ES Cornwall Memorial Scholarship

First Quarter Report

6 November 2023 to 6 February 2024

National Grid Electricity Transmission, Warwick, United Kingdom

by

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Acknowledgements

I would like to express my sincere gratitude to the following pillars that have played a pivotal role in shaping my personal and professional journey.

I would like to first express my sincere appreciation to Powerlink Queensland for their steadfast support, allowing me the opportunity to continue my development overseas. The encouragement I have received from my colleagues and their belief in my capabilities have been pivotal to my professional journey and my decision to pursue the ES Cornwall Memorial Scholarship.

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Executive Summary

Australia aims to achieve net zero emissions by 2050 as part of a global effort to mitigate climate change and ensure a sustainable future. This shift requires significant investment in renewable energy infrastructure, including expanding renewable energy capacity and improving energy storage technologies to address intermittency and stability challenges.

Over the next ten years, the Queensland power system will undergo significant change as the Queensland Energy and Jobs Plan is delivered, introducing 500kV to the state. All the while, a growing number of inverter-based resources in efforts to produce green power and electrify demand will create new challenges for the industry to solve.

I believe that Queensland can benefit from learning how other transmission system operators are developing their network, performance requirements and control practices to facilitate the connection of inverter-based resources in the transition to net zero.

This report provides an overview of the first quarter of my ES Cornwall Memorial Scholarship Experience. In November 2023, I began my placement at National Grid Electricity Transmission in Warwick, United Kingdom in the Future Network Blueprints team. In my first three months of the placement, I was tasked with developing Regional Strategies for the business.

Regional Strategies are documents that provide an accessible way for staff to gain an understanding of relevant projects in their area of operation. These documents bring together network and stakeholder requirements from across the business to provide a view of the power system that allows National Grid Electricity Transmission staff to assess the network holistically. In doing so, key network limitations and dependencies can be established which feed back into the optimisation of the planning and delivery of projects.

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Glossary

NAME	DESCRIPTION
AC	Alternating Current
AO	Asset Operations
CC	Customer Connections
CFD	Contract For Difference
DFES	Distributed Future Energy Scenarios
DV	Delivery Vehicle
EISD	Earliest In-Service Date
ESO	Electricity System Operator
ETYS	Electricity Ten Year Statement
FES	Future Energy Scenarios
FNB	Future Network Blueprints
HND	Holistic Network Design
HNDFUE	Holistic Network Design Follow Up Exercise
HVDC	High Voltage Direct Current
IDD	Infrastructure Development and Delivery
ND	Network Development
NGESO	National Grid Electricity System Operator
NGET	National Grid Electricity Transmission
NOA	Network Options Assessment
OFGEM	Office of Gas and Electricity Markets
PPA	Power Purchasing Agreements
QEJP	Queensland Energy and Jobs Plan
RIIO	Revenue = Incentives + Innovation + Outputs
SI	National Grid Strategic Infrastructure
T3	Price Control Period 2026-2031
TCSNP	Transitional Centralised Strategic Network Plan
TO	Transmission Owner
TSO	Transmission System Operator
UK	United Kingdom

1 Background

Many significant changes will be made to the Australian power system as the nation moves towards its net zero target. Much of the Australian landscape is suitable for wind and solar generation, making it an attractive investment for renewable developers. As more renewable developments are underway, the increasing number of power electronics in the generation mix will further complicate the stability challenges currently experienced in the National Electricity Market. Additionally, as new generators are commissioned in wind and solar rich areas, the system power flows will change resulting in a shifting energy landscape.

The Queensland Energy and Jobs Plan (QEJP) will revolutionise the Queensland power system, introducing a 500kV network and two pumped hydro projects. The QEJP will enable Queensland's transition to net zero and facilitate the electrification of her industries. The transition to green energy and the QEJP will change the Queensland power system at a speed and scale never seen before.

I believe that Queensland can benefit from learning how other Transmission System Operators (TSOs) are developing their network, performance requirements and control practices to facilitate the connection of these technologies in the transition to net zero.

2 Placement

2.1 Company Description

National Grid Electricity Transmission (NGET) is the Transmission System Operator (TSO) in England and Wales and is responsible for the high-voltage transmission of electricity from transmission connected power stations to major substations and bulk supply points. The United Kingdom transmission system is made up of an onshore 400kV AC backbone spanning from the Scottish-English border to the south coast of England, shown in blue in Figure 1 below. While more radially connected in northern England due to the National Parks in the region, the 400kV transmission network is well interconnected from the Midlands down to Southern England.

