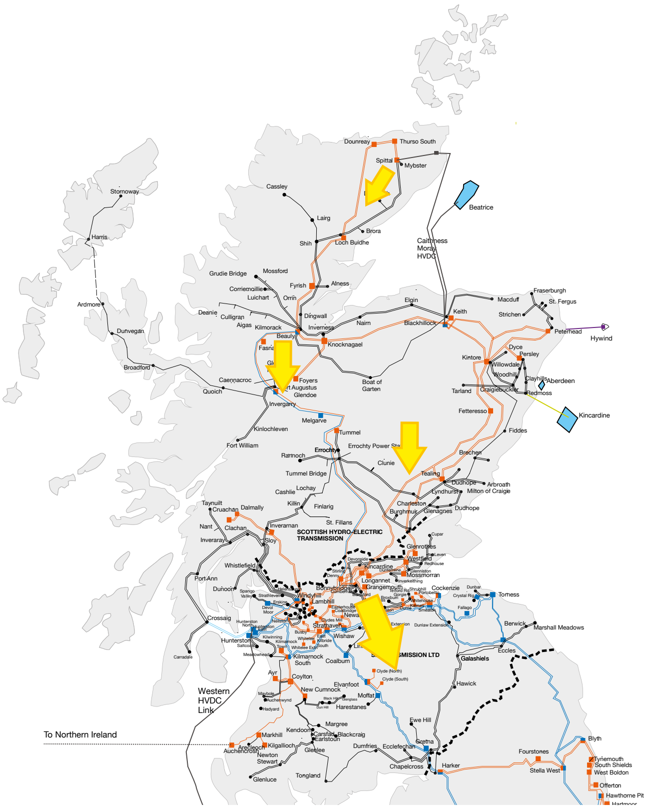
Stakeholder engagement
If you have feedback on any of the content of this document please send it to **transmission.etys@nationalgrid.com**, catch up with us at one of our consultation events or visit us at National Grid ESO, Faraday House, Warwick.

3.4 Network capability and requirements by region – Scottish boundaries

Introduction

The following section describes the Scottish transmission networks up to the transmission ownership boundary with the England and Wales transmission network. The onshore transmission network in Scotland is owned by SHE Transmission and SP Transmission but is operated by National Grid as the ESO. The Scottish NETS is divided by boundaries B0, B1, B1a, B2, B3b, B4, B5 and B6. The B4 boundary is shared by SHE Transmission and SP Transmission. The B6 boundary is shared by SP Transmission and National Grid Electricity Transmission. The figure below shows the general pattern of power flow directions expected to occur most of the time in the years to come up to 2028, i.e power will generally flow from north to south. The arrows in the diagram illustrate power flow directions and are approximately scaled relative to the winter peak flows. The flow of power is largely dependent on the output from wind and other generation sources in Scotland. There will be times, most likely when wind is low and demand is high, when power will flow from south to north.

Figure SR.1
Scottish transmission network and the typical direction of power flows



Primary challenge statement:

Scotland is experiencing large growth in renewable generation capacity, often in areas where the electricity network is limited.

Regional drivers

The rapidly increasing generation capacity, mostly from renewable sources and mainly wind, connecting within Scotland is leading to future growing needs in some areas. Across all the *FES*, the fossil fuel generating capacity in Scotland reaches nearly zero, while interconnector and storage capacity increases. By 2035, the scenarios (shown in Figure SR.2) suggest a total Scottish generating capacity of between 20 and 25 GW.

This potentially leads to increasingly dynamic Scottish network behaviour depending on factors such as weather condition and price of electricity. With gross demand in Scotland not expected to exceed 6 GW (shown in Figure SR.3) by 2040, which is much less than the Scottish generation capacity, Scotland will be expected to export power into England most of the time. At times of low renewable output, Scotland may need to import power from England. In a highly decentralised scenario like **Community Renewables**, local generation capacity connected at the distribution level in Scotland region could reach up to more than 13 GW by 2040. Of that capacity, a typical total embedded generation output on average might be around 4.7 GW. This will vary depending on factors like wind speeds, and how other local generators decide to participate in the market.

Figure SR.2
Generation capacity mix scenarios for Scotland

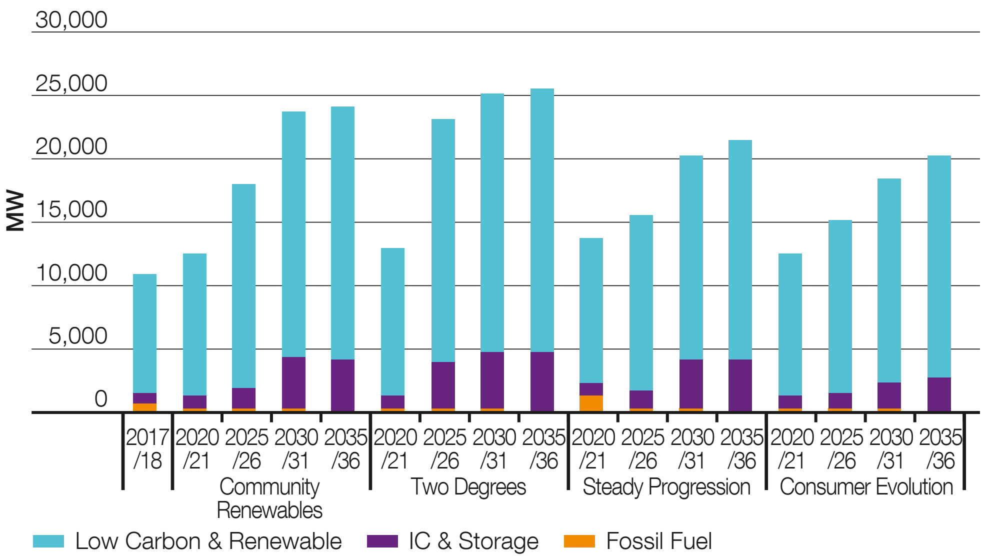
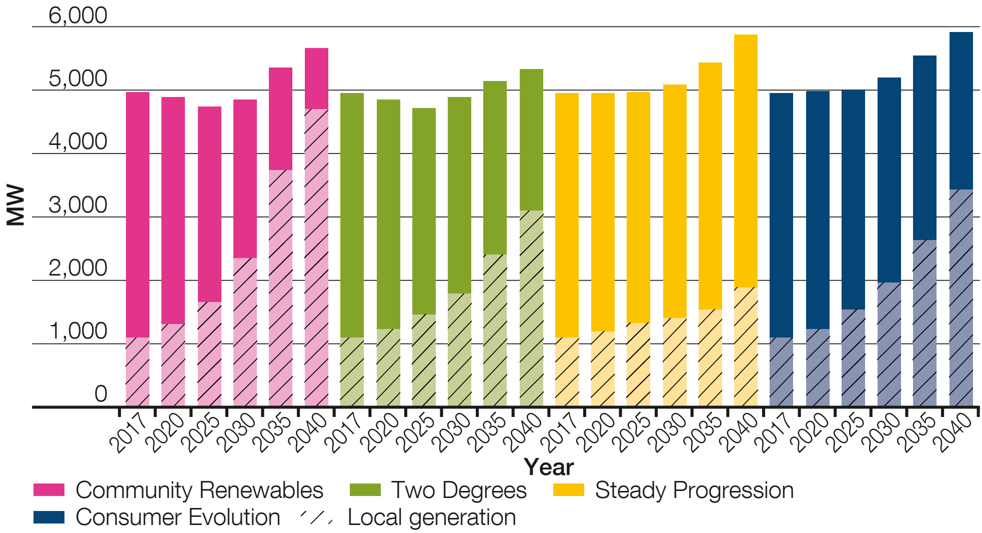


Figure SR.3
Gross demand scenarios for Scotland



The anticipated increase in renewable generation in Scotland is increasing power transfer across the Scottish boundaries. On a local basis, with the anticipated generation development in the north of Scotland, including generation developments on the Western Isles, Orkney and the Shetland Islands, there may be limitations on power transfer from generation in the remote Scottish NETS locations to the main transmission routes (B0, B1).

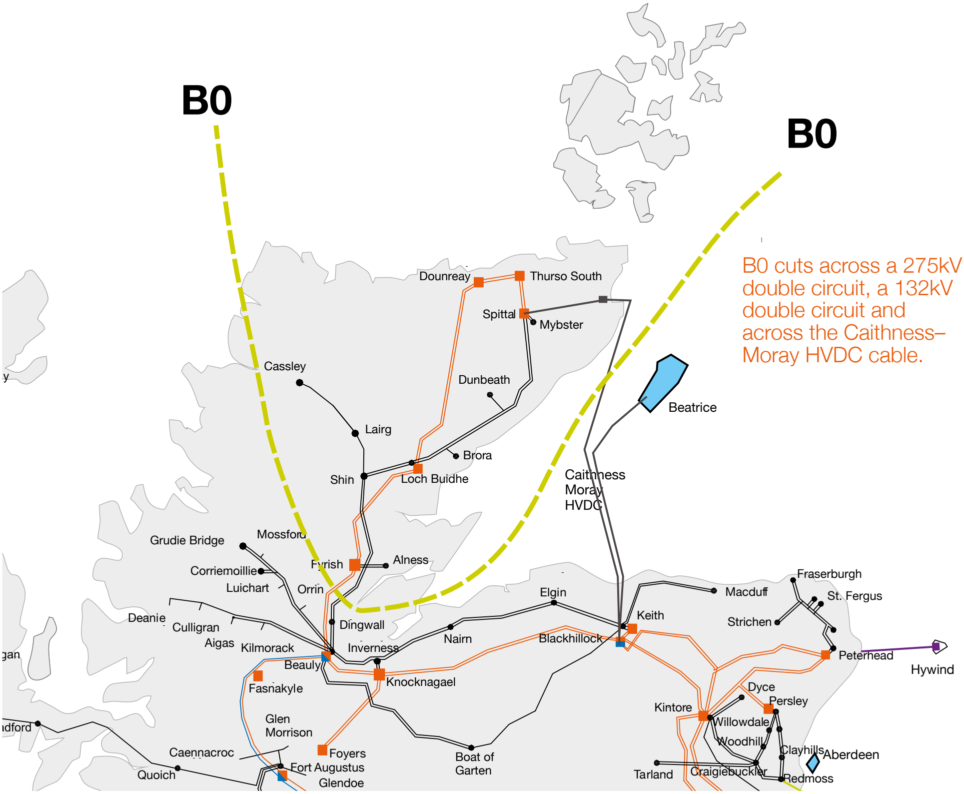
The Argyll and the Kintyre peninsula is an area with significant renewable generation activity and low demand. A boundary assessment is needed to show potential for high generation output and network limitations to power flows on this part of the NETS (B3b).

As generation within these areas increases over time because of the high volume of new renewable generation seeking connection, boundary transfers across the Scottish NETS boundaries (B0, B1, B1a, B2, B3b, B4 and B5 and B6) increase.

The need for network reinforcement to address the above mentioned potential capability issues will be evaluated in the *NOA 2018/19* CBA. Following the evaluation, the preferred reinforcements for the Scotland region will be recommended.

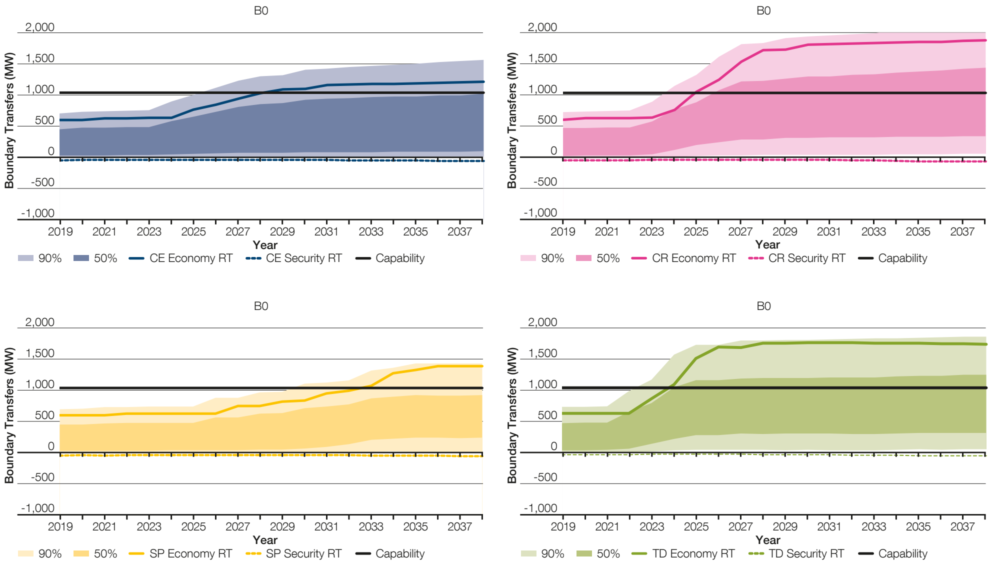
Boundary B0 – Upper North SHE Transmission

Figure B0.1
Geographic representation of boundary B0



Boundary B0 separates the area north of Beauly, comprising the north of the Highlands, Caithness, Sutherland and Orkney. The Caithness–Moray HVDC subsea cable, and associated onshore works, are scheduled to be completed in December 2018, and this will significantly strengthen the transmission network north of Beauly.

Figure B0.2
Boundary flows and base capability for boundary B0



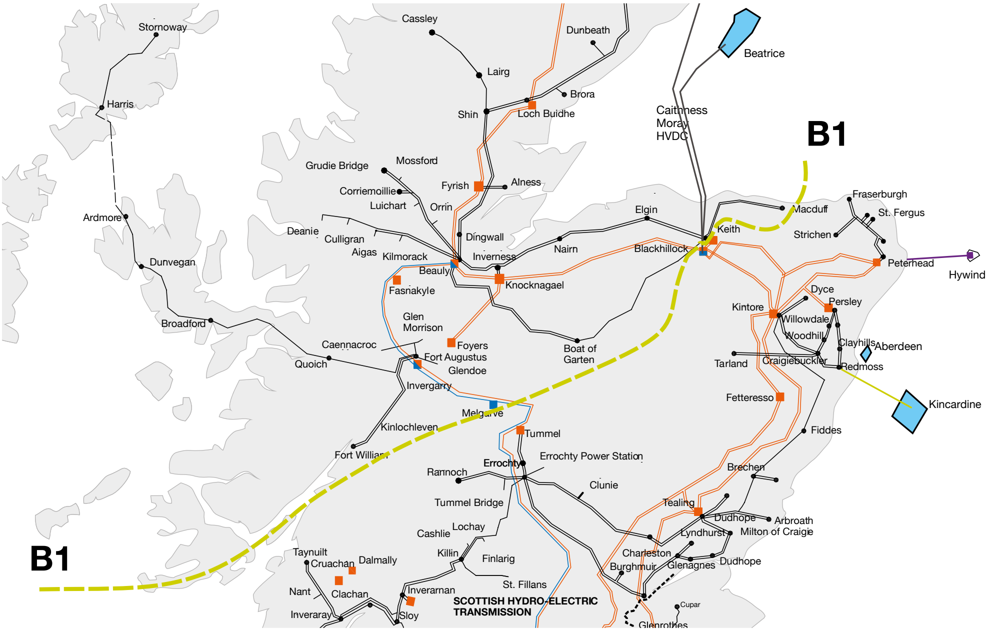
Boundary requirements and capability

Figure B0.2 above shows the projected boundary flows for B0 for the next 20 years. The boundary capability is limited to around 1.0 GW, following the completion of the Caithness–Moray reinforcement project in December 2018, due to a thermal constraint.

The power transfer through B0 is increasing due to the substantial growth of renewable generation north of the boundary. This generation is primarily onshore wind, with the prospect of significant marine generation resource in the Pentland Firth and Orkney waters in the longer term.

Boundary B1 – North West SHE Transmission

Figure B1.1
Geographic representation of boundary B1



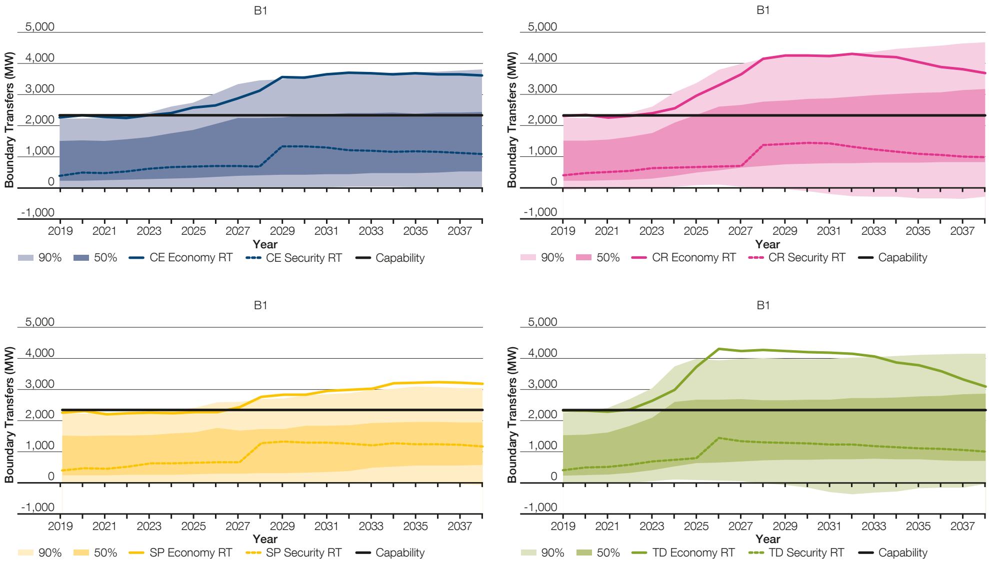
B1 crosses a 275kV double circuit, two 275/132kV auto-transformer circuits and a double circuit with one circuit at 400kV and the other at 275kV

Boundary B1 runs from the Moray coast near Macduff to the west coast near Oban, separating the north-west of Scotland from the southern and eastern regions.

The existing transmission infrastructure in this area comprises mostly 275kV and 132kV assets. The Caithness–Moray reinforcement project will increase the boundary capability allowing increased export in power across boundary B1.

Figure B1.2

Boundary flows and base capability for boundary B1



Boundary requirements and capability

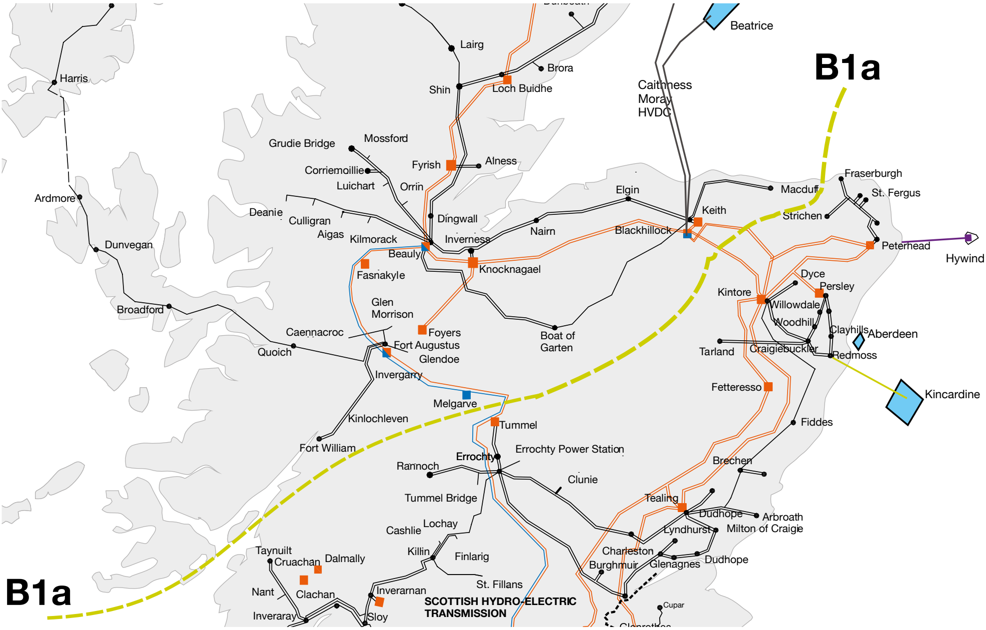
Figure B1.2 above shows the projected boundary flows for B1 for the next 20 years. The boundary capability is limited to around 2.3 GW, following the completion of the Caithness–Moray reinforcement project in December 2018, due to a thermal constraint.

New renewable generation connections north of the boundary are expected to result in a significant increase in export requirements across the boundary. All generation north of boundary B0 also lies behind boundary B1.

In all the scenarios, there is an increase in the power transfer through B1 due to the large volume of renewable generation connected to the north of this boundary. Although this is primarily onshore wind and hydro, there is the prospect of significant additional wind, wave and tidal generation resources being connected in the longer term. Contracted generation behind boundary B1 includes the renewable generation on the Western Isles, Orkney and the Shetland Isles as well as a considerable volume of large and small onshore wind developments. A large new pump storage generator is also planned in the Fort Augustus area. Some marine generation is also expected to connect in this region during the *ETYS* period. This is supplemented by existing generation, which comprises around 800 MW of hydro and 300 MW of pumped storage at Foyers.

Boundary B1a – North West 1a SHE Transmission

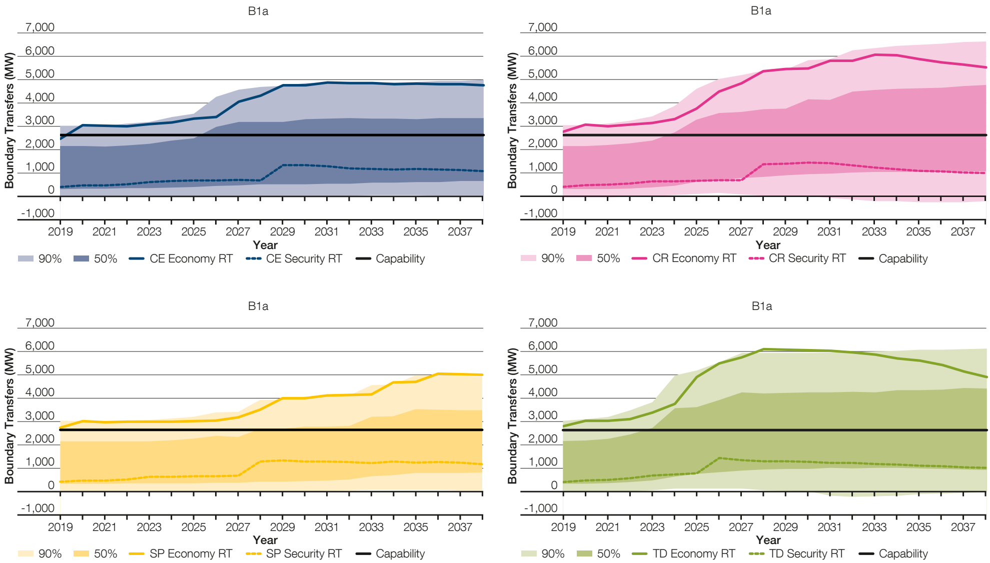
Figure B1a.1
Geographic representation of boundary B1a



B1a crosses two 275kV double circuits and a double circuit with one circuit at 400kV and the other at 275kV

Boundary B1a runs from the Moray coast near Macduff to the west coast near Oban, separating the north west of Scotland from the southern and eastern regions. High renewables output causes high transfers across this boundary. The difference from boundary B1 is that Blackhillock substation is north of the B1a boundary.

Figure B1a.2
Boundary flows and base capability for boundary B1a



Boundary requirements and capability

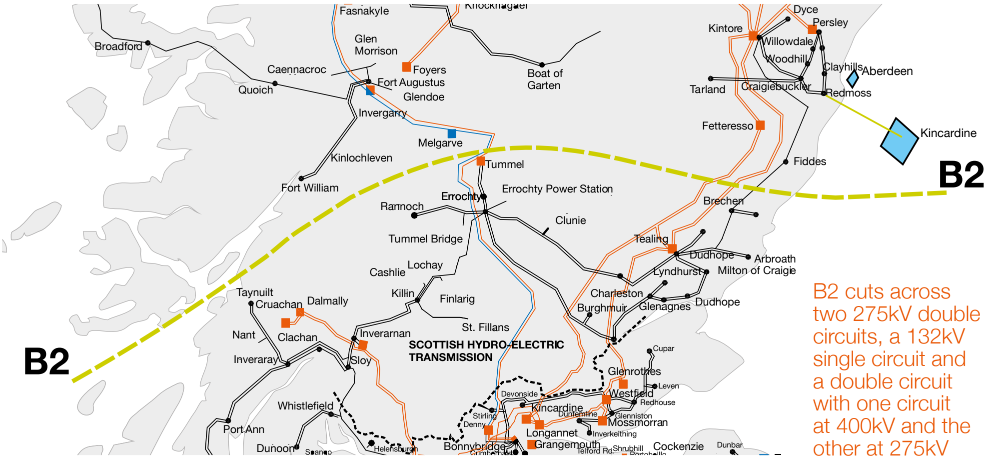
Figure B1a.2 above shows the projected boundary flows for B1a for the next 20 years. The boundary capability is currently limited to around 2.6 GW due to a thermal constraint.

New renewable generation connections north of the boundary are expected to result in a significant increase in export requirements across the boundary. All generation north of boundaries B0 and B1 also lies behind boundary B1a.

In all the *FES*, there is an increase in the power transfer through B1a due to the large volume of renewable generation connecting to the north of this boundary. Although this is primarily onshore wind and hydro, there is the prospect of significant additional wind, wave and tidal generation resources being connected in the longer term. Contracted generation behind boundary B1a includes the renewable generation on the Western Isles, Orkney and the Shetland Isles with a considerable volume of large and small onshore wind developments. A large new pump storage generator is also planned in the Fort Augustus area. Some marine generation is also expected to connect in this region during the *ETYS* period. This is supplemented by existing generation, which comprises around 800 MW of hydro and 300 MW of pumped storage at Foyers.

Boundary B2 – North to South SHE Transmission

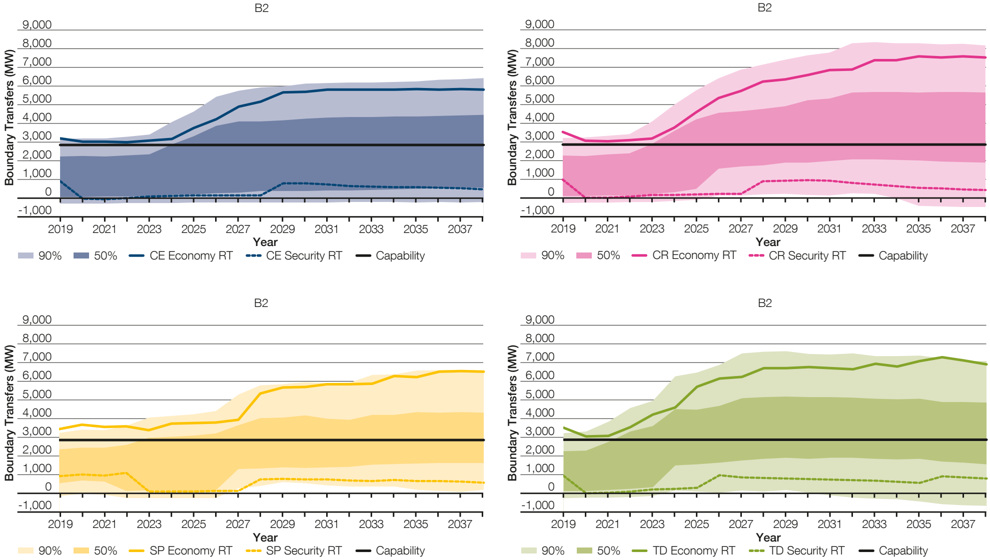
Figure B2.1
Geographic representation of boundary B2



Boundary B2 cuts across the Scottish mainland from the east coast between Aberdeen and Dundee to near Oban on the west coast. As a result it crosses all the main north-south transmission routes from the north of Scotland.

The generation behind boundary B2 includes both onshore and offshore wind, with the prospect of significant marine generation resource being connected in the longer term. There is also the potential for an additional pumped storage plant to be located in the Fort Augustus area. The thermal generation at Peterhead lies between boundaries B1 and B2, as do several offshore windfarms and the proposed future North Connect interconnector with Norway.

Figure B2.2
Boundary flows and base capability for boundary B2



Boundary requirements and capability

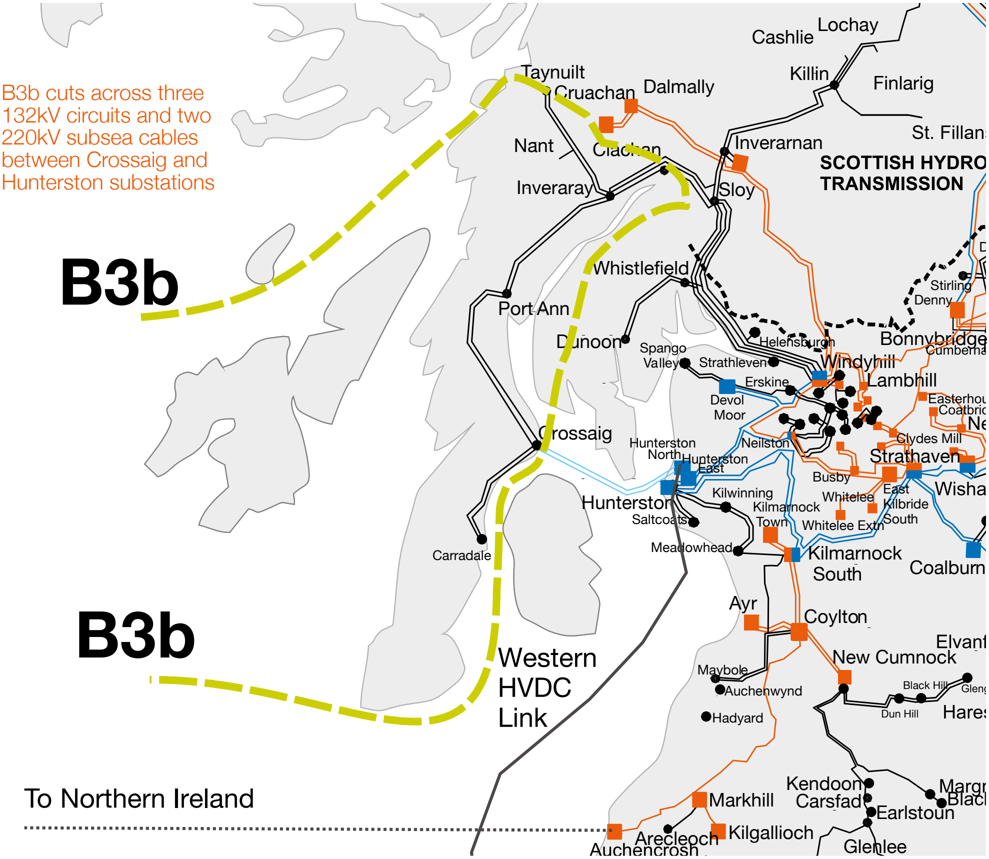
Figure B2.2 above shows the projected boundary flows for B2 for the next 20 years. The boundary capability is currently limited to around 2.9 GW due to a thermal constraint.

The potential future boundary transfers for boundary B2 are increasing at a significant rate because of the high volume of renewable generation to be connected to the north of the boundary.

The increase in the required transfer capability for this boundary across all generation scenarios indicates the strong potential need to reinforce the transmission system.

Boundary B3b – Kintyre and Argyll SHE Transmission

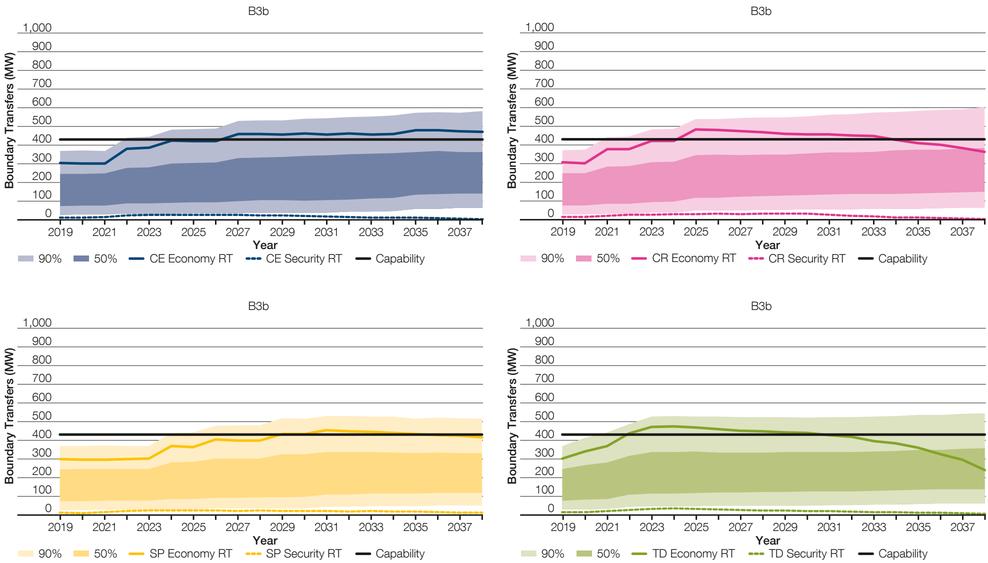
Figure B3b.1
Geographic representation of boundary B3b



Boundary B3b encompasses the Argyll and Kintyre peninsula, and boundary assessments are used to show limitations on the generation power flow out of the peninsula.

The generation within boundary B3b includes both onshore wind and hydro generation, with the prospect of further wind generation resource and the potential for marine generation being connected in the future, triggering the requirement for future reinforcement of this network.

Figure B3b.2
Boundary flows and base capability for boundary B3b



Boundary requirements and capability

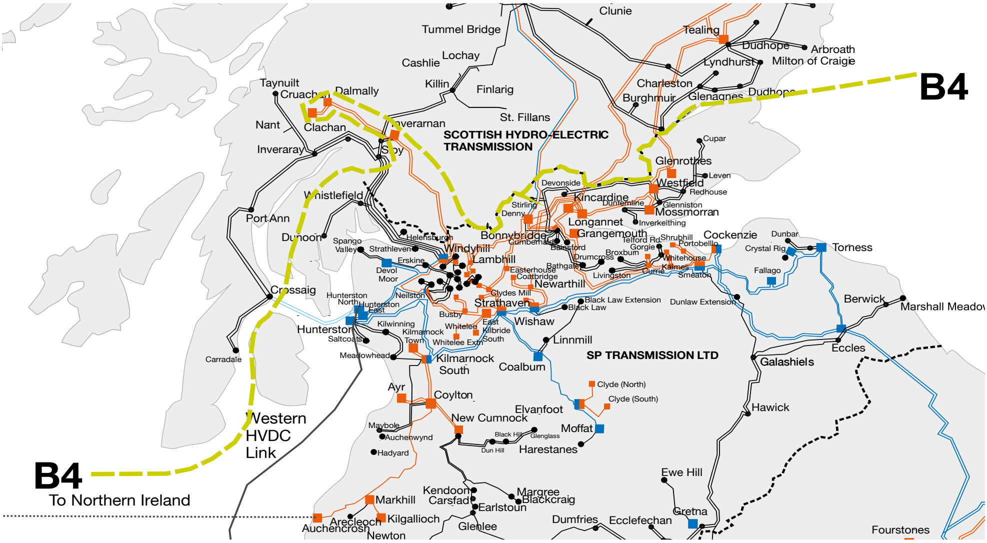
Figure B3b.2 above shows the projected boundary flows for B3b for the next 20 years. The boundary capability is currently limited to around 0.43 GW due to a thermal constraint.

In all of the *FES*, the power transfer across boundary B3b increases because of potential generation connecting within the boundary. This is primarily onshore wind generation, with the prospect of marine generation resource being connected as well.

The increase in the potential required transfer capability indicates the potential need to reinforce the transmission network across boundary B3b.

Boundary B4 – SHE Transmission to SP Transmission

Figure B4.1
Geographic representation of boundary B4

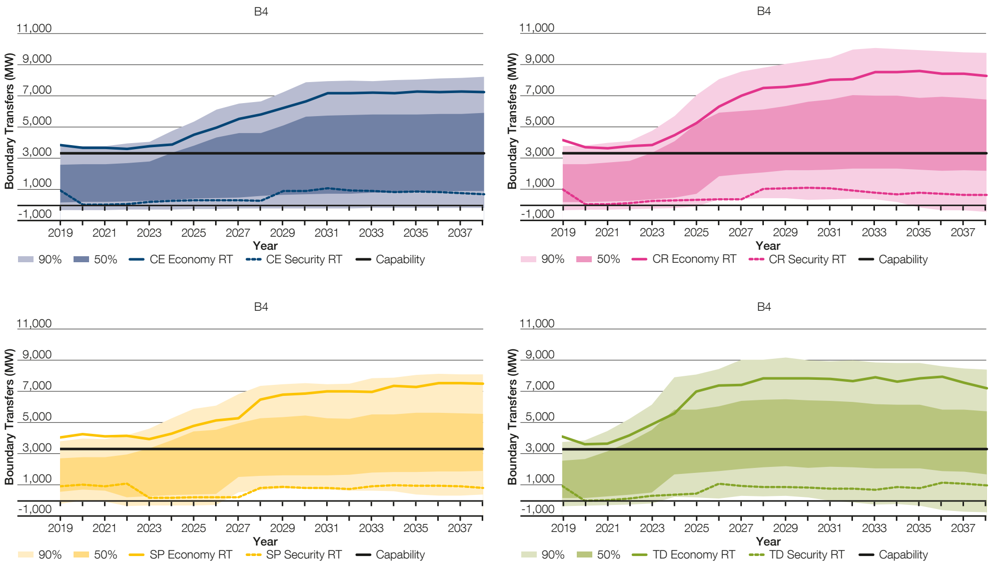


B4 cuts across two 275kV double circuits, two 132kV double circuits, two 275/132kV auto-transformer circuits, two 220kV subsea cables between Crossaig and Hunterston substations, and a double circuit with one circuit at 400kV and the other at 275kV

Boundary B4 separates the transmission network at the SP Transmission and SHE Transmission interface running from the Firth of Tay in the east to the north of the Isle of Arran in the west. With increasing generation and potential interconnectors in the SHE Transmission area for all scenarios, the required transfer across boundary B4 is expected to increase significantly over the *ETYS* period.

The prospective generation behind boundary B4 includes around 2.7 GW of offshore wind from Rounds 1-3 and Scottish territorial waters located off the coast of Scotland.

Figure B4.2
Boundary flows and base capability for boundary B4



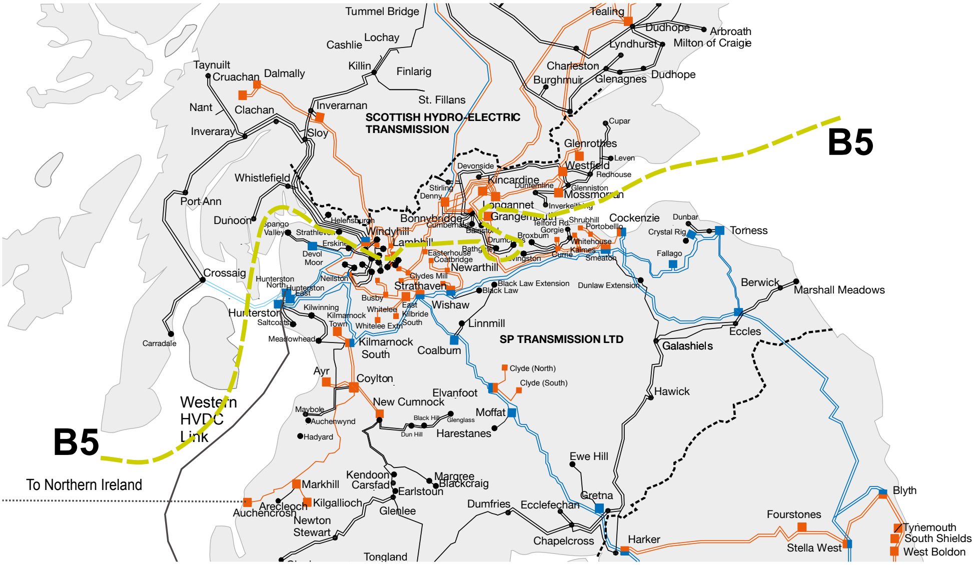
Boundary requirements and capability

Figure B4.2 above shows the projected boundary flows for B4 for the next 20 years. The current boundary capability is limited to around 3.3 GW due to a thermal constraint.

In all of the *FES*, the power transfer through boundary B4 increases because of the significant volumes of generation connecting north of the boundary, including all generation above boundaries B0, B1, B1a, B2 and B3b. This is primarily onshore and offshore wind generation, with the prospect of significant marine generation resource being connected in the longer term.

Boundary B5 – North to South SP Transmission

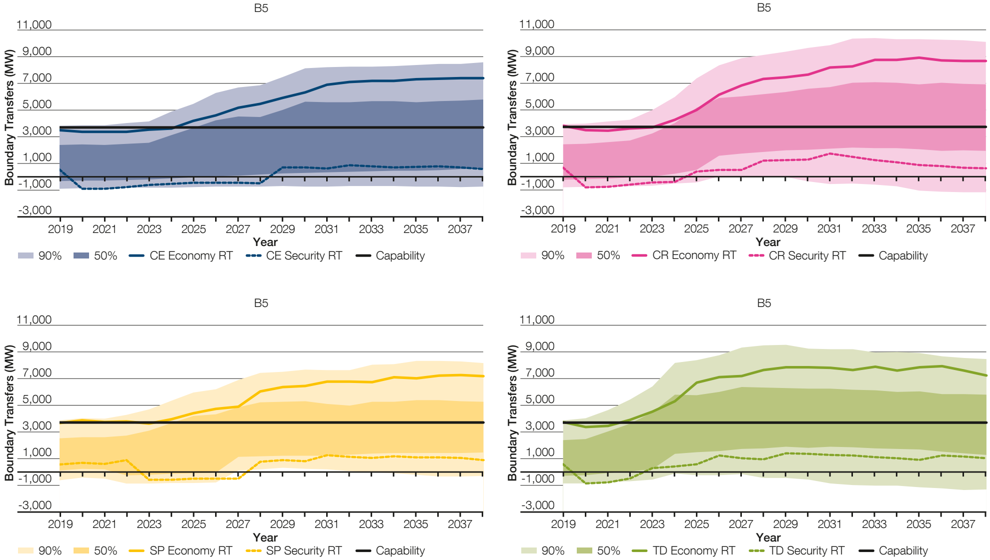
Figure B5.1
Geographic representation of boundary B5



B5 cuts across three 275kV double circuits and a double circuit with one circuit at 400kV and the other at 275kV. The Kintyre–Hunterston subsea link provides two additional circuits crossing B5

Boundary B5 is internal to the SP Transmission system and runs from the Firth of Clyde in the west to the Firth of Forth in the east. The generating station at Cruachan is located to the north of boundary B5, together with the demand groups served from Windyhill, Lambhill, Bonnybridge, Mossmorran and Westfield 275kV substations.

Figure B5.2
Boundary flows and base capability for boundary B5



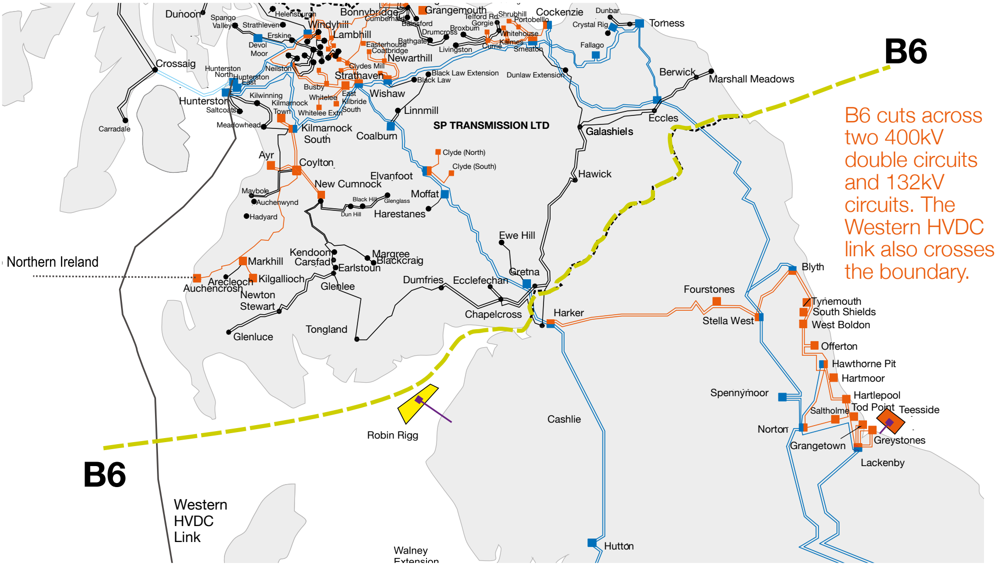
Boundary requirements and capability

Figure B5.2 above shows the projected boundary flows for B5 for the next 20 years. The capability of the boundary is presently limited by voltage constraints to around 3.7 GW.

In all of the *FES*, the power transfer through boundary B5 increases because of the significant volumes of generation connecting north of the boundary, including all generation above boundaries B0, B1, B2 and B4. This is primarily onshore and offshore wind generation.

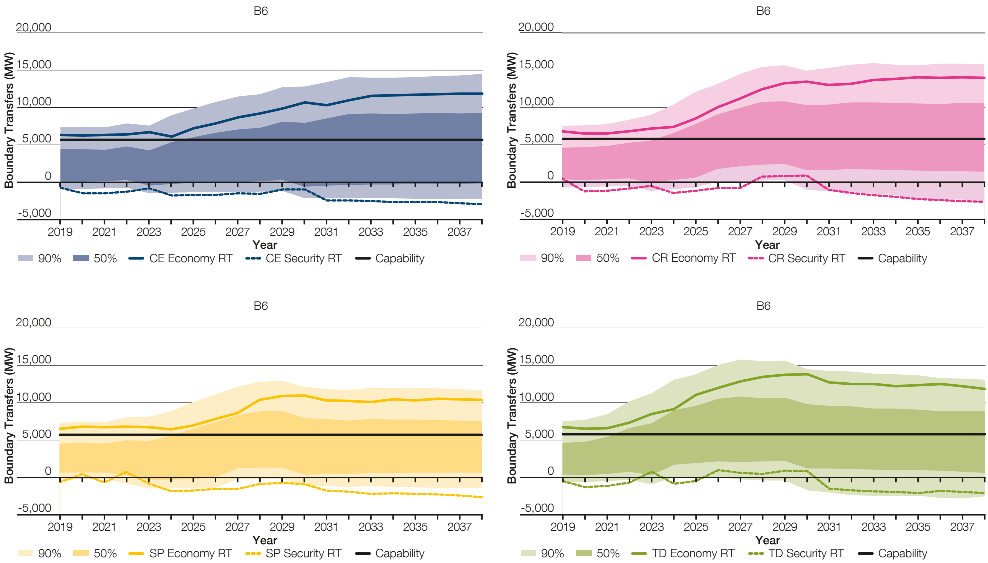
Boundary B6 – SP Transmission to NGET

Figure B6.1
Geographic representation of boundary B6



Boundary B6 separates the SP Transmission and the National Grid Electricity Transmission (NGET) systems. Scotland contains significantly more installed generation capacity than demand, increasingly from wind farms. Peak power flow requirements are typically from north to south at times of high renewable generation output.