The 275kV network, shown in red, is primarily used for the supply of electricity to regional centres. The 275kV London Ring, spotted in the bottom right part of England, provides the critical supply of electricity into London and is fed from all directions. The National Grid Electricity Transmission network forms the backbone of the English and Welsh electricity grid, ensuring the efficient and reliable delivery of electricity to homes, businesses, and industries across large geographic regions.

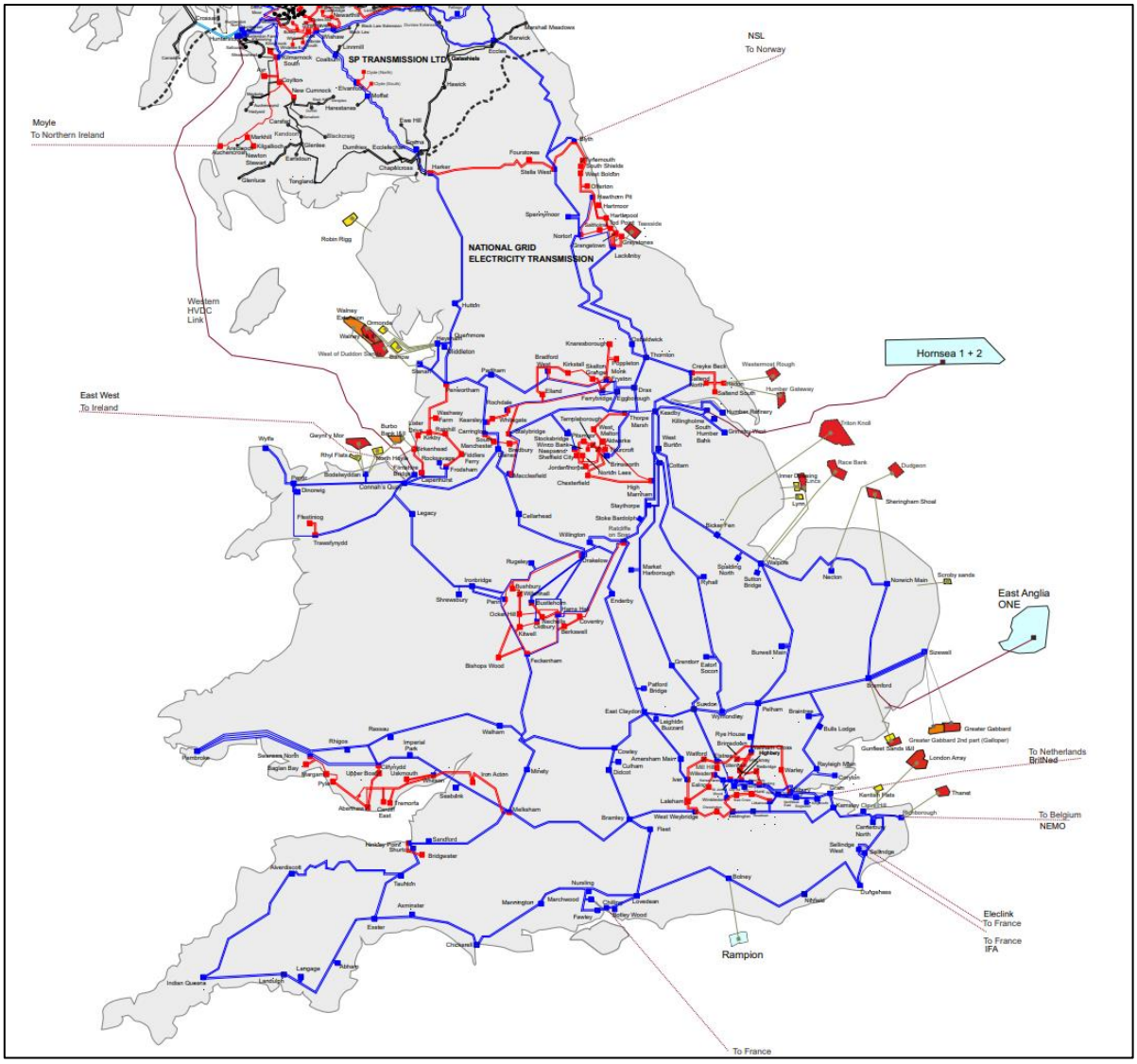


Figure 1 - National Grid Electricity Transmission Network

The key responsibilities of National Grid Electricity Transmission include:

- **High Voltage Transmission Lines**: NGET operates a network of high-voltage transmission lines, typically operating at voltages of 132 kV and above. These lines are designed to minimise energy losses during transmission over long distances.
- **Substations**: Along the transmission network, substations serve as critical nodes where voltage levels are adjusted, and the electricity is routed to different areas. Substations also play a role in maintaining grid stability and managing power flows.
- **Grid Operations**: NGET oversees the real-time operation of the transmission network, continuously monitoring power flows, voltage levels, and frequency to ensure system reliability and stability. Grid operators use advanced control systems to manage the transmission network and respond swiftly to any disturbances or emergencies.
- **Interconnections**: NGET operates High Voltage Direct Current (HVDC) interconnectors that link national transmission systems, enabling the exchange of electricity between countries. These interconnections enhance energy security,

facilitate the trading of electricity, and support the integration of renewable energy resources on a broader scale.

- **Grid Expansion and Upgrades**: NGET is responsible for planning and implementing expansions and upgrades to the transmission network to accommodate growing electricity demand, integrate new sources of generation, and enhance grid resilience.

National Grid Electricity Transmission plays a crucial role in facilitating the safe, secure, and efficient transmission of electricity, supporting economic development, and enabling the transition to a cleaner and more sustainable energy future.

2.1.1 National Grid Separation

In years past, the UK power system has been owned and operated by National Grid who have taken on the responsibility of both Transmission System Operator (TSO) and Electricity System Operator (ESO). The integration of TSO and ESO allowed for synergies in grid operation, planning, market participation, and risk management. In 2017, the Office of Gas and Electricity Markets (Ofgem) and National Grid published a joint statement setting out the decision for the greater separation of system operators. The separation was formalised in 2019.

The separation of National Grid was intended to ensure the independence and impartiality of system operation and planning activities. This separation was aimed to help prevent potential conflicts of interest, promote fair access to the grid for all market participants, and enhance the overall efficiency and competitiveness of the electricity sector. The separation would allow for clearer accountability and transparency in decision-making processes, and provide a more effective regulatory framework to oversee the activities of the resulting entities.

Two independent entities were created as a result of the separation. National Grid Electricity Transmission (NGET), became responsible for owning and maintaining the transmission infrastructure. National Grid Electricity System Operator (NGESO) took on the role of managing the operation of the electricity system.

2.1.2 National Grid Electricity Transmission Structure

Following the separation of NGET and NGESO, NGET restructured their business in an act to accelerate project workflows, and better allocate risk and accountability. From 2021, the business was divided into several Delivery Vehicles (DVs), each of which focussed on the delivery of projects associated with a particular portfolio of works. Engineering Delivery Vehicles at National Grid include:

- Asset Operations
- Customer Connections
- Infrastructure Development and Delivery
- Network Operations and Intelligence

Each Delivery Vehicle was equipped with its own planning, project, finance and human resource teams which, in theory, allowed the business groups to operate autonomously and thus deliver efficiency through vertically integrated processes. As similar roles existed across the business, only a brief handover period is required for National Grid staff to second between DVs. This enabled resources to be funnelled into understaffed areas quickly. However, as a consequence of the growing resource requirements in the business, there is

competition for the services of the best employees. As a result, under resourced areas of the business may not necessarily find relief under this business structure.

Under the Delivery Vehicle structure, employees have noted a marked reduction in organic workplace collaboration following the inception of the Delivery Vehicles. The business structure necessitates the need for regular cross-divisional meetings to fill informational gaps. As more processes are put in place to develop channels of communication, many hope that the dissemination of information can be improved.

2.1.3 My Role

My position at National Grid Electricity Transmission sits within the Infrastructure Development and Delivery DV under Owen Wilkes, the manager of Network Development. The Network Development team is responsible for operational and strategic planning as well as evaluating power systems performance. The position in this team enables me to witness the planning process within NGET. In my first three months at National Grid Electricity Transmission, the strategic planning arm of Network Development had recently finished an offshore HVDC strategic plan and was progressing towards the completion of an accompanying onshore strategic plan. However, I have not been assigned to perform work on behalf of the Network Development team. Instead, I reported to a separate team under Ben Haggerty.

Ben Haggerty is the manager of a team responsible for the early development of substation and overhead line strategies. This information is fed into the revenue proposal that will be submitted to the Office of Gas and Electricity Markets (OFGEM) for review.