Figure B6.2
Boundary flows and base capability for boundary B6



Boundary requirements and capability

Figure B6.2 above shows the projected boundary power flows crossing B6 for the next 20 years. The boundary capability has increased to 5.7 GW compared to last year due to the addition of the new Western HVDC circuit and upgrade of cables at Torness. The limit to the boundary capability now is a post-fault load rating of transformers at Harker.

Across all the *FES*, there is an increase in the required export capability from Scotland to England due to the connection of additional generation in Scotland, primarily onshore and offshore wind. This generation increase is partially offset by the expected closure of nuclear plants, the timing of which varies in each scenario.

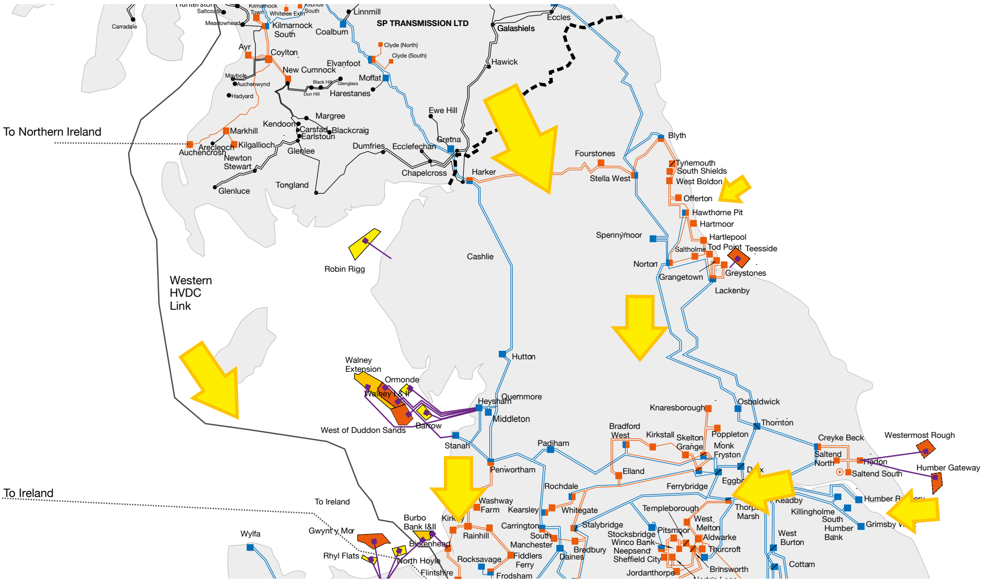
With the *FES* including many wind farms in Scotland, the spread of boundary power flows is very wide due to the intermittent nature of wind. With low generation output in Scotland it is credible to have power flowing from south to north feeding Scottish demand. The magnitude of the south to north power flows is low compared to those in the opposite direction so network capability should be sufficient to support those conditions. Some conventional synchronous generation must stay in Scotland to maintain year-round secure system operation.

3.5 Network capability and requirements by region – The North of England boundaries

Introduction

The North of England transmission region includes the transmission network between the Scottish border and the north Midlands. This includes the upper north boundaries B7, B7a and B8. The figure below shows likely power flow directions when it is windy.

Figure NE.1
North of England transmission network



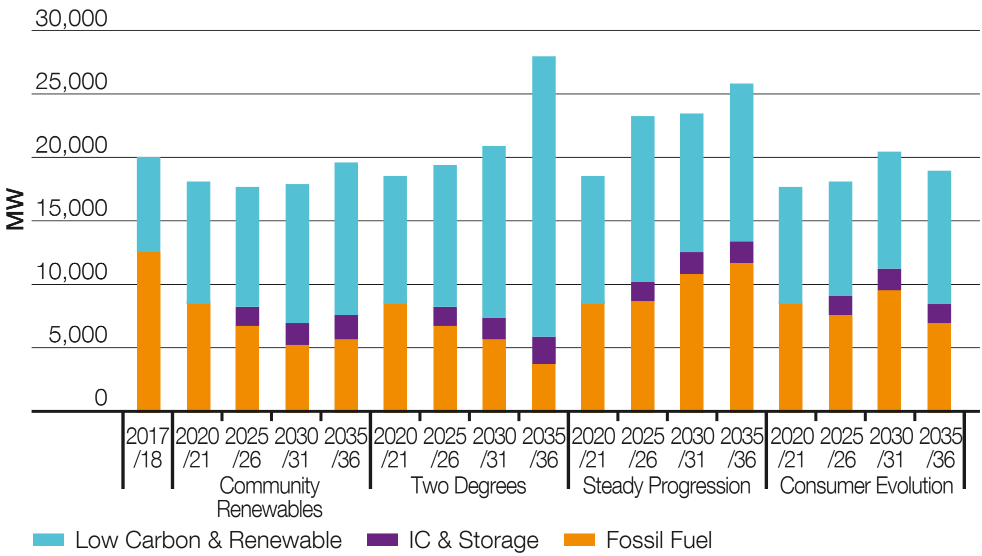
Primary challenge statement:

The connection of large amounts of new generation in Scotland and the north, most of which is intermittent renewables, will cause overloading in the northern transmission network unless appropriate reinforcements are in place. Future power transfer requirements could be more than double compared to what they are today.

Regional drivers

The *FES* suggest the northern transmission region could see a range of changes as shown in the graph below (Figure NE.2). All four scenarios suggest growth in low carbon and renewable generation in addition to new storage and interconnector developments. The connected fossil fuel generation could see either sustained decline or decline followed by growth depending on which way the scenarios develop. Large connections could cause network issues if connected to the north of the region.

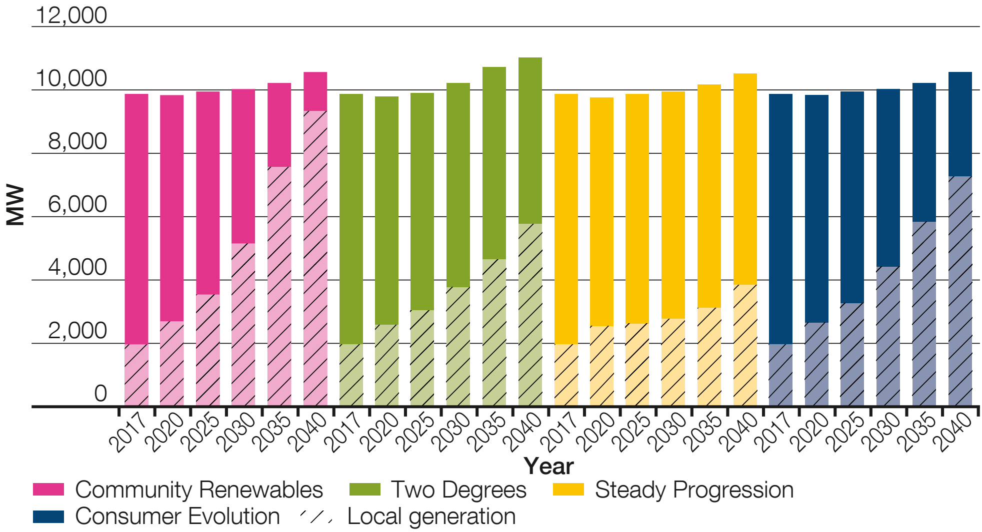
Figure NE.2
Generation capacity mix scenarios for the North of England



The gross demand in the region, as shown in Figure NE.3, could reasonably be expected to increase as can be seen for all scenarios. The amount of embedded local generation is also expected to increase, so the net demand seen by the transmission network could significantly reduce and even become net generation.

In a highly decentralised scenario like **Community Renewables**, local generation capacity connected at the distribution level in this northern region could reach up to more than 20 GW by 2040. Of that capacity, a typical total embedded generation output on average might be around 9 GW. This will vary depending on factors like wind speeds, and how other local generators decide to participate in the market.

Figure NE.3
Gross demand scenarios for the North of England



Presently, most of the northern transmission network is oriented for north-south power flows with connections for demand and generation along the way. At times of high wind generation the power flow will mostly be from north to south, with power coming from both internal boundary generation and generation further north in Scotland. When most of this area and Scotland is generating power, the transmission capability can be highly stressed. The loss of one of the north to south routes can have a highly undesirable impact on the remaining circuits.

The highly variable nature of power flows in the north presents challenges to voltage management, and therefore automatic reactive power control switching is utilised. This helps to manage the significant voltage drop due to reactive power demands which arise at times of high levels of power flow on long circuits. Operational reactive switching solutions are also used to manage light loading conditions when the voltage can rise to unacceptable levels. The region's voltage is also investigated in low demand summer hours, further details can be found in the case study presented at the end of the chapter.

The high concentration of large conventional generators around Humber and South Yorkshire means that system configuration can be limited by high fault levels. Therefore, some potential network capability restrictions in the north can be due to the inability to configure the network as desired due to fault level concerns.

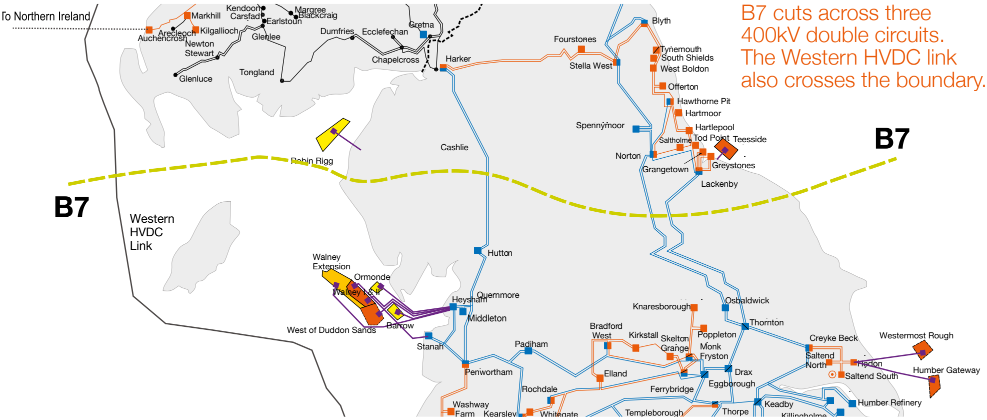
As the potential future requirement to transfer more power from Scotland to England increases, B7 and B7a are likely to reach their capability limits and may need network reinforcement. The potential future restrictions to be overcome across B7 and B7a are summarised:

- Limitation on power transfer out of North East England (boundary B7) is caused by voltage limitation for a fault on the double circuit between Hutton–Middleton–Penwortham.
- At high power transfer, thermal limitations occur on a number of circuits within the North East 275kV ring.
- Limitation on power transfer from Cumbria to Lancashire (boundary B7a) occurs due to thermal limitation at Padiham–Penwortham circuit.

The need for network reinforcement to address the above mentioned potential capability issues will be evaluated in the *NOA 2018/19* CBA. Following the evaluation, the preferred reinforcements for the North of England region will be recommended.

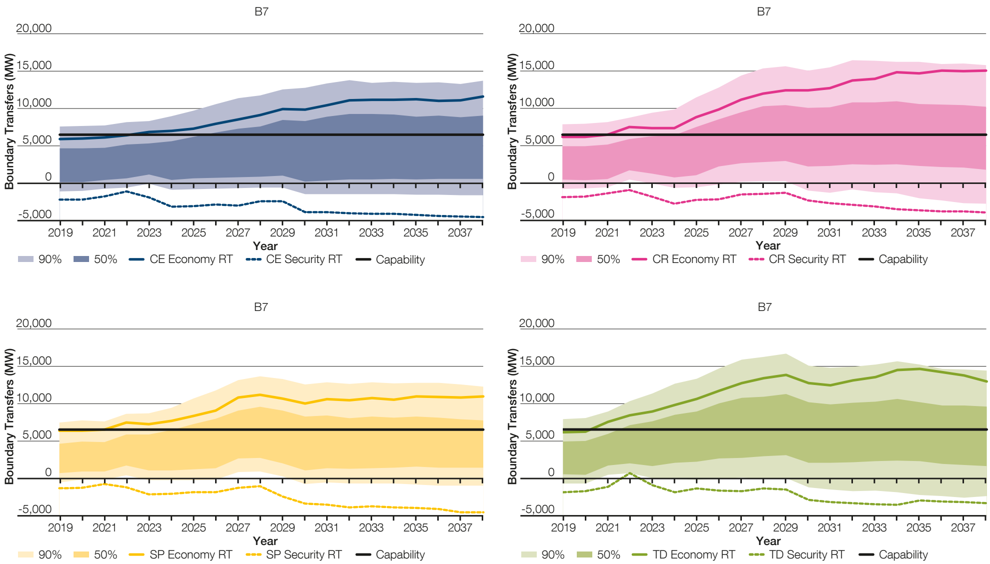
Boundary B7 – Upper North of England

Figure B7.1
Geographic representation of boundary B7



Boundary B7 bisects England south of Teesside. The area between B6 and B7 has been traditionally an exporting area, and constrained by the power flowing through the region from Scotland towards the south with the generation surplus from this area added.

Figure B7.2
Boundary flows and base capability for boundary B7



Boundary requirements and capability

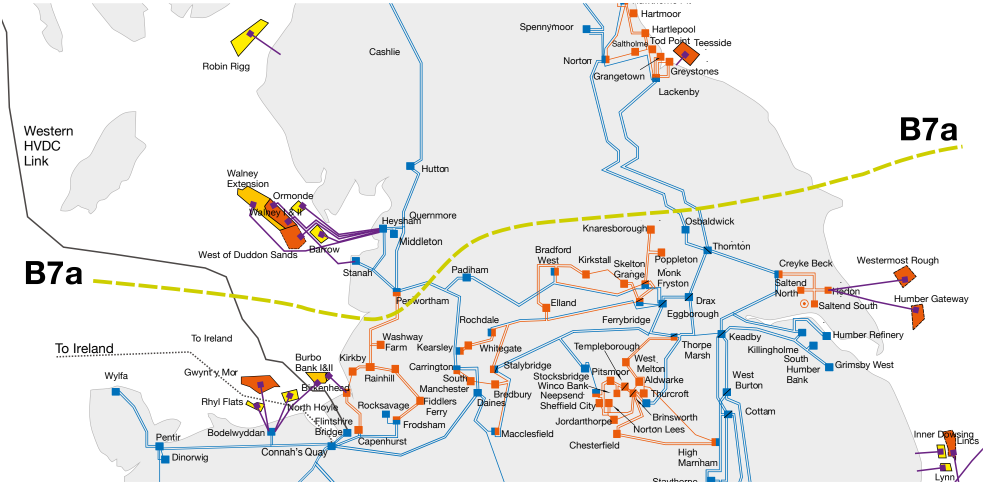
Figure B7.2 above shows the projected boundary power flows crossing B7 for the next 20 years. The boundary capability has increased to 6.5 GW compared to last year due to the addition of the new Western HVDC circuit. The limit to the boundary capability now is post-fault voltage depression close to the 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. This suggests a strong need for network development to manage the increasing power flows. Power flow requirements show a peak within ten years meaning development options will need to be delivered quickly.

The *FES* show a lot of wind farms in the north, meaning the spread of boundary power flows is very wide due to the intermittent nature of wind. With low generation output in the north it is credible to have power flowing from south to north feeding northern demand. The magnitude of the south to north power flows is low compared to those in the opposite direction so network capability should be sufficient to support those conditions.

Boundary B7a – Upper North of England

Figure B7a.1
Geographic representation of boundary B7a

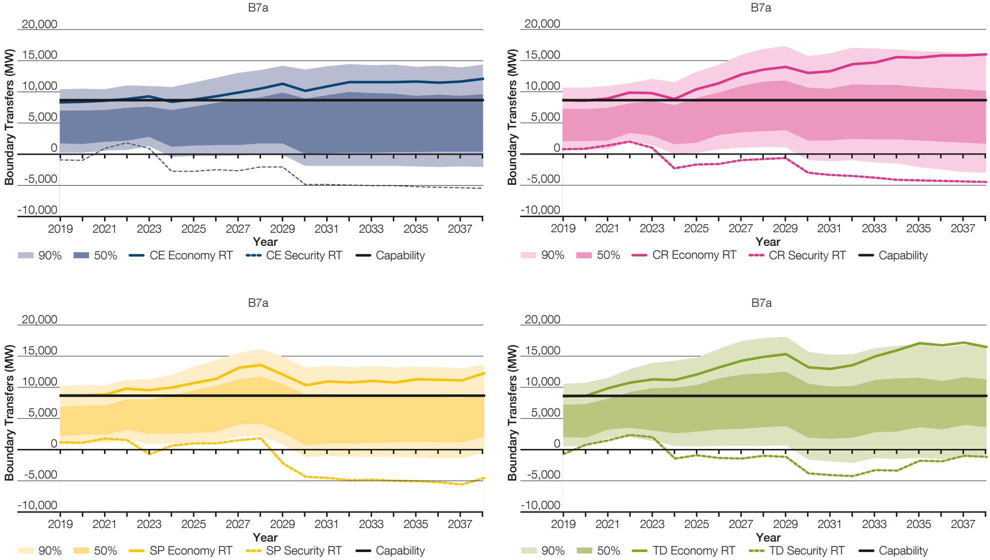


B7a cuts across three 400kV double circuits and one 275kV circuit. The Western HVDC link also crosses the boundary.

Boundary B7a bisects England south of Teesside and into the Mersey Ring area. It is used to capture network restrictions on the circuits feeding down through Liverpool, Manchester and Leeds.

Figure B7a.2

Boundary flows and base capability for boundary B7a



Boundary requirements and capability

Figure B7a.2 above shows the projected boundary power flows crossing B7a for the next 20 years. The boundary capability has increased to 8.7 GW compared to last year due to 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.

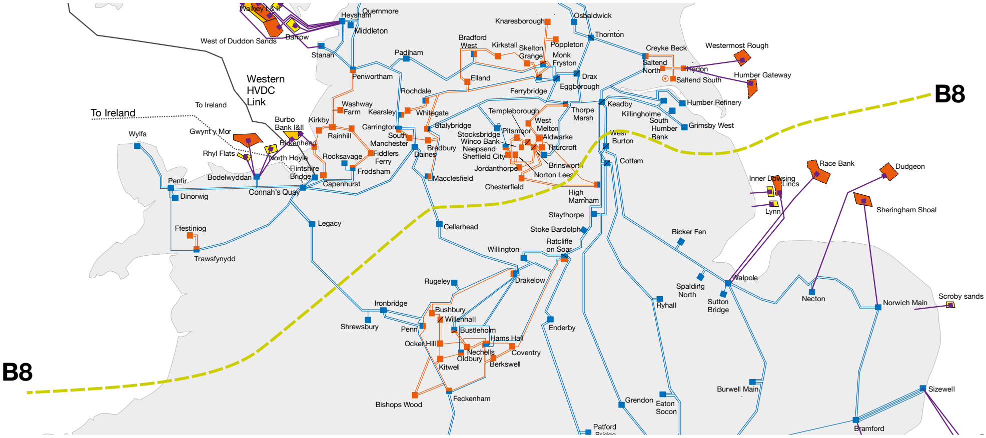
For all the *FES*, the SQSS Economy required transfer and expected power flows grow to well beyond the present boundary capability. This suggests a strong need for network development to manage the increasing power flows. There is a peak in power flow requirements within ten years, meaning development options will need to be done quickly.

Based on the *FES*, high levels of intermittent generation will be connecting to the north of the boundary, leading to a broad range of boundary power flows. With low northern generation output, it is credible to have power flowing from south to north feeding northern demand. The magnitude of the south to north power flows is low compared to those in the opposite direction so network capability should be sufficient to support those conditions.

Boundary B8 – North of England to Midlands

Figure B8.1

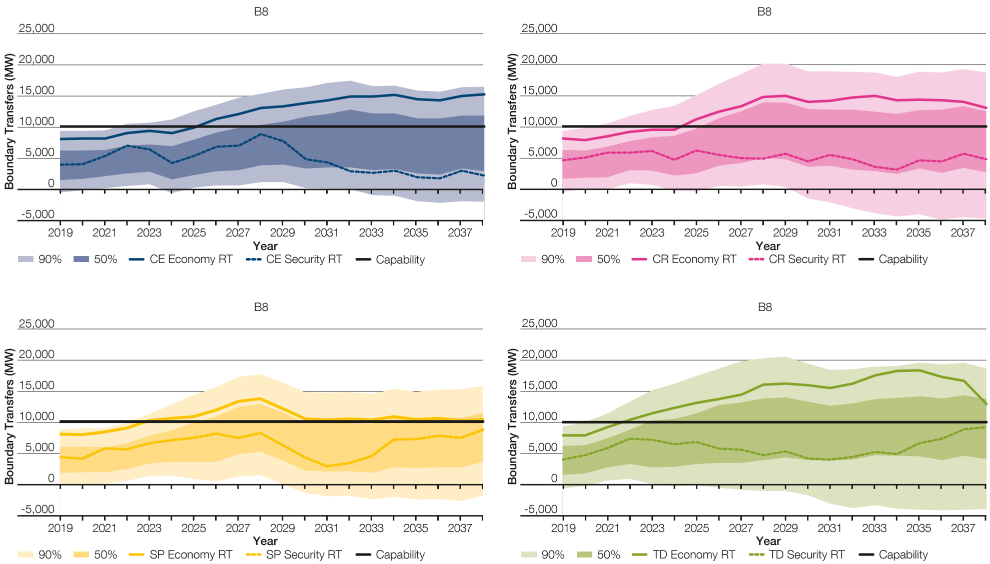
Geographic representation of boundary B8



B8 cuts across four 400kV double circuits and a limited 275kV connection to South Yorkshire.

The North to Midlands boundary B8 is one of the wider boundaries that intersects the centre of GB, separating the northern generation zones, including Scotland, Northern England and North Wales, from the Midlands and southern demand centres.

Figure B8.2
Boundary flows and base capability for boundary B8



Boundary requirements and capability

Figure B8.2 above shows the projected boundary power flows crossing B8 for the next 20 years. The boundary capability is limited to 10 GW 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. This suggests a need for network development to manage the increasing power flows. Some of the *FES* show a peak in power flow requirements within ten years, meaning development options could need to be done quickly.

Based on the *FES*, high levels of intermittent generation will be connecting to the north of the boundary, leading to a broad range of boundary power flows. With low northern generation output, it is credible to have power flowing from south to north feeding northern demand, although this is not significant until more than ten years into the future. The magnitude of the south to north power flows is low compared to those in the opposite direction so network capability should be sufficient to support those conditions.

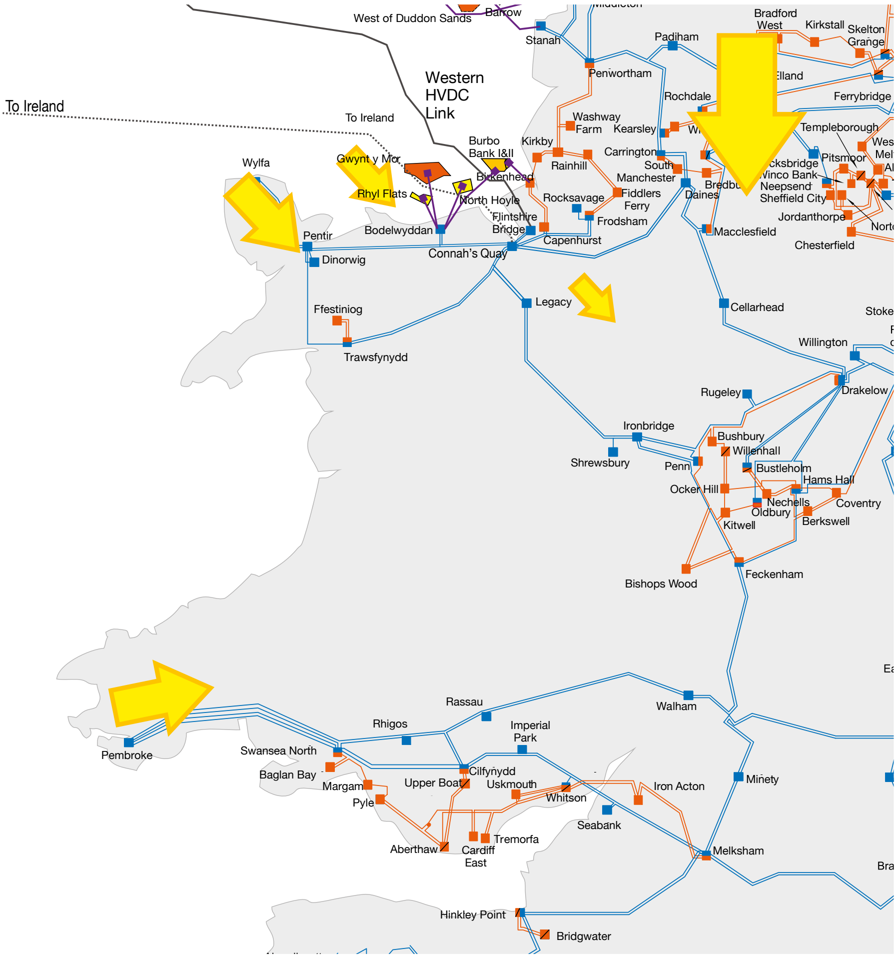
3.6 Network capability and requirements by region – Wales and the Midlands boundaries

Introduction

The Western transmission region includes boundaries in Wales and the Midlands. The figure below shows likely power flow directions in the years to come up to 2028.

The arrows in the diagram illustrate power flow directions and are approximately scaled relative to the winter peak flows.

Figure WM.1
Wales and Midlands transmission network



Primary challenge statement:

Future nuclear generation combined with wind and biomass generation, connecting in North Wales, has the potential to drive increased power flows eastward into the Midlands where power plant closures are set to occur and demand is set to remain fairly high.

Regional drivers

By 2035, in all the *FES* the total amount of generation in the region remains approximately as present or shows slight reduction (See Fig WM.2). At present, this region has significant levels of fossil fuel (about 19 GW), most of which is set to close and be replaced by a combination of low carbon technologies, interconnectors and storage.

Figure WM.2
Generation capacity mix scenarios for Wales and the Midlands

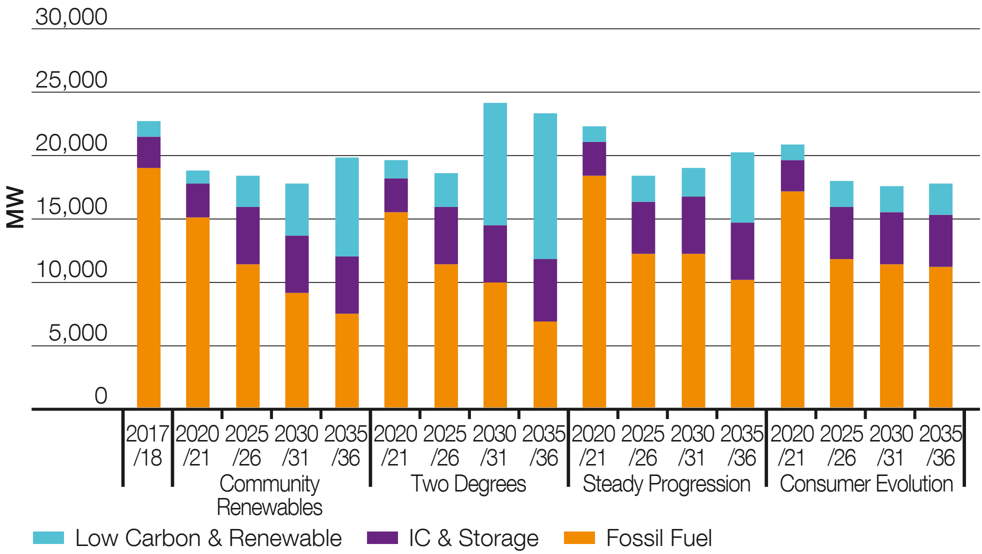
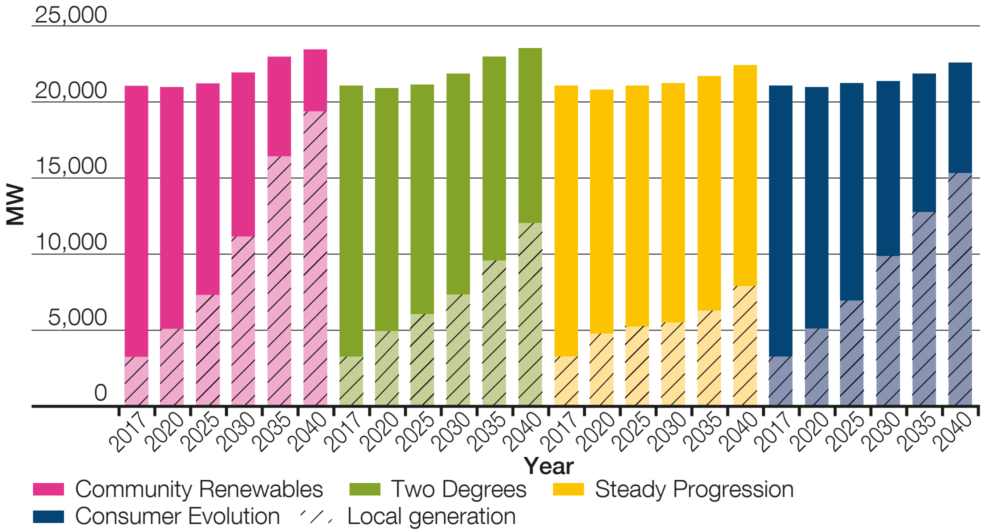


Figure WM.3 shows that the gross demand as seen from the transmission network in the region will increase across all scenarios. This is driven by the adoption of technologies such as electric vehicles, heat pumps and embedded storage.

In a highly decentralised scenario like **Community Renewables**, local generation capacity connected at the distribution level in this western region could reach up to more than 50 GW by 2040. Of that capacity, a typical embedded generation output on average might be around 19 GW. This will vary depending on factors like wind speeds, and how other local generators decide to participate in the market.

Figure WM.3
Gross demand scenarios for Wales and the Midlands



The majority of expected westerly increases in generation are from low carbon technologies, embedded generation and interconnectors. Most of this is expected in the Wales region.

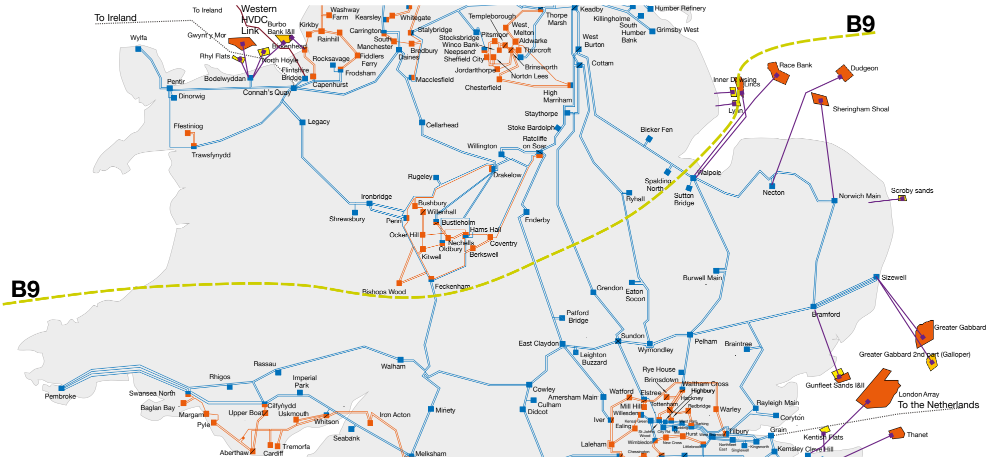
The transmission network in North Wales consists of only nine 400kV double circuits with limited capacity which are likely to be stressed to their capability limits if much of the new future generation connects. The potential limitation on future power exports are covered by boundaries B9, NW1, NW2, and NW3.

The *NOA 2018/19* will assess the above mentioned potential scenarios and accordingly recommend preferred reinforcements for this Western transmission region.

Boundary B9 – Midlands to South of England

Figure B9.1

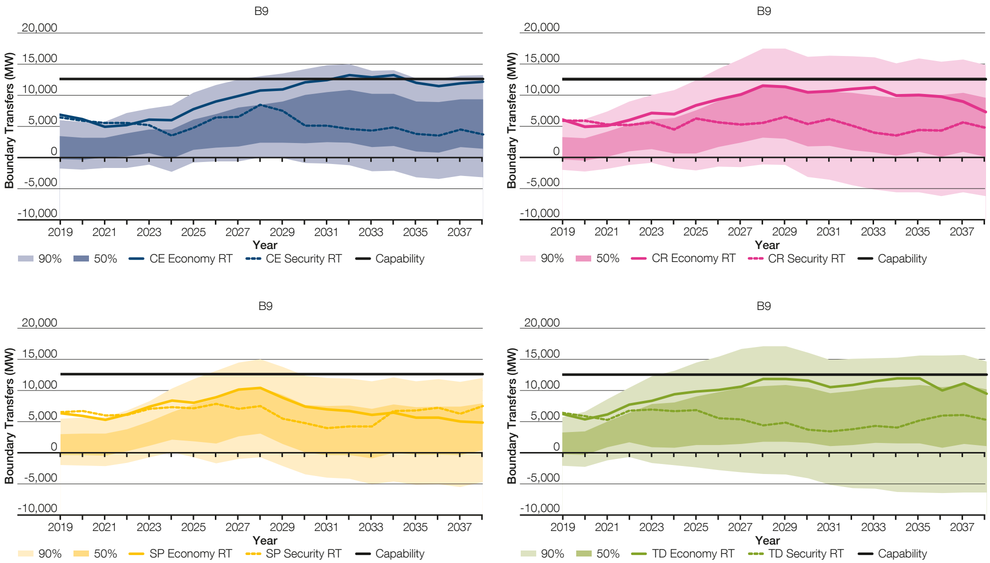
Geographic representation of boundary B9



B9 cuts across five major 400kV double circuits transporting power over a long distance

The Midlands to South of England boundary B9 separates the northern generation zones and the southern demand centres. Developments in the East Coast and the East Anglia regions, such as the locations of offshore wind generation connection and the network infrastructure requirements, will affect the transfer requirements and capability of boundary B9.

Figure B9.2
Boundary flows and base capability for boundary B9



Boundary requirements and capability

Figure B9.2 above shows the projected boundary power flows crossing B9 for the next 20 years. The boundary capability is voltage limited at 12.6 GW for a fault on the double circuit Walpole–Spalding North–Bicker Fenn which leads to low voltage at Feckenham substation.

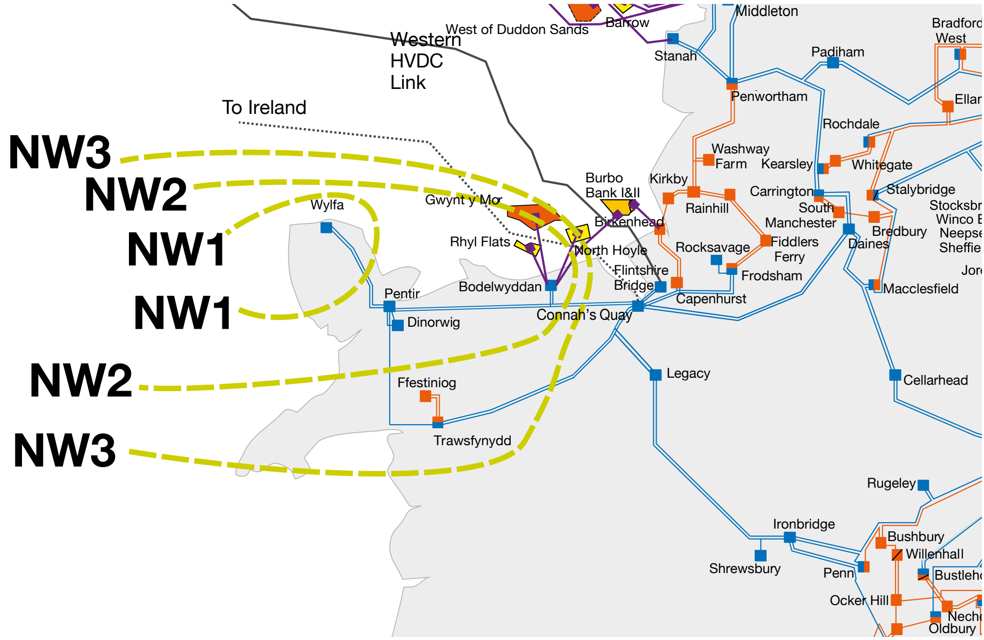
Across all the *FES*, the expected power flows grow beyond the present boundary capability. But from the diagram above it is clear that the flows beyond the capability are not significant for **Community Renewables** and **Two Degrees** scenarios and even less significant in **Steady Progression** and **Consumer Evolution** scenarios. It is unlikely to have any network development required to manage the flows through B9.

North Wales – overview

The onshore network in North Wales comprises a 400kV circuit ring that connects Pentir, Connah's Quay and Trawsfynydd substations. A 400kV double circuit spur crossing the Menai Strait and running the length of Anglesey connects the now decommissioned nuclear power station at Wylfa to Pentir. A short 400kV double circuit cable spur from Pentir connects Dinorwig pumped storage power station.

In addition, a 275kV spur traverses north of Trawsfynydd to Ffestiniog pumped storage power station. Most of these circuits are of double circuit tower construction. However, Pentir and Trawsfynydd within the Snowdonia National Park are connected by a single 400kV circuit, which is the main limiting factor for capacity in this area. The area is studied by analysing the local boundaries NW (North Wales) 1 to 3.

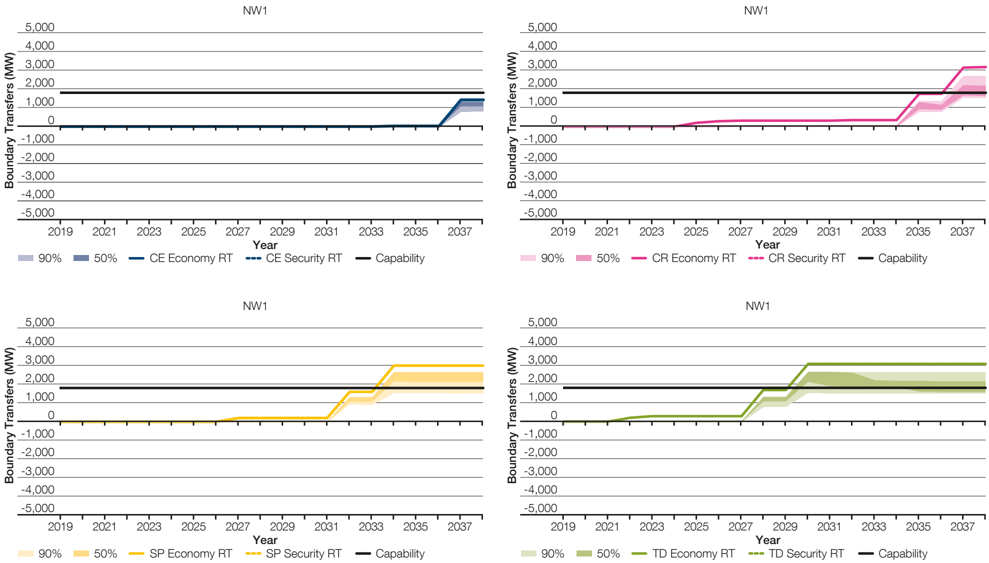
Figure NW
Geographic representation of North Wales boundaries



- NW1 is a local boundary crossing a 400kV double circuit.
- NW2 is a local boundary crossing a 400kV double circuit and a 400kV single circuit.
- NW3 a local boundary crossing a pair of 400kV double circuits.

Boundary NW1 – Anglesey

Figure NW1
Boundary flows and base capability for boundary NW1



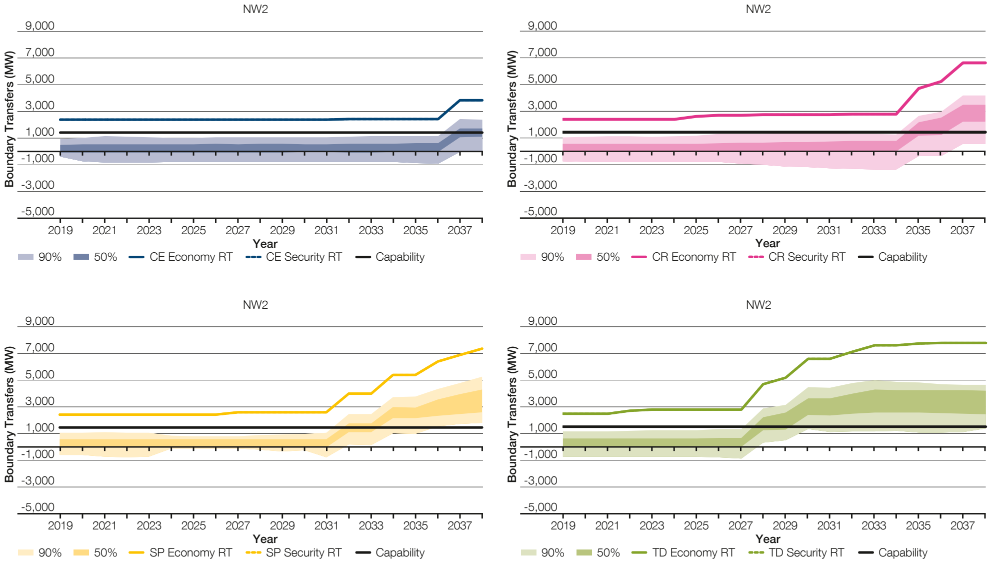
Boundary requirements and capability

Figure NW1 above shows the projected boundary power flows crossing NW1 for the next 20 years. The boundary transfer capability is limited by the infrequent infeed loss risk criterion set in the SQSS, which is currently 1.8 GW. If the infrequent infeed loss risk is exceeded, the boundary will need to be reinforced by adding a new transmission route across the boundary.

Across all scenarios, except **Consumer Evolution**, the SQSS Economy required transfer and expected power flows grow beyond the present boundary capability. All the scenarios show similar requirements until 2027, where they diverge. The only large scale generation expected behind NW1 is a new nuclear power station which appears in the background in two stages and within different time horizons.

Boundary NW2 – Anglesey and Caernarvonshire

Figure NW2
Boundary flows and base capability for boundary NW2



Boundary requirements and capability

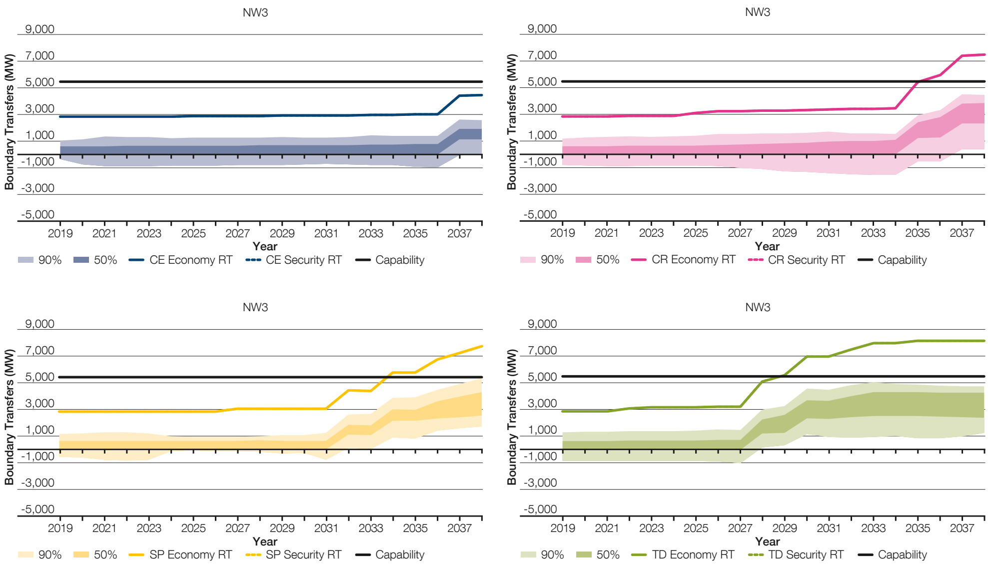
Figure NW2 above shows the projected boundary power flows crossing NW2 for the next 20 years. The boundary capability is thermally limited at 1.4 GW for a double circuit fault on the Connah's Quay–Bodelwyddan–Pentir circuits which overloads the Pentir–Trawsfynydd single circuit.

Across all the *FES*, the SQSS Economy required transfer and expected power flows grow beyond the present boundary capability. The scenarios show similar requirements until 2027 where they diverge due to different assumptions of connection time and dispatching of potential interconnector, wind and nuclear generation behind this boundary.

Boundary NW3 – Anglesey and Caernarvonshire and Merionethshire

Figure NW3

Boundary flows and base capability for boundary NW3



Boundary requirements and capability

Figure NW3 above shows the projected boundary power flows crossing NW3 for the next 20 years. The boundary capability is thermally limited at 5.5 GW for a double circuit fault on the Trawsfynydd–Treuddyn–Connah's Quay Tee circuits which overloads the Connah's Quay–Bodelwyddan–Pentir Tee circuits.