My role as Regional and Site Strategy Engineer is responsible for collating information from around the business to create strategic regional plans, known as Regional Strategies, for the next price control period and beyond. The information in the Regional Strategies will be used to guide investment decisions for substations, overhead lines and cables.

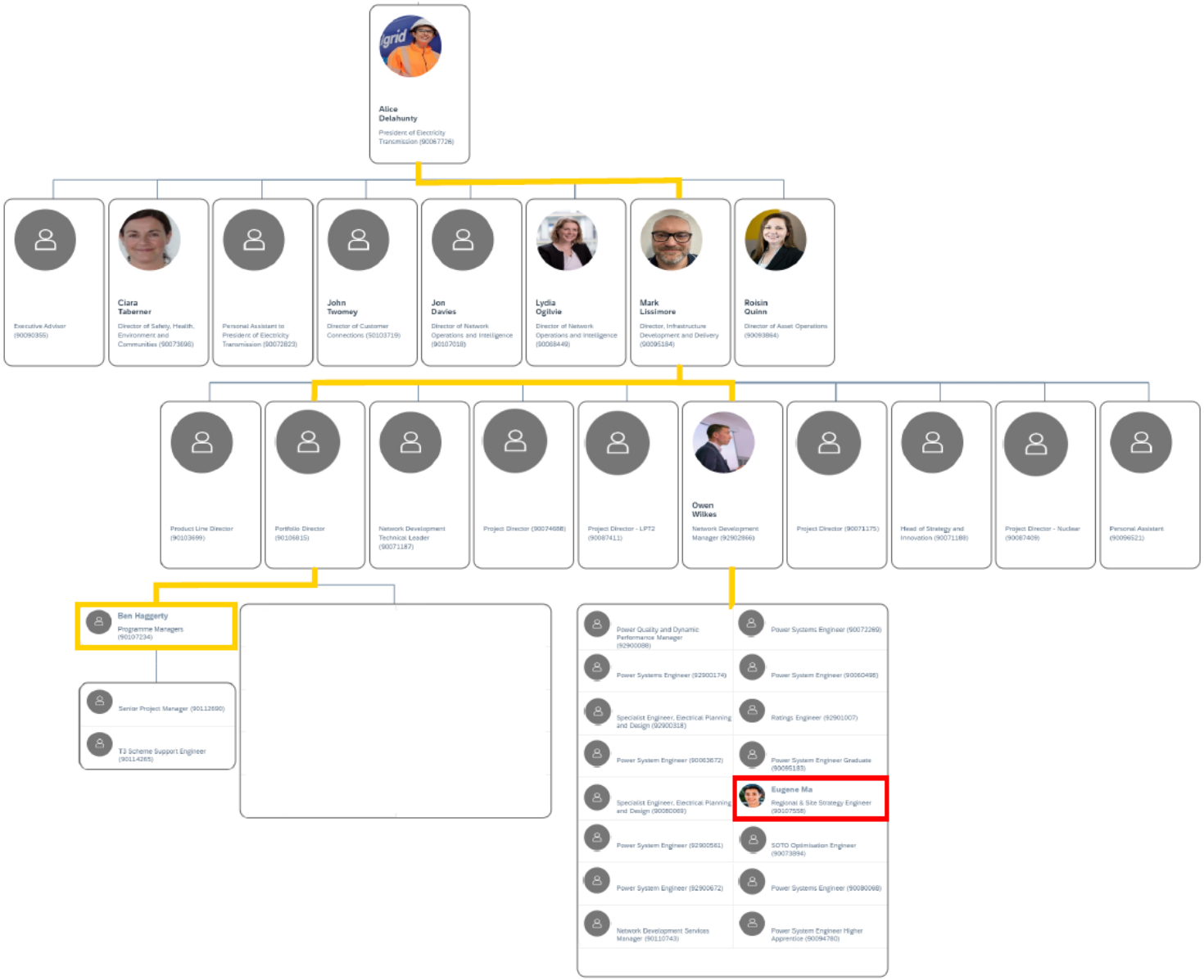


Figure 2 - My Role Organisation Chart

2.2 State of the Network

The United Kingdom has set world-leading climate change targets. By 2030, the government intends to deliver 40GW of offshore wind generation and by 2050, achieve Net Zero.