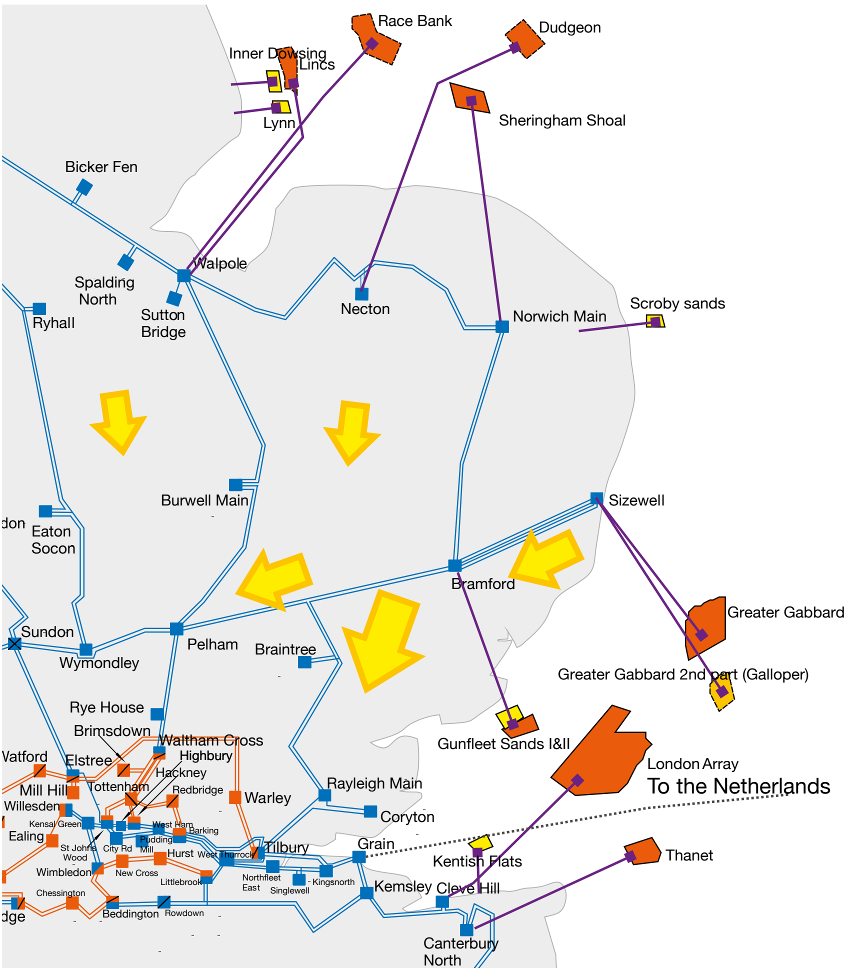
Across all scenarios except **Consumer Evolution**, the SQSS Economy required transfer and expected power flows grow beyond the present boundary capability. The scenarios show a similar requirement until 2027 where they diverge due to different assumptions of connection time and dispatching of potential interconnector, wind and nuclear generation behind this boundary.

3.7 Network capability and requirements by region – The East of England boundaries

Introduction

The East of England region includes the counties of Norfolk and Suffolk. The figure below shows likely power flow directions in the years to come up to 2027. The arrows in the diagram illustrate power flow directions and are approximately scaled relative to the winter peak flows.

Figure EE.1
East of England transmission network



Primary challenge statement:

With the large amount of generation contracted to be connected in the area, predominantly offshore wind and nuclear, supply may significantly exceed the local demand which could cause heavy circuit loading, voltage depressions and stability issues.

Regional drivers

The *FES* highlight that generation between 7 and 20 GW could be expected to connect within this region by 2035 as shown in Figure EE.2. All scenarios show that, in the years to come, large amounts of low carbon generation, predominantly wind, can be expected to connect. Fossil-fuel generation can also be expected to connect within this region. The total generation in all the scenarios will exceed the local demand; thus East Anglia will be a power exporting region.

Figure EE.2
Generation capacity mix scenarios for the East of England

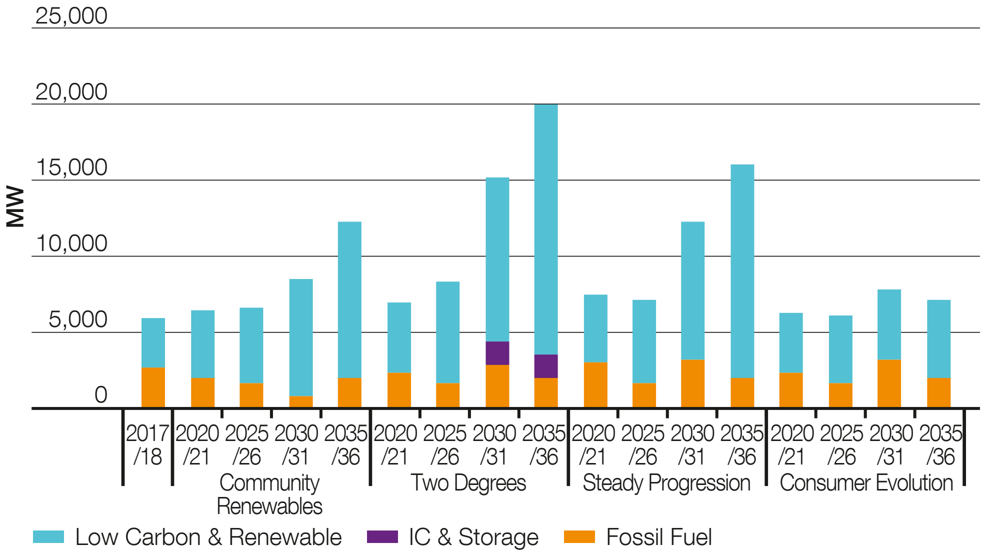
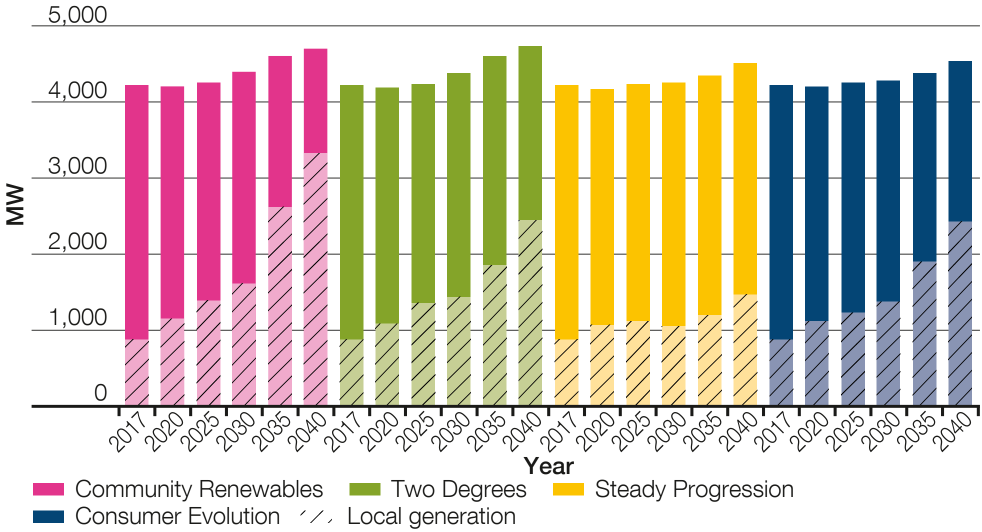


Figure EE.3
Gross demand scenarios for the East of England



Peak gross demand in the Eastern region is expected to remain less than 5 GW by 2040. Figure EE.3 shows snapshots of the peak gross demand for the East of England across the four different scenarios. In a highly decentralised scenario like **Community Renewables**, local generation capacity connected at the distribution level in this eastern region could reach more than 13 GW by 2040. Of that capacity, a typical embedded generation output on average might be around 3 GW. This will vary depending on factors like wind speeds, and how other local generators decide to participate in the market.

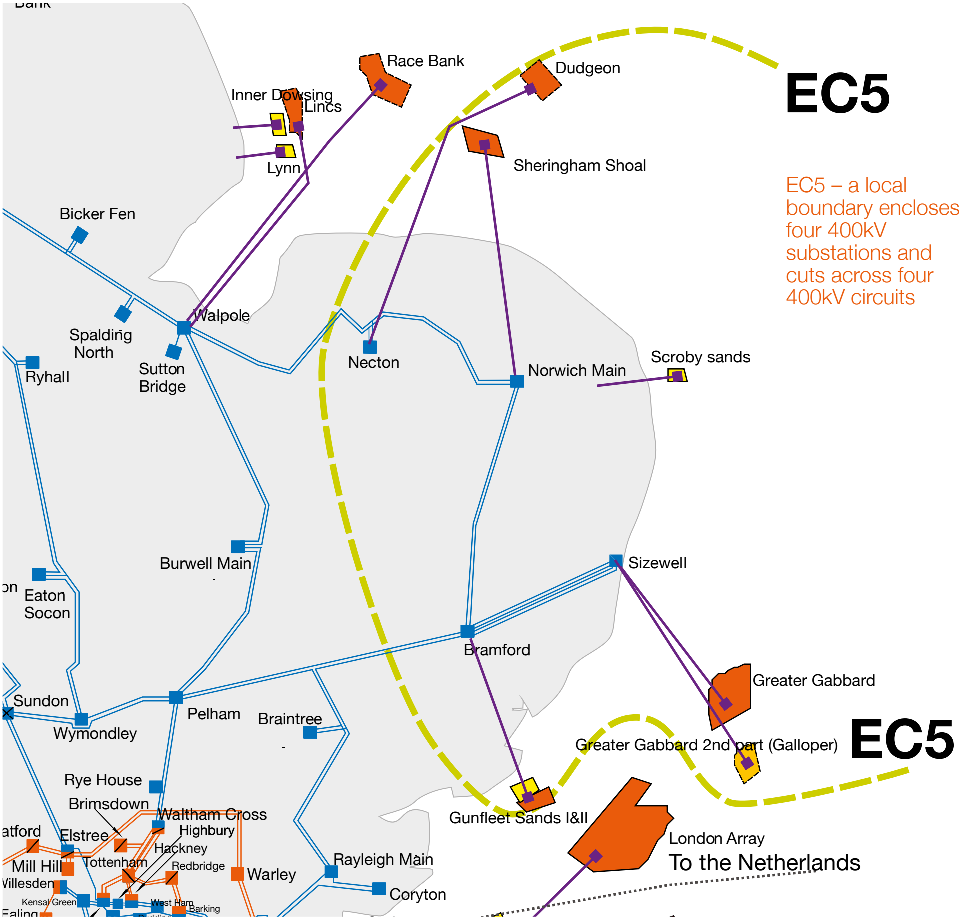
The East Anglia transmission network to which the *FES* generation will connect has eight 400kV double circuits. The potential future increase in generation within this region could force the network to experience very heavy circuit loading, stability issues and voltage depressions – for power transfer scenarios from East Anglia to London and South East England. This is explained as follows:

- The East England region is connected by several sets of long 400kV double circuits, including Bramford–Pelham–Braintree, Walpole–Spalding North–Bicker Fenn and Walpole–Burwell Main. During a fault on any one set of these circuits, power exported from this region is forced to reroute. This causes some of the power to flow through a much longer distance to reach the rest of the system, predominantly the Greater London and South East England networks via the East Anglia region. As a result, the reactive power losses in these high impedance routes will also increase. If these losses are not compensated, they will eventually lead to voltage depressions within the region.
- Stability becomes an additional concern when some of the large generators connect, further increasing the size of the generation group in the area connected to the network. Losing a set of double circuits when a fault occurs will lead to significant increases in the impedance of the connection between this large generation group and the remainder of the system. As a result, the system may be exposed to a risk of instability as power transfer increases.

The *NOA 2018/19* will assess the likelihood and impact of the above mentioned potential scenarios and accordingly recommend preferred reinforcements for the East of England transmission region.

Boundary EC5 – East Anglia

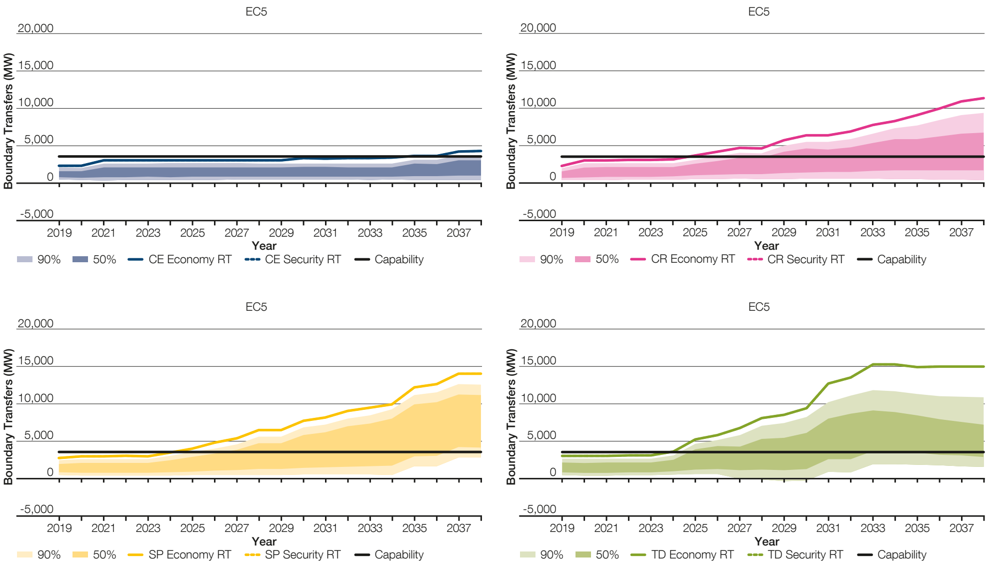
Figure EC5.1
Geographic representation of boundary EC5



Boundary EC5 (East Coast 5) is a local boundary enclosing most of East Anglia. The coastline and waters around East Anglia are attractive for the connection of offshore wind projects including the large East Anglia Round 3 offshore zone that lies directly to the east. The existing nuclear generation site at Sizewell is one of the approved sites selected for new nuclear generation development.

Figure EC5.2

Boundary flows and base capability for boundary EC5



Boundary requirements and capability

Figure EC5.2 above shows the projected boundary power flows for boundary EC5 for the next 20 years. The boundary capability is currently a voltage compliance limit at 3.5 GW for a double circuit fault on the Bramford–Pelham and Bramford–Braintree–Rayleigh Main circuits causing low voltage at Burwell Main substation.

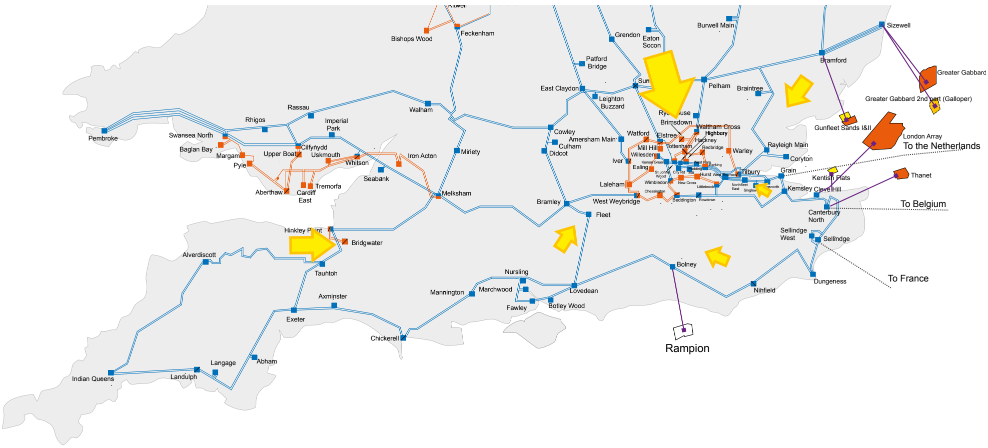
The growth in offshore wind and nuclear generation capacities connecting behind this boundary greatly increase the transfer capability requirements. This is particularly prominent with the **Two Degrees** scenario. The present boundary capability is sufficient for today's needs but potentially grossly short of the future capability requirements. Across all scenarios except **Consumer Evolution**, the SQSS Economy required transfer and expected power flows grow rapidly in a 10-year time span to beyond the present boundary capability. This suggests a need for network development to manage the increasing power flows. The required transfer is higher than expected boundary flows in all scenarios.

3.8 Network capability and requirements by region – The South of England boundaries

Introduction

The South of England transmission region includes boundaries B13, B14, LE1, SC1 and SC3. The region includes the high demand area of London, generation around the Thames estuary and the long set of circuits that run around the south coast. Interconnection to central Europe is connected along the south east coast and this interconnection has significant influence on power flows in the region by being able to both import and export power with Europe. The figure below shows likely power flow directions in the years to come up to 2028. The arrows in the diagram illustrate power flow directions and are approximately scaled relative to the winter peak flows.

Figure SE.1
South of England transmission network



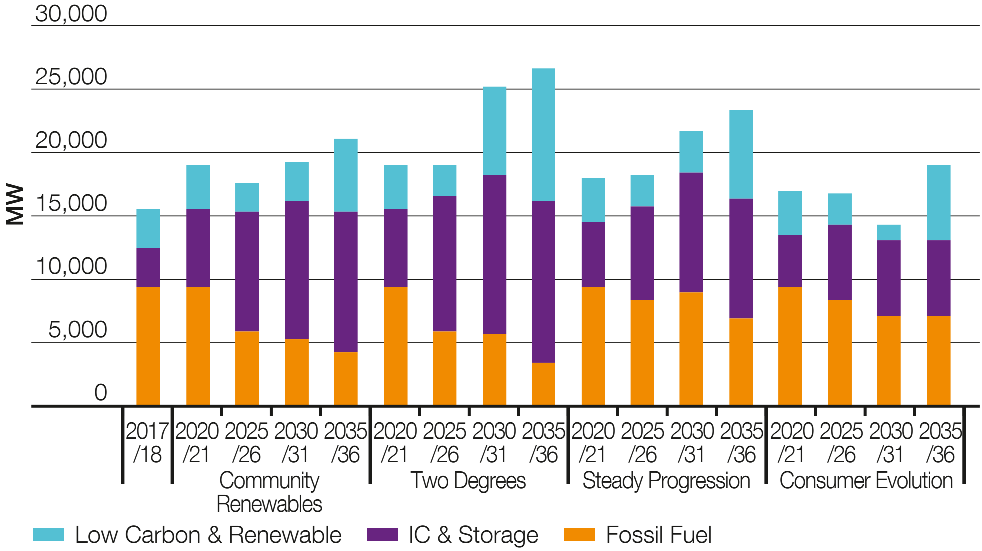
Primary challenge statement:

European interconnector developments along the south coast could potentially drive very high circuit flows causing circuit overloads, voltage management and stability issues.

Regional drivers

The **Two Degrees** scenario suggests that up to 10 GW of interconnectors and energy storage capacity may connect in the south as shown in Figure SE.2. As interconnectors and storage are bi-directional, the south could see their capacity act as up to 10 GW power injection or 10 GW increased demand. This variation could place a very heavy burden on the transmission network. Most of the interconnectors will be connected south of boundary SC1 so the impact on them can be seen in the SC1 requirements section later in the chapter.

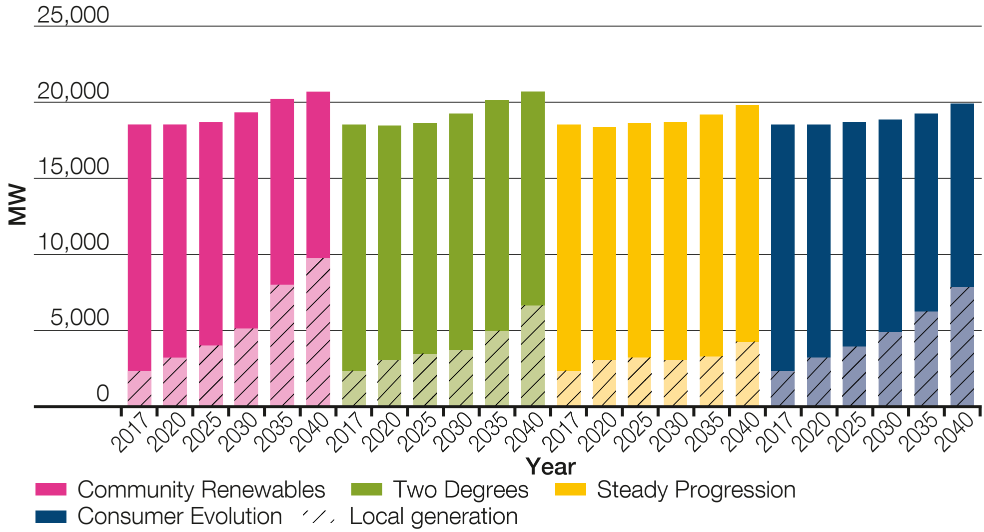
Figure SE.2
Generation capacity mix scenarios for the South of England



Peak gross demand in the south as seen by the transmission network is not expected to change significantly for most of the scenarios. By 2040, the expected peak demand is around 20 GW across all scenarios as shown in Figure SE.3.

In a highly decentralised scenario like **Community Renewables**, local generation capacity connected at the distribution level in this eastern region could reach up to 30 GW by 2040. Of that capacity, a typical embedded generation output on average might be around 10 GW. This will vary depending on factors like wind speeds, and how other local generators decide to participate in the market.

Figure SE.3
Gross demand scenarios for the South of England



The transmission network in the south is heavily meshed in and around London (B14) and the Thames estuary, but below there and towards the west the network becomes more radial with relatively long distances between substations.

In the future, the southern network could potentially see a number of issues driven by future connections. If the interconnectors export power to Europe at the same time that high demand power is drawn both into and through London then the northern circuits feeding London will be thermally overloaded. The high demand and power flows may also lead to voltage depression in London and the south east. The closure of conventional generation within the region will present added stability and voltage depression concerns which may need to be solved through reinforcements.

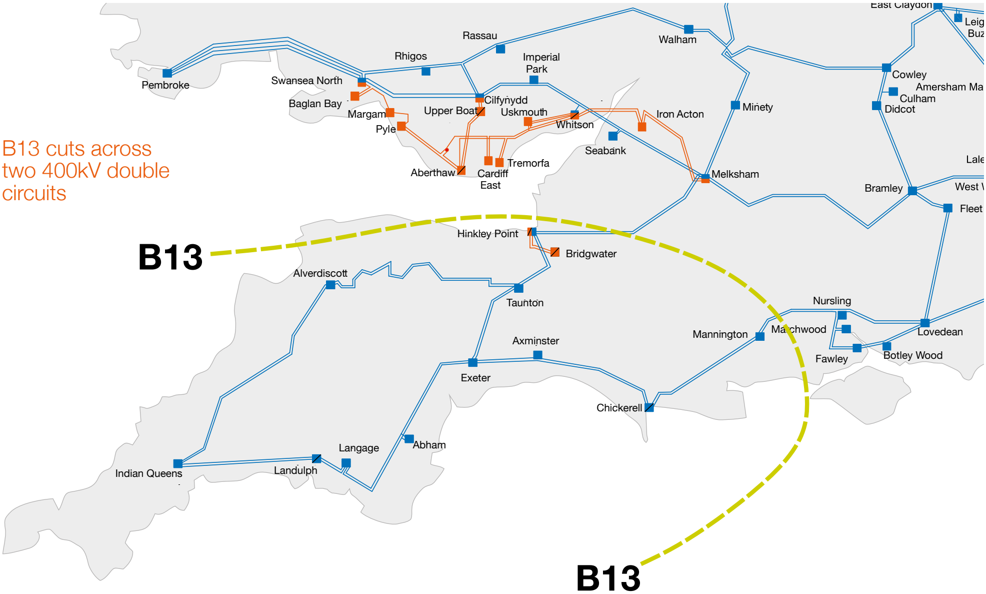
If the south-east interconnectors are importing from the Continent and there is a double circuit fault south of Kemsley, then the south-east circuits may overload and there could be significant voltage depression along the circuits to Lovedean.

With future additional interconnector connections, the south region will potentially be unable to support all interconnectors importing or exporting simultaneously without network reinforcement. Overloading can be expected on many of the southern circuits. The connection of the new nuclear generating units at Hinkley may also require reinforcement of the areas surrounding Hinkley. With new interconnector and generation connections, boundaries SC1, SC3, LE1 and B13 will need to be able to support large power flows in both directions which is different from today when power flow is predominantly in one direction. Furthermore, SC3 was investigated using probabilistic techniques as a case study to analyse the high uncertainty in the background conditions of the area.

The *NOA 2018/19* will assess the likelihood and impact of the above mentioned potential scenarios and accordingly recommend preferred reinforcements for the South of England transmission region.

Boundary B13 – South West

Figure B13.1
Geographic representation of boundary B13



Wider boundary B13 is defined as the southernmost tip of the UK below the Severn Estuary, encompassing Hinkley Point in the South West and stretching as far east as Mannington.

The south-west peninsula is a region with a high level of localised generation and demand.

Figure B13.2
Boundary flows and base capability for boundary B13

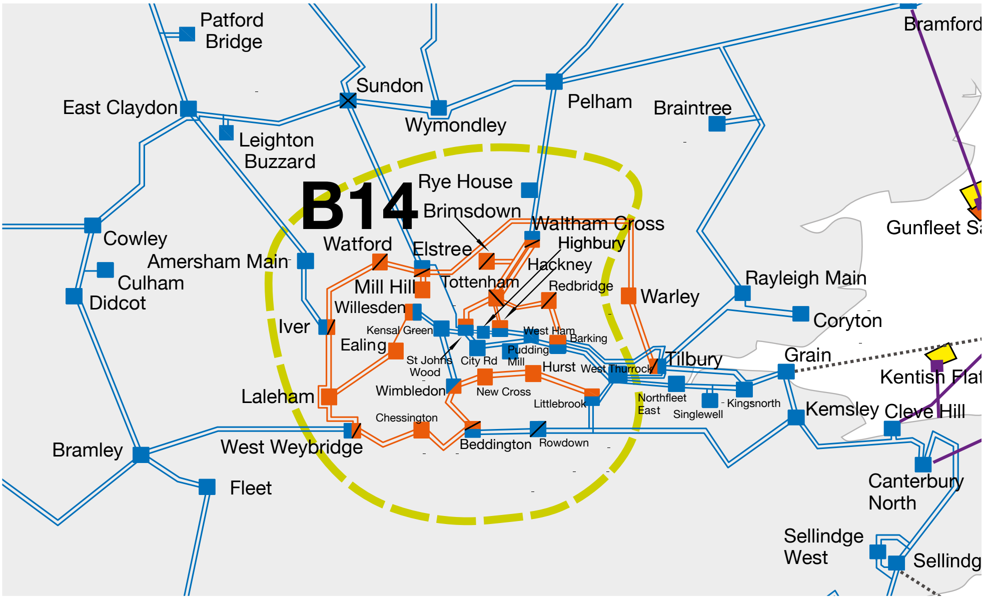
Boundary requirements and capability

Figure B13.2 above shows the projected boundary power flows for boundary B13 for the next 20 years. The boundary capability is limited at 2.4 GW due to voltage collapse post a fault on the Alverdiscott–Indian Queens double circuit.

It can be seen that until new generation or interconnectors connect there is very little variation in boundary requirements, and that the current importing boundary capability is sufficient to meet the short-term needs. The large size of the potential new generators wishing to connect close to boundary B13 is likely to push it to large exports and require additional boundary capacity. For **Consumer Evolution**, this happens after 2032 and for other scenarios takes place after 2027.

Boundary B14 – London

Figure B14.1
Geographic representation of boundary B14

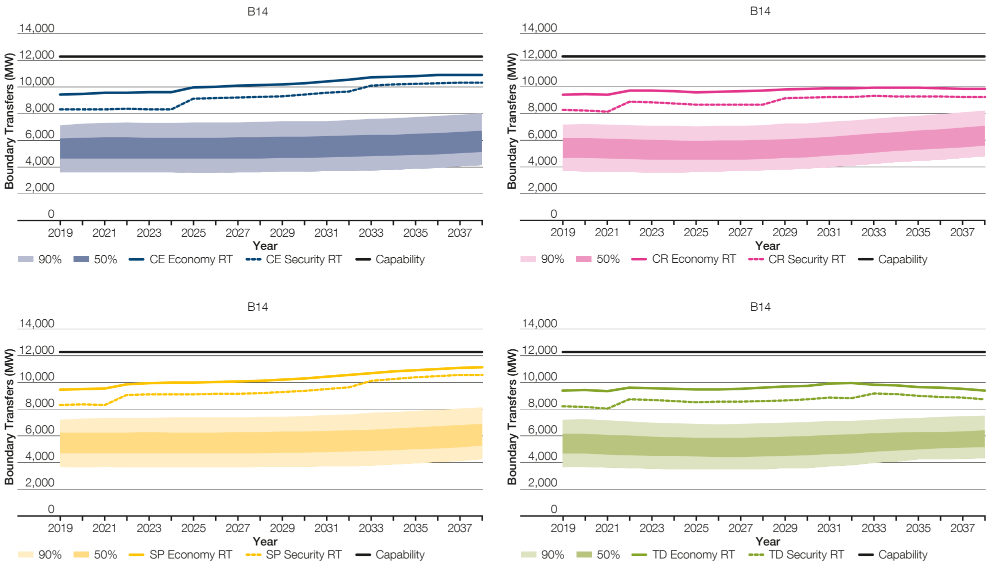


B14 cuts across eight 400kV double circuits and a 275kV double circuit

Boundary B14 encloses London and is characterised by high local demand and a small amount of generation. London's energy import relies heavily on surrounding 400kV and 275kV circuits. The circuits entering from the north can be particularly heavily loaded at winter peak conditions.

The circuits are further stressed when the European interconnectors export to mainland Europe as power is transported via London to feed the interconnectors along the south coast. The North London circuits can also be a bottleneck for power flow from the East Coast and East Anglia regions as power flows through London north to south.

Figure B14.2
Boundary flows and base capability for boundary B14



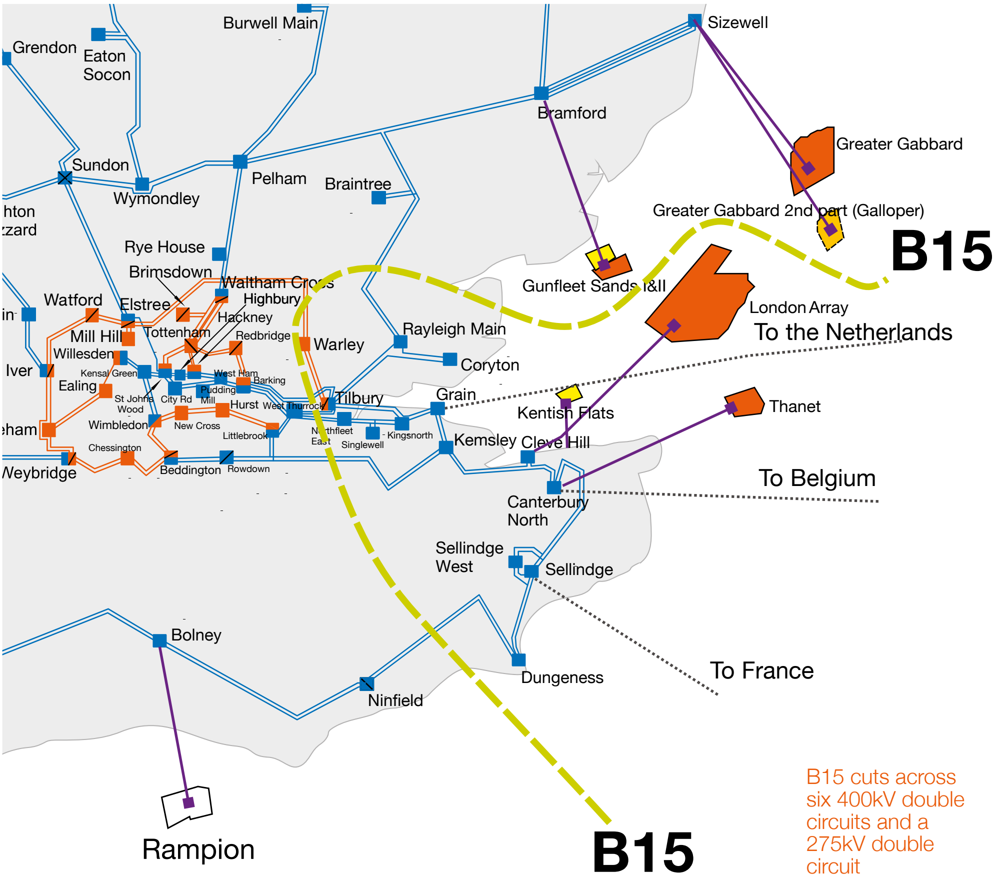
Boundary requirements and capability

Figure B14.2 above shows the projected boundary power flows for boundary B14 for the next 20 years across the *FES*. The boundary capability is currently limited by thermal constraints at 12.3 GW for a double circuit fault on the Pelham–Rye House–Waltham Cross circuits.

As the transfer across this boundary is mostly dictated by the contained demand, the scenario requirements mostly follow the demand with little deviation due to generation changes. The boundary requirements are close to each other across all four scenarios for Security and Economy required transfer. In both criteria, the required transfer is above 90% flows, meaning planning for these values covers all possible flows. Compared to last year's requirements, the boundary requirements have decreased due to the *FES* demand reduction projection around London area.

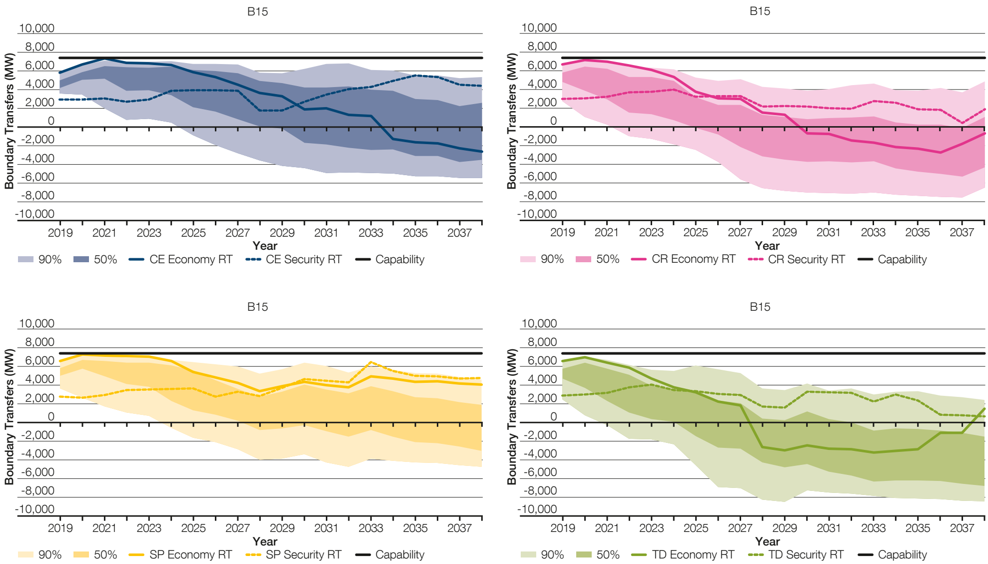
Boundary B15 – Thames Estuary

Figure B15.1
Geographic representation of boundary B15



Boundary B15 is the Thames Estuary boundary, enclosing the south east corner of England. It has significant thermal generation capacity and some large offshore wind farms to the east. With its large generation base, the boundary normally exports power to London. With large interconnectors at Sellindge and Grain connecting to France and the Netherlands, power flow of boundary B15 is greatly influenced by their power flows.

Figure B15.2
Boundary flows and base capability for boundary B15



Boundary requirements and capability

Figure B15.2 above shows the projected boundary power flows for boundary B15 for the next 20 years across the *FES*. The boundary capability currently has a thermal limit of 7.4 GW on the Littlebrook–Longfield Tee for a double circuit fault on the Grain–Kingsnorth and Grain–Tilbury circuits.

The interconnectors connected within this boundary are expected to import during winter peak. This leads to the boundary exporting. With sensitivities for the interconnectors exporting to Europe, the boundary can switch to an importing state – but only when new interconnectors connect, as shown for the **Two Degrees** scenario post 2027 and for the **Community Renewables** scenario post 2029.

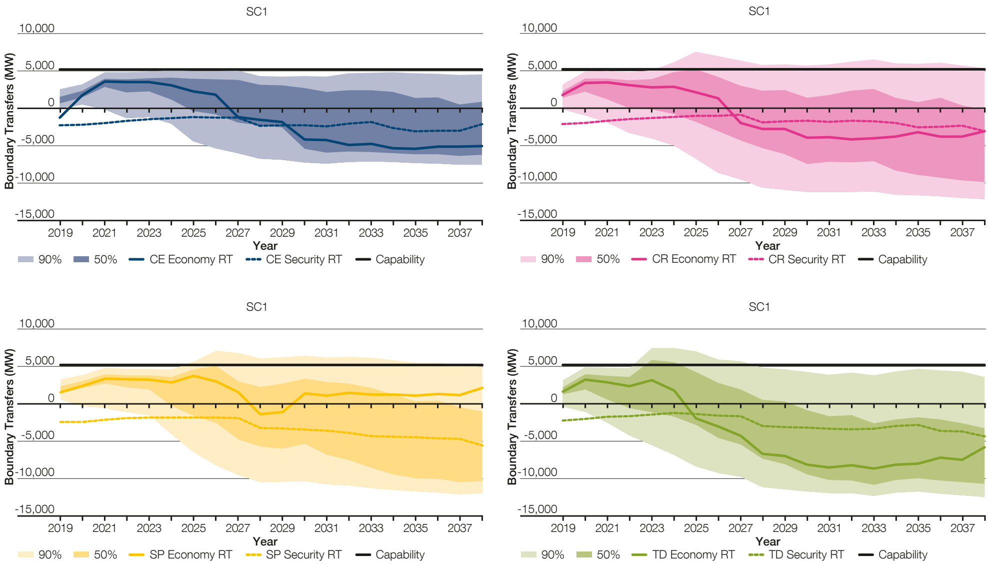
Boundary SC1 – South Coast

Figure SC1.1
Geographic representation of boundary SC1

SC1 cuts across three 400kV double circuits

The South Coast boundary SC1 runs parallel with the south coast of England between the Severn and Thames Estuaries. At times of peak winter GB demand the power flow is typically north to south across the boundary, with more demand enclosed in the south of the boundary than supporting generation. Interconnector activity can significantly influence the boundary power flow. The current interconnectors to France and the Netherlands connect at Sellindge and Grain respectively.

Figure SC1.2
Boundary flows and base capability for boundary SC1



Boundary requirements and capability

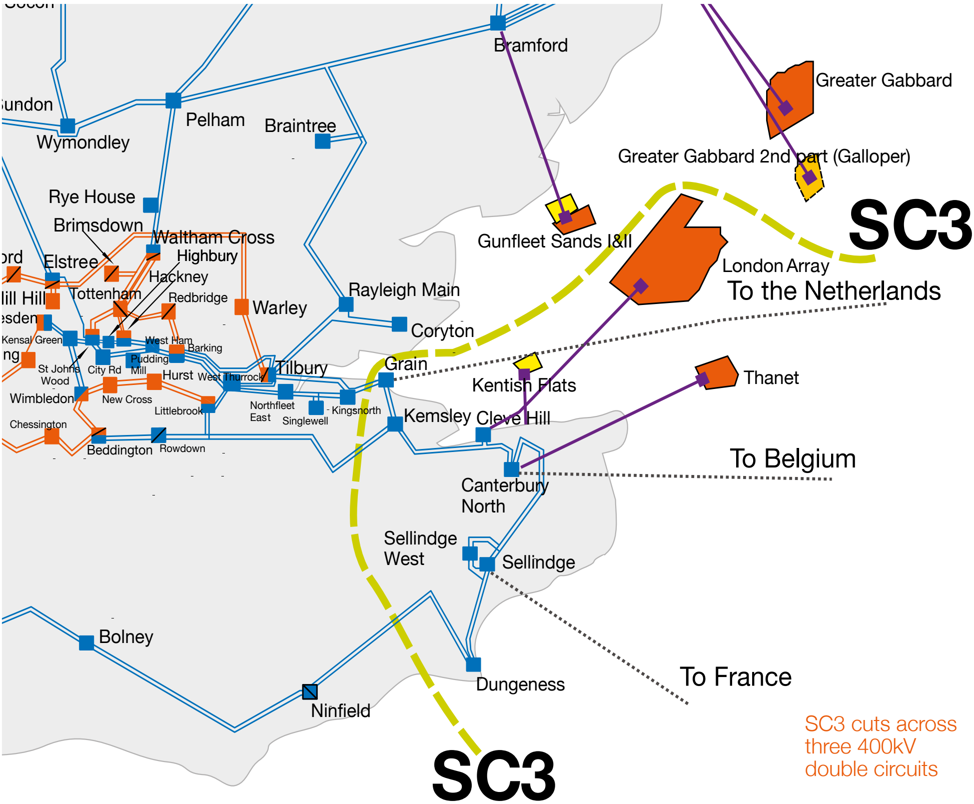
Figure SC1.2 shows the projected boundary power flows for boundary SC1 for the next 20 years across the *FES*. Positive values represent power flow across the boundary from north to south. The boundary capability is currently limited by voltage compliance at 5.2 GW for a double circuit fault on the Kemsley–Clevehill and Kemsley–Canterbury circuits for interconnector import sensitivity. For the interconnector export sensitivity, the limit is also voltage compliance at 6 GW of transfer. This happens after Hinckley Point–Taunton double circuit fault.

The interconnectors to Europe have a massive impact on the power transfers across SC1. A 2 GW interconnector such as IFA can make 4 GW of difference on the boundary from full export to full import mode or vice versa. The biggest potential driver for SC1 will be the connection of new continental interconnectors. With their ability to transfer power in both directions boundary SC1 could be stressed much harder than would normal with conventional generation and demand. Some of the scenarios suggest that up to 12 GW of interconnector capacity could connect below SC1 by 2026.

Across all *FES*, the SQSS Security required transfer follows a flat pattern whereas the Economy required transfer moves from exporting to importing in around 2026. The volatility of interconnector activity can be seen in the required transfers as the requirements swing from power flow south and north. The SQSS calculation of required transfers does not place high loading on the interconnectors so the transfers are not seen to peak at very high values. Credible sensitivities of the interconnectors operating at their rated capacities suggest that boundary power flows could exceed 10 GW which is well outside current network capability.

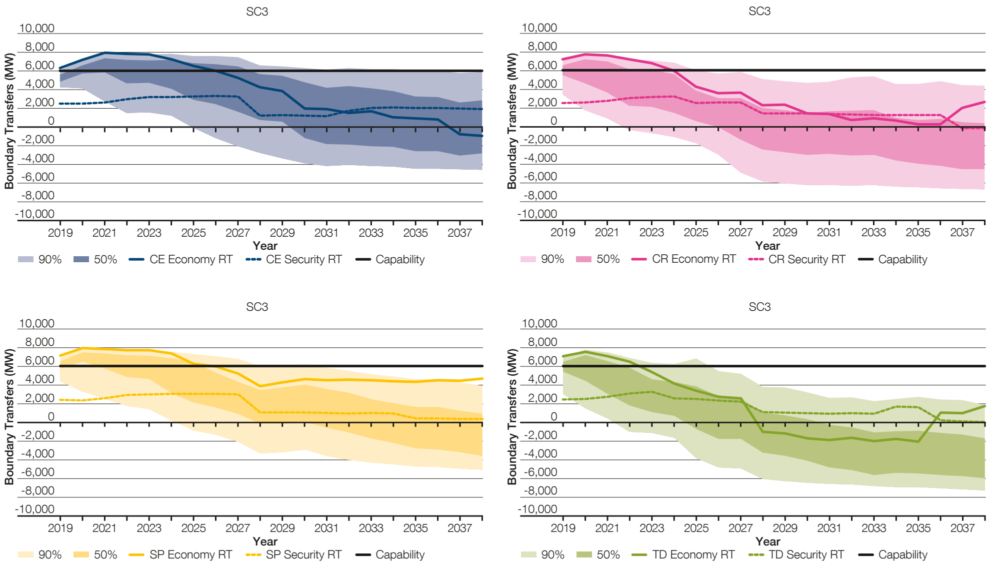
Boundary SC3 – South Coast

Figure SC3.1
Geographic representation of boundary SC3



The South Coast boundary SC3 is created to capture transmission issues specifically in the south-east part of the network. The current and future interconnectors to Europe have a massive impact on the power transfers across SC3. The current interconnectors to France and the Netherlands connect at Sellindge and Grain, respectively.

Figure SC3.2
Boundary flows and base capability for boundary SC3



Boundary requirements and capability

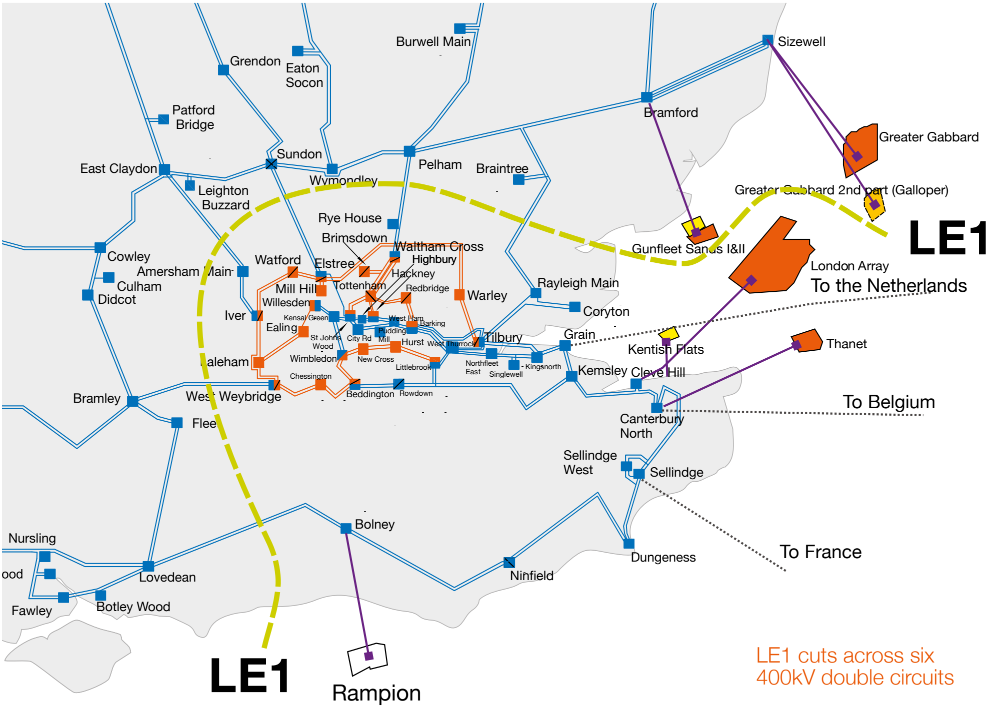
Figure SC3.2 shows the projected boundary power flows for boundary SC3 for the next 20 years across the *FES*. Positive values represent power flow across the boundary from north to south. The boundary capability is currently limited by thermal loading at 6 GW for a double circuit fault on the Grain–Tilbury–Kingsnorth circuits.

The current and future interconnectors to Europe have a massive impact on the power transfers across SC3 with their ability to transfer power in both directions.

Across all *FES*, the SQSS Security required transfer follows similar patterns and is mainly lower compared to the Economy required transfer. In general, the Economy required transfer faces a decline over time, albeit it does not reflect the interconnectors' uncertainties. The uncertainty of interconnector activity can be seen in the wide range of the boundary flows. Credible sensitivities of the interconnectors operating at their rated capacities suggest that boundary power transfers could exceed 5 GW in the opposite direction which necessitates studying the import sensitivity for future years.