The decarbonisation of the energy system is one of the biggest challenges facing the world, and National Grid has a critical role to play in transitioning towards a cleaner future. The existing network was designed to connect and transport energy from coal, nuclear and gas-fired power stations. In many parts of the country, those power stations were located close to large centres of population.

Many wind developments are looking to connect their energy into Scotland and into the East England network. Due to the growing amount of generation in Scotland, it is forecasted that the Scottish-English transmission will need to quadruple to meet transfer requirements during periods of high sun and wind. The East England network will require a transformation on a similar scale. As a consequence, there is a strong need to increase not only the north-to-south capability in the NGET network but also the east-to-west capability. National Grid Electricity Transmission aims to develop a well interconnected network capable of distributing supply from Scotland and East England.

Despite the level of investment expected to be required in the future, the power system owners have remained cautious due to the lack of clarity around the specific investment needs of the network. Similarly, generator projects have been delayed due to the potential lack of capacity in the network. To avoid stand-offs between developers and network owners, National Grid Electricity System Operator has stepped in to create the Future Energy Scenarios (FES).

2.2.1.1 Future Energy Scenarios

Future Energy Scenarios (FES) outlines four possible pathways of the whole energy system out to 2050. Based on extensive stakeholder engagement, research and modelling, each scenario considers how much energy the UK might need to reach net zero, where it could come from and how outstanding levels of system reliability can be maintained. The information is used to:

- Underpin energy network investment;
- Support financial investment decisions for net zero technologies;
- Inform national and regional policy, and;
- Carry out academic research and innovation.

The four energy scenarios are shown below in Figure 3.