Boundary LE1 – South East

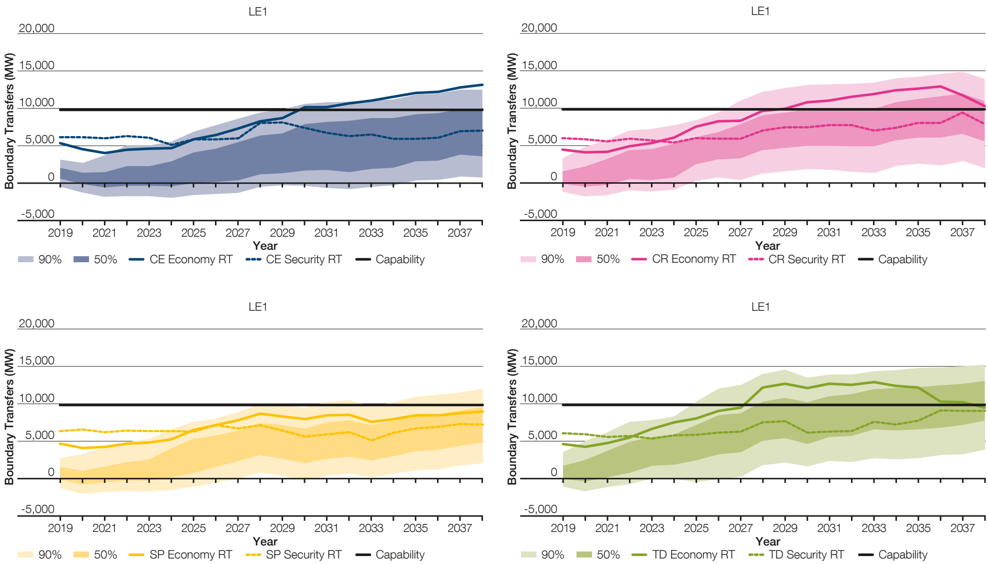
Figure LE1.1
Geographic representation of boundary LE1



Boundary LE1 (London and East) encompasses the south east of the GB network, incorporating London and the areas to the south and east of it. LE1 is characterised by two distinct areas. Within London there is high local demand and little generation. The remainder of the area contains both high demand and high levels of generation. In particular, there are a number of gas power generators in the Thames Estuary area and an interconnector to the Netherlands, while connected to the South East Coast are a number of wind farms, an interconnector to France and nuclear and gas power stations. There are several potential interconnectors to France, Belgium and the Netherlands located around the coast of both of these areas, leading to a high concentration of connections in this area.

LE1 almost exclusively imports power from the North and West into the South East, and the purpose of the boundary is to monitor flows in this direction. With the existing and proposed interconnectors importing power from the Continent, power flows enter London from all directions, so the extent of flows across LE1 reduce and no constraints are seen other than those shown by B14, B15 or the South Coast boundaries. However, with an increased number of interconnectors, and (in some scenarios) increased likelihood of them exporting power in future years, LE1 can become a high demand area, with any locally generated power feeding straight into the interconnectors. As such, the circuits entering from the North can become overloaded as power is drawn into and through London toward the South and East.

Figure LE1.2
Boundary flows and base capability for boundary LE1



Boundary requirements and capability

Figure LE1.2 shows the projected boundary power flows for boundary LE1 for the next 20 years across the *FES*. The boundary capability is currently limited by thermal constraints at 9.8 GW with overloads of the Rayleigh Main–Tilbury and Elstree–Sundon circuits.

Across all the *FES* except **Steady Progression**, the SQSS Economy required transfer follows similar patterns. The SQSS Security required transfer is similar for all scenarios. Both **Two Degree** and **Community Renewables** experience a period of high transfer requirement in later years. The uncertainty of interconnector activity can be seen in the wide range of the boundary flows.

3.9 Probabilistic thermal analysis case study

Introduction

To improve how we address the possible impacts of intermittent and volatile energy resources in the planning and operation of the NETS, it is necessary to quantify the costs/risks of the likely background conditions. The use of probabilistic risk assessment techniques in the development and operation of the NETS has the potential to quantify the magnitude and likelihood of events on the transmission system throughout a year. This will lead to more informed network investment and operational planning decisions, with clear cost/risk measures being applied.

Current approach and new requirements

The long-term development planning of the NETS has traditionally been carried out against single-snapshot "worst-case" scenarios, at winter peak demand. This is consistent with the boundary required transfer methodology in the NETS SQSS. Changes in generation and demand mean that planning to meet winter peak demand requirements might not satisfy all of the conditions that could arise through the course of a year. By simulating year-round conditions using probabilistic distribution of variables we can look at a broader range of conditions and highlight the magnitude and likelihood of events on the transmission system throughout the year.

We have carried out a case study to investigate using a probabilistic approach in one GB region. The following sections describe our probabilistic tool, methodology and some findings from this approach.

New assessment approach

The probabilistic element of our long-term assessment process is based on the Monte-Carlo[4] method to estimate the likely power flow on individual transmission circuits or a group of circuits at a boundary level.

Monte-Carlo is used to sample likely background generation and demand conditions which are then fed into an economic dispatch algorithm. This allows us to find out what would be the position of available energy resources assuming an ideal electricity market. The results are hourly generation and demand snapshots which are subsequently evaluated by power system analysis to understand their impacts on the GB NETS.

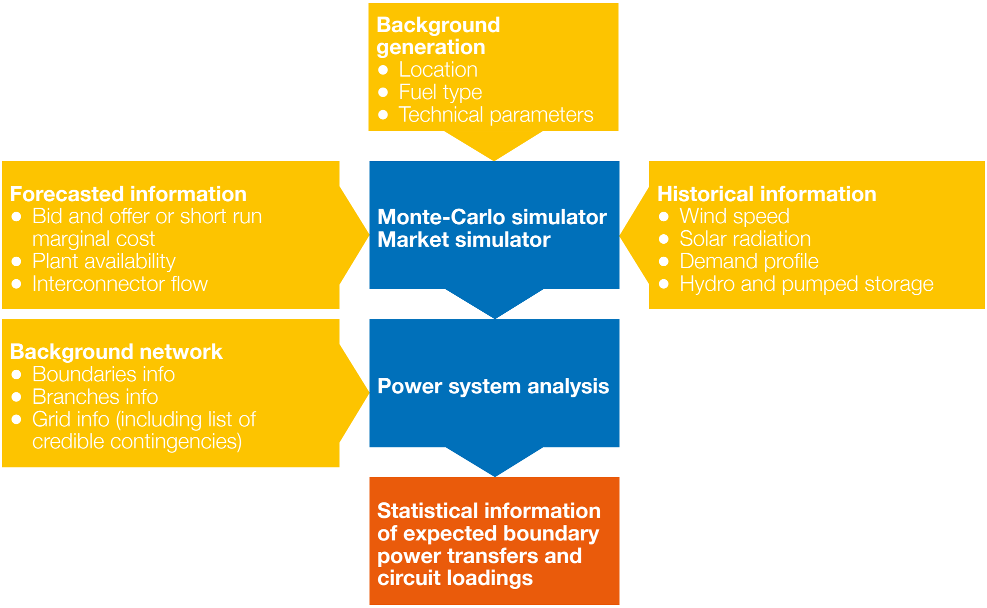
Study case and results

The case study covers the south-east region of GB and considers only network thermal constraints. The current single-snapshot approach is difficult for this area because of the highly variable power flows on HVDC interconnectors to mainland Europe. The targeted region covers a variety of energy resources such as nuclear generation, wind farms and interconnectors. We created a new boundary – South Coast 3 (SC3) – based on the contingencies in this area and associated circuits' loading. You can find its description and flow graph in the previous section. The technique described here can be used to update the existing boundaries we currently use to capture relevant network issues year-on-year.

For this case, the background generation is based on the **Two Degrees** energy scenario. For each sample year, 8,760 sequential snapshots are generated by the Monte-Carlo simulator to represent each hour of the year. Each snapshot is assessed by the electricity market simulator and finally evaluated by the power system analysis based on DC power flow approximation. This process is depicted in Figure PT.1.

[4] A mathematical technique widely used to model risk and uncertainty

Figure PT.1
Probabilistic thermal analysis diagram



Figures PT.2 and PT.3 depict the expected power transfer across SC3 during winter and summer of 2018/2019. These are based on multiple sampled scenarios of different generation, demand and outage patterns per season. Each bar shows the expected number of hours per season for the corresponding boundary transfer. Acceptable boundary transfers are shown in blue, whereas unacceptable ones are purple. An unacceptable boundary transfer means that there is at least one overloaded circuit. Boundary transfer numbers using the single-snapshot method are shown by the red number in the power transfer axis in the figures. The single-snapshot boundary capability numbers are 6,015 MW and 4,810 MW for winter and summer, respectively. The identified limiting fault and thermal constraint using single-snapshot criteria align with those found through probabilistic techniques.

We can see that the full range of boundary capability will vary based on the background conditions. The single-snapshot boundary numbers are over-estimated in this case and there are many instances that the actual boundary capability is less than these fixed capability values. In this case, the single-snapshot value is over-estimated for both summer and winter; however, for other conditions that may not be the case.

If we are going to choose a single boundary capability number per season based on the probabilistic approach, the challenge is how to choose this value. For example, the winter boundary capability number based on the probabilistic technique lies between 4,100 MW and 5,800 MW (see Figure PT.2). If we choose a number close to 4,100 MW, we are under-estimating the boundary capability; whereas a number close to 5,800 MW means we are over-estimating the boundary capability. Our current idea for this example is to use constraint forecast-error concept. The determined boundary capability based on this concept is 4,750 MW. This concept and the associated technique to calculate the boundary capability are briefly described in Appendix H. Further details will be provided in our full report in Q1 2019 and we welcome stakeholders' views on this proposed approach.

Figure PT.2
Acceptable and unacceptable SC3 power transfers (winter 2018/19) – (the red number indicates the single-snapshot boundary capability)

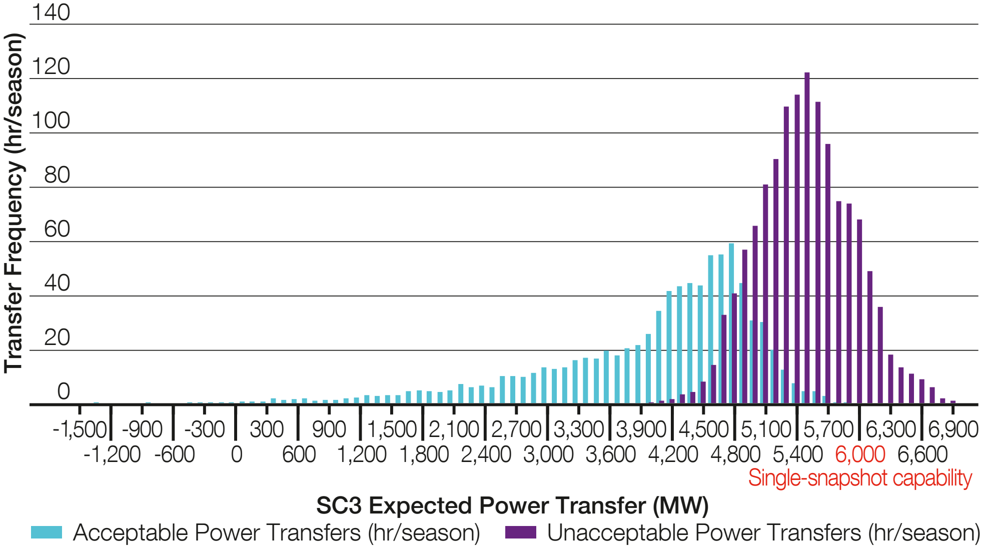
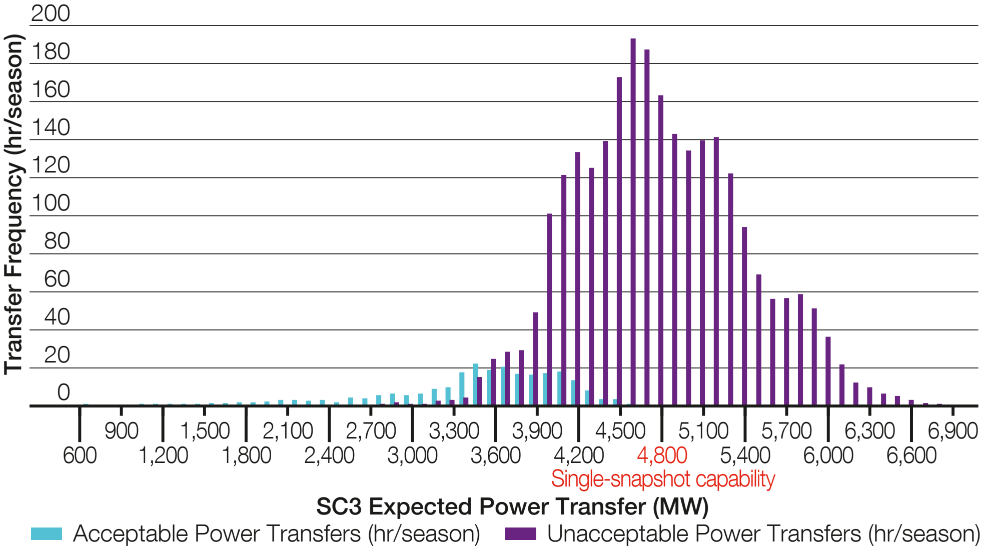


Figure PT.3
Acceptable and unacceptable SC3 power transfers (summer 2018/19) – (the red number indicates the single-snapshot boundary capability)



Remarks and way forward

From the testing of a single region of transmission network that is difficult to analyse by traditional methods due to highly variable generation and demand, we have found that the traditional single-snapshot boundary capability approach may, in this case, over-estimate boundary capability when compared to a more comprehensive probabilistic based analysis. The over-estimated boundary capability, when applied to network requirements identification, might expose the network to unforeseen risks. In this case, additional reinforcements beyond that identified through the *NOA* process could be required.

The probabilistic technique looks at a broader range of snapshots and can calculate boundary capability based on multiple background conditions. We intend to use this information to investigate what impact it will have on the *NOA* recommendation for this boundary (SC3), the outcome of which we will publish in Q1 of 2019. Note that we investigated the probabilistic approach for only one boundary and presented the results; however, the outcomes could be different for other boundaries. Although in this case we demonstrated that the single-snapshot technique might result in under-investment, it might result in over-investment for other boundaries and/or different background conditions. Thus, the results cannot be applied generically to all boundaries as background conditions can vary widely.

Stakeholder engagement
If you have feedback on any of the content of this document please send it to **transmission.etys@nationalgrid.com**, catch up with us at one of our consultation events or visit us at National Grid ESO, Faraday House, Warwick.

3.10 Regional voltage analysis case study

Introduction

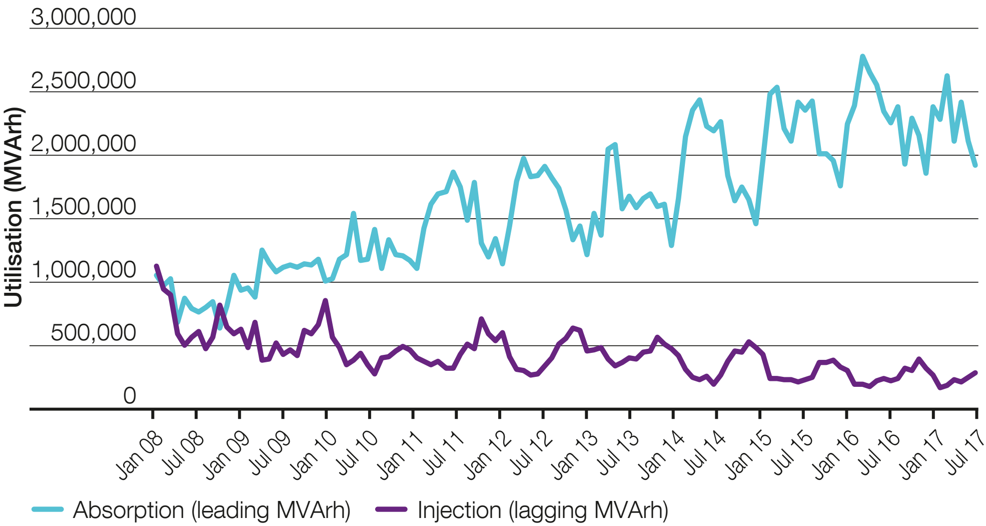
We operate the transmission system so that voltage levels remain within the normal operating ranges defined within the NETS SQSS. This ensures we operate the system safely and efficiently.

The specific voltage limits used in planning and operating the transmission system can be found in Chapter 6 of the SQSS[5].

Voltage management has become increasingly challenging

Over the last decade, operationally managing system voltages, particularly within the upper limit, has become an area of increasing challenge for the ESO. We've observed a continual decrease in both minimum demand and reactive power consumption at Grid Supply Points (GSP), as shown in Figure RV.1, which has resulted in an increasing need to absorb more reactive power on the transmission network.

Figure RV.1
Reactive power utilisation



[5] https://www.nationalgrideso.com/codes/security-and-quality-supply-standards?overview

The pace and scale of changing reactive power flows in recent years, combined with the lead times involved in the investment of network assets, has created an increased reliance on balancing services for reactive power. We currently spend over £150m per annum on these services. This shows no sign of slowing and, with further potential traditional generation plant closures, the ability to manage system voltages will become increasingly difficult. In the long term, to ensure we can operate the transmission system securely, efficiently and economically, we need to consider how to best strike a balance between the use of asset options and balancing services to meet the needs for reactive power. To improve our understanding of the system needs we have decided to undertake regional investigations of voltage performance.

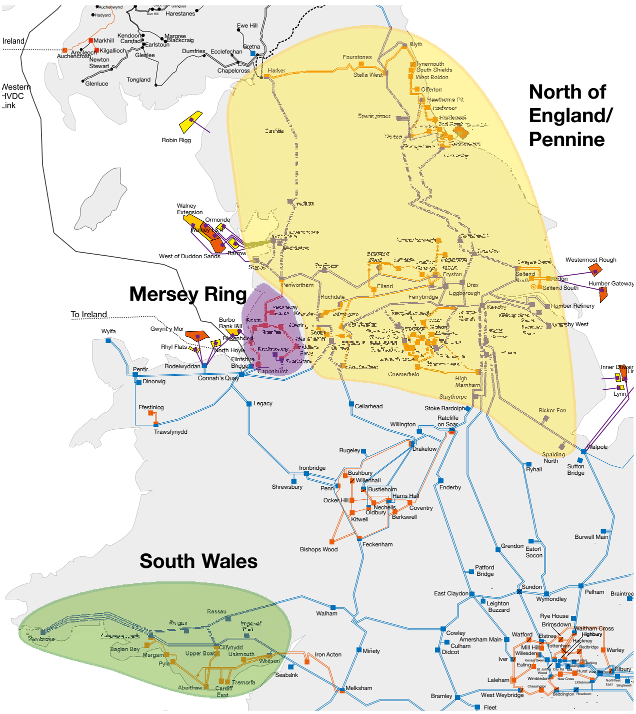
A regional approach

Voltage is a localised property of the system which means that requirements vary from one region to another. The voltage management requirements are determined by the configuration of the local network and the behaviours of generation and demand in that part of the network in real time. Since voltage is a local phenomenon, reactive power is most effective for voltage control when close to the region of imbalance. We are currently studying several regions to understand the local reactive power requirements. We will also look to identify the most economic and efficient solutions to fulfil the requirements where necessary. The plans for regional assessments are as follows:

North of England/Pennine

- Phase 1:
  - Explore solutions from Transmission Owners (TOs) and Distribution Network Operators (DNOs)
  - Publish findings of Phase 1 – Q4 2018
- Phase 2:
  - Expand to consider new commercial solutions – 2019 (following completion of a request for information for Mersey and South Wales).

Figure RV.2
Regional assessment areas



Mersey Ring

- Communicate needs to stakeholders (TOs, DNOs and commercial providers).
- Publish Request for Information.
- Explore solutions from TOs, DNOs and commercial providers.
- Solutions assessment.
- Publish recommendation.

South Wales

- Communicate needs to stakeholders (TOs, DNOs and commercial providers).
- Publish Request for Information.
- Explore solutions from TOs, DNOs and commercial providers.
- Solutions assessment.
- Publish recommendation.

Pennine case study

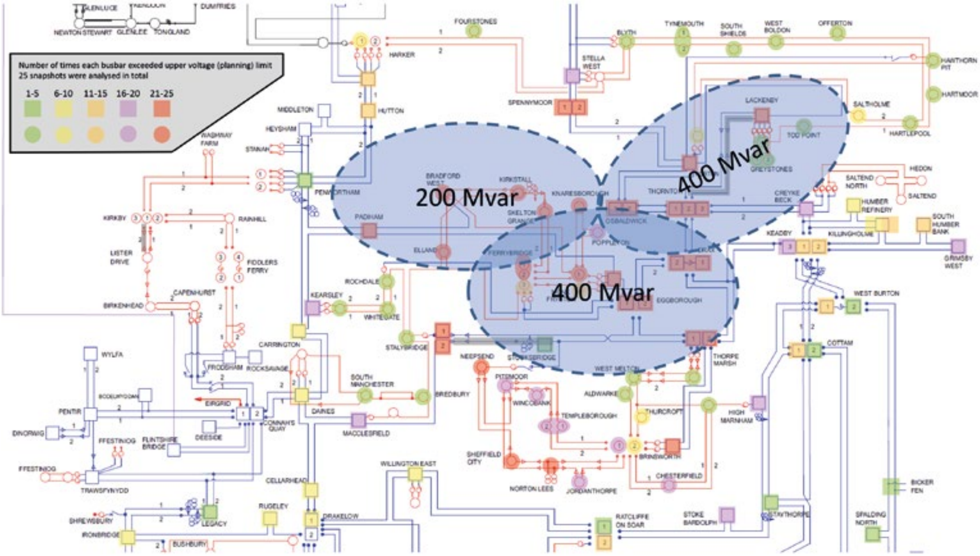
The first region we studied was the North of England/Pennine area. A *NOA*-style assessment was developed through the ENA Open Networks Project to decide the most economic and efficient way to manage the voltage in this region.

Set background and assumptions → **Identify regional issues** → **Request for solutions** → **Analyse solutions** → **Set rules for cost-benefit analysis to evaluate voltage costs** → **Cost-benefit analysis** → **Recommend solutions**

We analysed a range of scenarios to identify the voltage requirements. High voltage issues are present at times of low demand in the North of England/Pennine area – this is typically during the overnight hours of the summer months. The analysis studied the existing asset and operational voltage management solutions, and concluded that the system requires extra capability to absorb excessive reactive power in this area. The voltage issues heatmap, shown in Figure RV.3, summarises the results of our analysis for the North of England/Pennine area. Further details about the assessment can be found in the ENA Open Networks Workstream 1 Product 1 report to be published by the end of 2018.

Traditionally the identification of NETS voltage issues would lead to the TO considering various transmission asset options as reinforcement to relieve the problems. As part of this case study, we also explore the potential of using distribution asset options. We worked closely with the TO (NG ET) and DNOs (Electricity North West and Northern Powergrid) that cover the North of England/Pennine area to explore the options available. Now that Phase 1 of the Pennine case study has concluded, we have assessed a range of options, at both transmission and distribution levels, that can absorb approximately 1 GVAr of additional reactive power. Although the technical analysis identified regional reactive absorption needs of 1 GVAr, the economic analysis found only 800 MVAr absorption requirement could be justified. We plan to publish our findings of the work to-date by the end of 2018 as part of the ENA Open Networks Workstream 1 Product 1 report.

Figure RV.3
Heatmaps of the voltage issues in the North of England/Pennine area



Mersey Ring and South Wales

For the Mersey Ring and South Wales areas, we have completed our analysis on the voltage requirements. We are currently collating our data in preparations for communicating the system needs in these areas to our stakeholders. Like the Pennine case study, we plan to work with the TO and DNOs that cover the areas to explore the potential network asset options to fulfil the requirements. We also intend to expand our option analysis to include commercial options.

Next steps

We are working on improving the approach we took for the case studies so that it can be built into our enduring process. What we learn from these case studies will be used to further develop the process and it will form part of the *NOA* methodology.

Examples of areas identified for further development include:

- A screening process which identifies high priority regions to consider in terms of analysing system voltage needs. We will develop a screening tool which uses data we hold as the ESO to inform the conditions and situations which we should focus on through power system studies.
- Improving the way we represent the system needs for voltages to our stakeholders, including TOs, DNOs and commercial providers. We welcome any stakeholder views on this.
- Expanding our long-term option analysis of voltage to include distribution asset options and commercial options.

We are committed to work closely with our stakeholders to further develop our process for addressing the long-term reactive requirements for high voltage issues. Any new proposed methodologies will be consulted on with stakeholders as part of our annual consultation on the *NOA* methodology.

Chapter 4
The Way Forward

The *ETYS* and *NOA* documents are continuing to evolve to help us meet our ambition set out in the ESO Forward Plan. As the documents expand to a wider audience, we hope you will help shape them to become even more valuable for you and others to use.

4.1 Shaping our network planning through the ESO Forward Plan and Network Development Roadmap

The ESO Forward Plan[1] sets out our ambitious commitments to evolve and enhance our role to meet the requirements of the changing electricity system.

We want to be sure we are most effectively meeting the needs of our customers and stakeholders. The Forward Plan includes two principles to drive greater value for consumers through the way we plan the network:

- Principle 5 – Coordinate across system boundaries to deliver efficient network planning and development.
- Principle 7 – Facilitate timely, efficient and competitive network investments.

The *ETYS* and *NOA*, in line with our licence obligations, are part of our baseline delivery against these principles and we have also made other commitments to transform our approach in this area.

[1] https://www.nationalgrideso.com/about-us/future-electricity-system-operator

4.2 Legal separation of the ESO and *ETYS*

Through the Future of the SO (FSO) programme, we're moving to a more independent ESO. This will shape the future development of the *ETYS* and *NOA* publications, as we look to facilitate competition and improve our recommendations for reinforcements for the benefit of our customers and consumers.

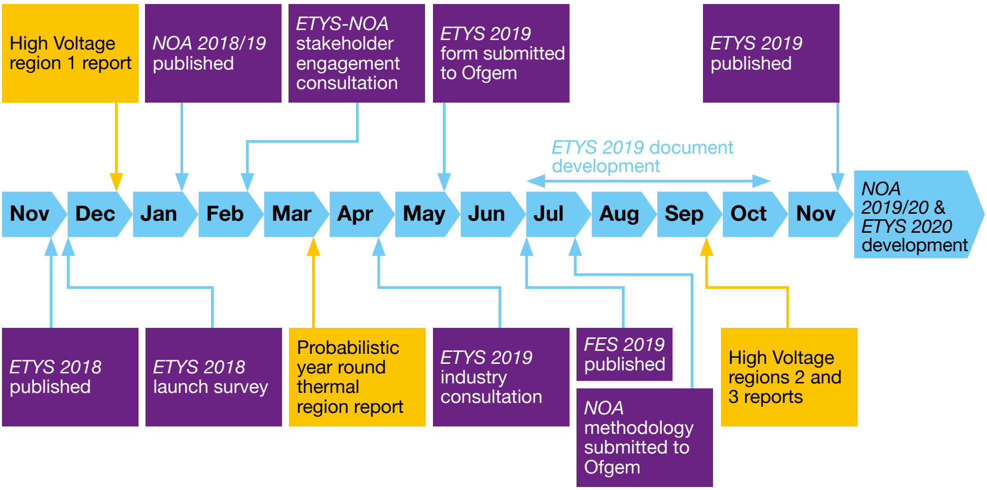
The ESO has an important role in the transition to a more decentralised, low carbon electricity industry. The Forward Plan shows how the ESO is promoting more whole system thinking to enhance network and market access. Our customers and stakeholders need to be confident that the ESO is performing its enhanced roles in a neutral way.

To achieve this, we are creating a new ESO business that is separate from the Electricity Transmission (ET). From April 2019, National Grid Electricity System Operator (NGESO) will be a legally separate company but will remain a valued for-profit part of the National Grid Group. The legal separation allows the ESO, as well as ET, to step up into new roles.

4.3 Stakeholder feedback

We would like to hear your views on how we should shape both *ETYS* and *NOA* documents to make them more valuable. An indicative draft timetable for our 2018 and 2019 *ETYS/NOA* stakeholder activities programme is shown below

Figure 4.1
ETYS/NOA stakeholder activities programme



We welcome your views on this year's *ETYS*, and would like to know what you think works well and what you would like us to improve. Please complete our survey at **https://www.surveymonkey.co.uk/r/ETYS2018** and take part in our written consultation (planned for April 2019 for *ETYS*).

Our stakeholder activities are a great way for us to:

- learn more about the views and opinions of all our stakeholders;
- provide opportunities for constructive feedback and debate;
- create open, two-way communication with our stakeholders about assumptions, analyses and findings; and
- let stakeholders know how we have taken their views into consideration and the outcomes of our engagement activities.

We are always happy to listen to our stakeholders' views. We do this through:

- consultation events as part of our customer seminars;
- industry engagement events e.g. operational forums, ENA meetings, etc;
- responses to transmission.etys@nationalgrid.com; and
- stakeholder meetings.

Chapter 5
Further Information

Appendices overview

Appendix A – System schematics & geographic drawings

Appendix A includes a set of system schematics and geographic drawings of the current NETS, with the approximate locations of existing power stations and reactive compensation plants shown. The schematics also show the NETS boundaries and *ETYS* zones we have used in our analysis.

You can view the system schematics and geographic drawings at: **https://www.nationalgrideso.com/sites/eso/files/documents/ETYS_2018_Appendix_A.pdf**

Appendix B – System technical data

To allow modelling of the transmission network, basic network parameters such as connectivity and impedances are provided in Appendix B. The expected changes in the network based on the previous year's development decisions are also provided.

You can view the system technical data at: **https://www.nationalgrideso.com/sites/eso/files/documents/ETYS_2018_Appendix_B.xlsx**

Appendix C – Power flow diagrams

To demonstrate the impact of future changes on the transmission network a set of winter peak power flow diagrams are presented in Appendix C. These show snapshots of present and future power flows along major circuit routes for the **Two Degrees** scenario. The expected changes in the network are based on the previous year's development decisions.

You can view the diagrams at: **https://www.nationalgrideso.com/sites/eso/files/documents/ETYS_2018_Appendix_C.pdf**

Appendix D – Fault levels

Appendix D gives indications of peak GB fault levels at nodal level for the current and future transmission network. The fault levels are at peak generation and demand conditions and can used to investigate local area system strength.

You can find out more at: **https://www.nationalgrideso.com/sites/eso/files/documents/ETYS_2018_Appendix_D_Narrative.pdf**

You can view the fault level data at: **https://www.nationalgrideso.com/sites/eso/files/documents/ETYS_2018_Appendix_D_Data.xlsx**

Appendix E – *FES* charts and workbook

This appendix contains data and charts relating to national and/or regional National Electricity Transmission System (NETS) information about

- energy storage and interconnectors
- summer minimum demand
- embedded generation.

You can find the regional modelling narrative at: **http://fes.nationalgrid.com/media/1374/regional-modelling.pdf**

You can find the transmission level data at: **https://www.nationalgrideso.com/sites/eso/files/documents/ETYS_2018_Appendix_E_Transmission.xlsx**

You can find the distribution level data at: **https://www.nationalgrideso.com/sites/eso/files/documents/ETYS_2018_Appendix_E_Distribution.xlsx**

Appendix H – Further information in inputs and methodologies

This appendix explains how the *FES* generation, demand and interconnector data is applied to the network simulation models. It also explains how we estimate boundary capability using probabilistic technique results.

Please note that Appendices F and G which contain week 24 generation and demand data are no longer published within *ETYS* and have moved to the Transmission Network Use of System (TNUoS)[1] page under tools and calculations.

You can find out more at: **https://www.nationalgrideso.com/sites/eso/files/documents/ETYS_2018_Appendix_H.pdf**

[1] https://www.nationalgrideso.com/charging/transmission-network-use-system-tnuos-charges

Meet the *ETYS* team

Julian Leslie
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Network Development

In addition to publishing the *ETYS* we are responsible for developing a holistic strategy for the NETS. This includes performing the following key activities:

- The management and implementation of the *Network Options Assessment (NOA)* process in order to assess the need to progress wider transmission system reinforcements.
- Producing recommendations on preferred options for NETS investment under the Integrated Transmission Planning and Regulation (ITPR)[2] arrangements and publishing results annually in the *NOA* report.

You can contact us to discuss:

Network requirements and *Electricity Ten Year Statement*

James Whiteford
GB System Capability Manager
James.Whiteford@nationalgrid.com

Cost-benefit analysis and *Network Options Assessment*

Hannah Kirk-Wilson
Technical and Economic Assessment Manager
Hannah.Kirk-Wilson@nationalgrid.com

Network Operability and Data and Modelling

In our Network Operability department, we are responsible for studying a variety of power system issues including generator and HVDC compliance. We develop and produce the *System Operability Framework* each year. From our Data and Modelling department we produce power system models and datasets for network analysis. We also manage the technical aspects of the GB and European electricity frameworks, codes and standards that are applicable to network development.

Contact details to discuss the network data used in *ETYS*:

Geoff Ray
Data and Modelling Manager
Geoff.Ray@nationalgrid.com

Contact details to discuss the *SOF*:

Network Risk and Performance Team
sof@nationalgrid.com

[2] https://www.ofgem.gov.uk/electricity/transmission-networks/integrated-transmission-planning-and-regulation

Supporting parties

Strategic network planning and producing the *ETYS* requires support and information from many people. Parties who provide support and information that makes our work possible includes:

- the GB Electricity Transmission Owners
- our customers.

Don't forget you can email us with your views on *ETYS* at: **transmission.etys@nationalgrid.com**

Glossary

Acronym	Word	Description
	Ancillary services	Services procured by a system operator to balance demand and supply and to ensure the security and quality of electricity supply across the transmission system. These services include reserve, frequency control and voltage control. In GB these are known as balancing services and each service has different parameters that a provider must meet.
ACS	Average cold spell	Average cold spell is defined as a particular combination of weather elements which gives rise to a level of winter peak demand which has a 50% chance of being exceeded as a result of weather variation alone. There are different definitions of ACS peak demand for different purposes.
	Boundary allowance	An allowance in MW to be added in whole or in part to transfers arising out of the NETS SQSS economy planned transfer condition to take some account of year-round variations in levels of generation and demand. This allowance is calculated by an empirical method described in Appendix F of the Security And Quality of Supply Standards (SQSS).
	Boundary transfer capacity	The maximum pre-fault power that the transmission system can carry from the region on one side of a boundary to the region on the other side of the boundary while ensuring acceptable transmission system operating conditions will exist following one of a range of different faults.
CBA	Cost-benefit analysis	A method of assessing the benefits of a given project in comparison to the costs. This tool can help to provide a comparative base for all projects to be considered.
CCS	Carbon capture and storage	Carbon capture and storage (CCS) is a process by which the CO_2 produced in the combustion of fossil fuels is captured, transported to a storage location and isolated from the atmosphere. Carbon capture and storage can be applied to large emission sources like power plants used for electricity generation and industrial processes. The CO_2 is then compressed and transported for long-term storage in geological formations or for use in industrial processes.
	Climate change targets	Targets for share of energy use sourced from renewable sources. The 2020 UK targets are defined in the Directive 2009/28/EC of the European Parliament and of the Council of the European Union, see **http://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:32009L0028&from=EN#ntc1-L_2009140EN.01004601-E0001**
CCGT	Combined cycle gas turbine	Gas turbine that uses the combustion of natural gas or diesel to drive a gas turbine generator to generate electricity. The residual heat from this process is used to produce steam in a heat recovery boiler which, in turn, drives a steam turbine generator to generate more electricity.
CHP	Combined heat and power	A system whereby both heat and electricity are generated simultaneously as part of one process. Covers a range of technologies that achieve this.
CR	Community Renewables	One of the *Future Energy Scenarios*. A world where people are engaged and able to invest in local innovative solutions to meet their energy needs. This allows the 2050 target to be successfully met.
CE	Consumer Evolution	One of the *Future Energy Scenarios*. A world where advances continue in the energy sector. There is more take-up in small scale solutions. These prove insufficient, particularly for green transport, and thus the 2050 target is missed.
	Contracted generation	A term used to reference any generator who has entered into a contract to connect with the National Electricity Transmission System (NETS) on a given date while having a transmission entry capacity (TEC) figure as a requirement of said contract.

Acronym	Word	Description
	Double circuit overhead line	In the case of the onshore transmission system, this is a transmission line which consists of two circuits sharing the same towers for at least one span in SHE Transmission's system or NGET's transmission system or for at least two miles in SP Transmission system. In the case of an offshore transmission system, this is a transmission line which consists of two circuits sharing the same towers for at least one span.
DSR	Demand side response	A deliberate change to an industrial and commercial user's natural pattern of metered electricity or gas consumption, brought about by a signal from another party.
DNO	Distribution Network Operator	Distribution Network Operators own and operate electricity distribution networks.
	Embedded generation	Power generating stations/units that don't have a contractual agreement with the Electricity System Operator (ESO). They reduce electricity demand on the National Electricity Transmission System.
ENTSO-E	European Network of Transmission System Operators – Electricity	ENTSO-E is an association of European electricity TSOs. ENTSO-E was established and given legal mandates by the EU's Third Legislative Package for the Internal Energy Market in 2009, which aims at further liberalising electricity markets in the EU.
EU	European Union	A political and economic union of 28 member states that are located primarily in Europe.
FES	*Future Energy Scenarios*	The *FES* is a range of credible futures which has been developed in conjunction with the energy industry. They are a set of scenarios covering the period from now to 2050, and are used to frame discussions and perform stress tests. They form the starting point for all transmission network and investment planning, and are used to identify future operability challenges and potential solutions.
GEP	Grid entry point	A point at which a generating unit directly connects to the National Electricity Transmission System. The default point of connection is taken to be the busbar clamp in the case of an air insulated substation, gas zone separator in the case of a gas insulated substation, or equivalent point as may be determined by the relevant transmission licensees for new types of substation. When offshore, the GEP is defined as the low voltage busbar on the platform substation.
GSP	Grid supply point	A point of supply from the GB transmission system to a distribution network or transmission-connected load. Typically only large industrial loads are directly connected to the transmission system.
GW	Gigawatt	1,000,000,000 Watts, a measure of power.
GWh	Gigawatt hour	1,000,000,000 Watt hours, a unit of energy.
GB	Great Britain	A geographical, social and economic grouping of countries that contains England, Scotland and Wales.
HVAC	High voltage alternating current	Electric power transmission in which the voltage varies in a sinusoidal fashion, resulting in a current flow that periodically reverses direction. HVAC is presently the most common form of electricity transmission and distribution, since it allows the voltage level to be raised or lowered using a transformer.
HVDC	High voltage direct current	The transmission of power using continuous voltage and current as opposed to alternating current. HVDC is commonly used for point to point long-distance and/or subsea connections. HVDC offers various advantages over HVAC transmission, but requires the use of costly power electronic converters at each end to change the voltage level and convert it to/from AC.
IED	Industrial Emissions Directive	The Industrial Emissions Directive is a European Union directive which commits member states to control and reduce the impact of industrial emissions on the environment post-2015 when the Large Combustion Plant Directive (LCPD) expired.
ITPR	Integrated Transmission Planning and Regulation	Ofgem's Integrated Transmission Planning and Regulation (ITPR) project examined the arrangements for planning and delivering the onshore, offshore and cross-border electricity transmission networks. Ofgem published the final conclusions in March 2015.
	Interconnector	Electricity interconnectors are transmission assets that connect the GB market to Europe and allow suppliers to trade electricity between markets.

Glossary

Acronym	Word	Description
LCPD	Large Combustion Plant Directive	The Large Combustion Plant Directive is a European Union directive which introduced measures to control the emissions of sulphur dioxide, oxides of nitrogen and dust from large combustion plant.
	Load factor	The average power output divided by the peak power output over a period of time.
	Marine technologies	Tidal streams, tidal lagoons and energy from wave technologies (see **http://www.emec.org.uk/**).
MW	Megawatt	1,000,000 Watts, a measure of power.
MWh	Megawatt hour	1,000,000 Watt hours, a measure of power usage or consumption in 1 hour.
	Merit order	An ordered list of generators, sorted by the marginal cost of generation.
MITS	Main Interconnected Transmission System	This comprises all the 400kV and 275kV elements of the onshore transmission system and, in Scotland, the 132kV elements of the onshore transmission system operated in parallel with the supergrid, and any elements of an offshore transmission system operated in parallel with the supergrid, but excludes generation circuits, transformer connections to lower voltage systems, external interconnections between the onshore transmission system and external systems, and any offshore transmission systems radially connected to the onshore transmission system via single interface points.
NETS	National Electricity Transmission System	The National Electricity Transmission System comprises the onshore and offshore transmission systems of England, Wales and Scotland. It transmits high-voltage electricity from where it is produced to where it is needed throughout the country. The system is made up of high voltage electricity wires that extend across Britain and nearby offshore waters. It is owned and maintained by regional transmission companies, while the system as a whole is operated by a single Electricity System Operator (ESO).
NETS SQSS	National Electricity Transmission System Security and Quality of Supply Standards	A set of standards used in the planning and operation of the National Electricity Transmission System of Great Britain. For the avoidance of doubt the National Electricity Transmission System is made up of both the onshore transmission system and the offshore transmission systems.
NGET	National Grid Electricity Transmission plc	National Grid Electricity Transmission plc (No. 2366977) whose registered office is 1-3 Strand, London, WC2N 5EH.
	Network access	Maintenance and system access is typically undertaken during the spring, summer and autumn seasons when the system is less heavily loaded and access is favourable. With circuits and equipment unavailable the integrity of the system is reduced. The planning of system access is carefully controlled to ensure system security is maintained.
NOA	*Network Options Assessment*	The *NOA* is the process for assessing options for reinforcing the National Electricity Transmission System (NETS) to meet the requirements that the Electricity System Operator (ESO) finds from its analysis of the *Future Energy Scenarios (FES)*.
OFGEM	Office of Gas and Electricity Markets	The UK's independent National Regulatory Authority, a non-ministerial government department. Their principal objective is to protect the interests of existing and future electricity and gas consumers.
	Offshore	This term means wholly or partly in offshore waters.
	Offshore transmission circuit	Part of an offshore transmission system between two or more circuit breakers which includes, for example, transformers, reactors, cables, overhead lines and DC converters but excludes busbars and onshore transmission circuits.

Acronym	Word	Description
	Onshore	This term refers to assets that are wholly on land.
	Onshore transmission circuit	Part of the onshore transmission system between two or more circuit breakers which includes, for example, transformers, reactors, cables and overhead lines but excludes busbars, generation circuits and offshore transmission circuits.
OCGT	Open cycle gas turbine	Gas turbines in which air is first compressed in the compressor element before fuel is injected and burned in the combustor.
	Peak demand	The maximum power demand in any one fiscal year: Peak demand typically occurs at around 5:30pm on a week-day between December and February. Different definitions of peak demand are used for different purposes.
pa	Per annum	per year.
PV	Photovoltaic	A method of converting solar energy into direct current electricity using semi-conducting materials.
	Planned transfer	A term to describe a point at which demand is set to the National Peak when analysing boundary capability.
	Power supply background (aka generation background)	The sources of generation across Great Britain to meet the power demand.
	Ranking order	A list of generators sorted in order of likelihood of operation at time of winter peak and used by the NETS SQSS.
	Reactive power	Reactive power is a concept used by engineers to describe the background energy movement in an alternating current (AC) system arising from the production of electric and magnetic fields. These fields store energy which changes through each AC cycle. Devices which store energy by virtue of a magnetic field produced by a flow of current are said to absorb reactive power; those which store energy by virtue of electric fields are said to generate reactive power.
	Real power	This term (sometimes referred to as “Active Power”) provides the useful energy to a load. In an AC system, real power is accompanied by reactive power for any power factor other than 1.
	Seasonal circuit ratings	The current carrying capability of circuits. Typically, this reduces during the warmer seasons as the circuits’ capability to dissipate heat is reduced. The rating of a typical 400kV overhead line may be 20% less in the summer than in winter.
	SHE Transmission	Scottish Hydro-Electric Transmission (No.SC213461) whose registered office is situated at Inveralmond HS, 200 Dunkeld Road, Perth, Perthshire PH1 3AQ.
SP	Steady Progression	One of the *Future Energy Scenarios*. Steady Progression is a world where current advances continue in the energy sector. There is muted investment in large scale solutions. Ultimately, heating stalls the movement towards the 2050 target.
	SP Transmission	Scottish Power Transmission Limited (No. SC189126) whose registered office is situated at Ochil House, 10 Technology Avenue, Blantyre G72 0HT.
	Summer minimum	The minimum power demand of the transmission network in any one fiscal year. Minimum demand typically occurs at around 06:00am on a Sunday between May and September.
	Supergrid	That part of the National Electricity Transmission System operated at a nominal voltage of 275kV and above.
SGT	Supergrid transformer	A term used to describe transformers on the NETS that operate in the 275–400kV range.
	Switchgear	The term used to describe components of a substation that can be used to carry out switching activities. This can include, but is not limited to, isolators/disconnectors and circuit breakers.
	System inertia	The property of the system that resists changes. This is provided largely by the rotating synchronous generator inertia that is a function of the rotor mass, diameter and speed of rotation. Low system inertia increases the risk of rapid system changes.

Glossary

Acronym	Word	Description
	System operability	The ability to maintain system stability and all of the asset ratings and operational parameters within pre-defined limits safely, economically and sustainably.
SOF	System Operability Framework	The SOF identifies the challenges and opportunities which exist in the operation of future electricity networks and identifies measures to ensure the future operability.
ESO	Electricity System Operator	An entity entrusted with transporting electric energy on a regional or national level, using fixed infrastructure. Unlike a TO, the ESO may not necessarily own the assets concerned. For example, National Grid ESO operates the electricity transmission system in Scotland, which is owned by Scottish Hydro Electricity Transmission and Scottish Power.
	System stability	With reduced power demand and a tendency for higher system voltages during the summer months, fewer generators will operate and those that do run could be at reduced power factor output. This condition has a tendency to reduce the dynamic stability of the NETS. Therefore network stability analysis is usually performed for summer minimum demand conditions as this represents the limiting period.
	Transmission circuit	This is either an onshore transmission circuit or an offshore transmission circuit.
TEC	Transmission entry capacity	The maximum amount of real power deliverable by a power station at its grid entry point (which can be either onshore or offshore). This will be the maximum power deliverable by all of the generating units within the power station, minus any auxiliary loads.
	Transmission losses	Power losses that are caused by the electrical resistance of the transmission system.
TO	Transmission Owners	A collective term used to describe the three transmission asset owners within Great Britain, namely National Grid Electricity Transmission, Scottish Hydro-Electric Transmission Limited and SP Transmission Limited.
TSO	Transmission System Operators	An entity entrusted with transporting energy in the form of natural gas or power on a regional or national level, using fixed infrastructure.
TD	Two Degrees	One of the *Future Energy Scenarios*. A world where there is the money and a collective will to invest in large scale ground-breaking energy solutions for GB. These allow the 2050 target to be successfully met.

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