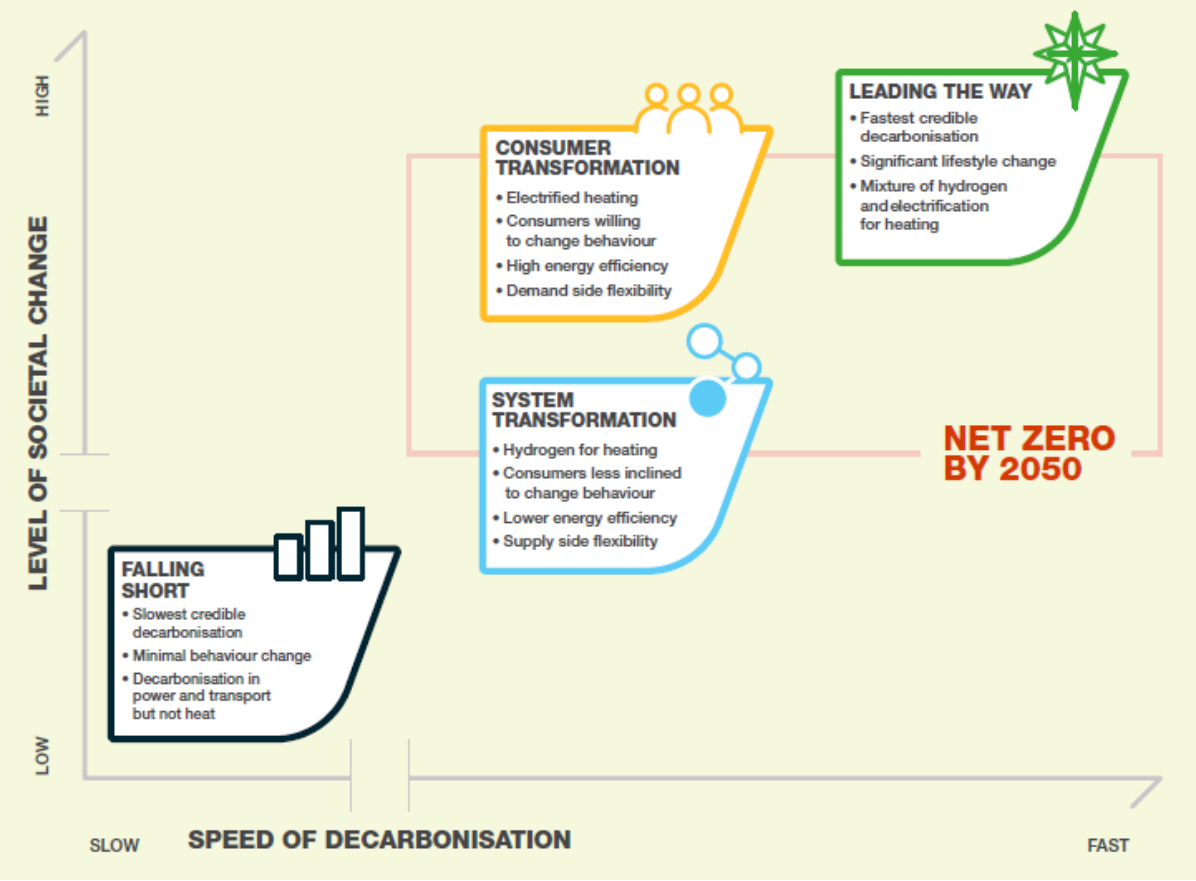


Figure 3 - Future Energy Scenarios

Leading the Way is a scenario that reaches net zero by 2046. The scenario assumes that Great Britain would decarbonise rapidly with high levels of investment in world-leading decarbonisation technologies, where areas of decarbonisation are pushed to the earliest credible dates. Consumers would be highly engaged in reducing and managing their own energy consumption and hydrogen is used to decarbonise some of the most challenging areas such as some industrial processes, produced mostly from electrolysis powered by renewable electricity.

Consumer Transformation describes the scenario where the net zero target is met in 2050 with measures that have a greater impact on consumers. In this scenario, the consumer would have made extensive changes to improve their home's energy efficiency and most of their electricity demand would be smartly controlled to provide flexibility to the system. The system would have higher peak electricity demands managed with flexible technologies including energy storage, demand side response and smart energy management.

System Transformation describes a scenario where the net zero target is met in 2050. The typical domestic consumer would experience less change than in Consumer Transformation as more of the significant changes in the energy system would happen on the supply side. Total hydrogen demand would be high, mostly produced from natural gas with Carbon Capture, Usage and Storage (CCUS).

Falling Short is described to be the scenario that does not meet the net zero by the 2050 target. There would still be progress on decarbonisation compared to today, however, it would be slower than in the other scenarios. While home insulation improves, there would be

still heavy reliance on natural gas, particularly for domestic heating. Electric Vehicle take-up would grow more slowly, displacing petrol and diesel vehicles for domestic use.

The key purpose of these scenarios is currently to underpin network investment decisions aimed at improving the delivery of generation to load centres. Limited information has been provided by the FES or by NGESO regarding changes to demand in the UK. The possibility remains that the demand landscape may change significantly as a result of increasing power requirements in traditionally overlooked areas. It is expected that the network reinforcements used to increase the north-to-south capability will be capable of supply demand up to 2040. Beyond this, there is significant uncertainty.

To combat the lack of clarity regarding demand growth in long term planning windows, the Distribution Network Operators (DNOs) in the UK have started the process of publishing Distributed Future Energy Scenarios (DFES). The creation of the DFES has required significant engagement with the NGESO, NGET and local governments. Developing an improved understanding of local targets and trends will enable accurate forecasts that will ensure that the transmission and distribution network requirements are met.

2.2.2 The National Grid Challenge

National Grid Electricity Transmission is faced with a myriad of challenges inherent to the dynamic energy landscape. These challenges span from the fundamental need to modernise aging infrastructure to the intricate demands of transitioning towards a sustainable, resilient, and digitally connected energy future. I have described a number of challenges that are considered in my role as a Regional and Site Strategy Engineer.

- **Boundary Constraints** – Managing power flows and the thermal capacity of the network is one of the key focus areas for National Grid. To facilitate the connection of renewables, National Grid Electricity Transmission is investing heavily in their network and in new infrastructure to increase capability across key planning boundaries. The NGET planning boundaries shown in Figure 4 are publicly available.
- **System Voltage** – Traditionally located around the country, power stations have been a critical source of voltage control in the UK network thanks to their reactive power capability and their proximity to sensitive areas. As power stations retire and generation moves away, the UK network will face challenges in managing voltages due to reducing reactive compensation in the network.
- **Asset Health** – Managing the health of National Grid infrastructure is currently a significant challenge and will continue to be so in the coming years. The UK 275kV network was constructed in the 1950s and only a decade later, construction on the 400kV supergrid began. With most assets aged between 40-60 years old, difficult investment decisions will need to be made for substations, overhead lines and cables.
- **Resourcing** – The generation landscape described by the FES and reflected in the connection data presents a network powered by offshore wind and solar/battery hybrids. The volume of connections is vast with around 1000 contracted connection requests equating to a total generating capacity of 300GW. National Grid Electricity Transmission faces an incredible challenge of allocating resources between connection responsibilities and network reinforcement tasks.

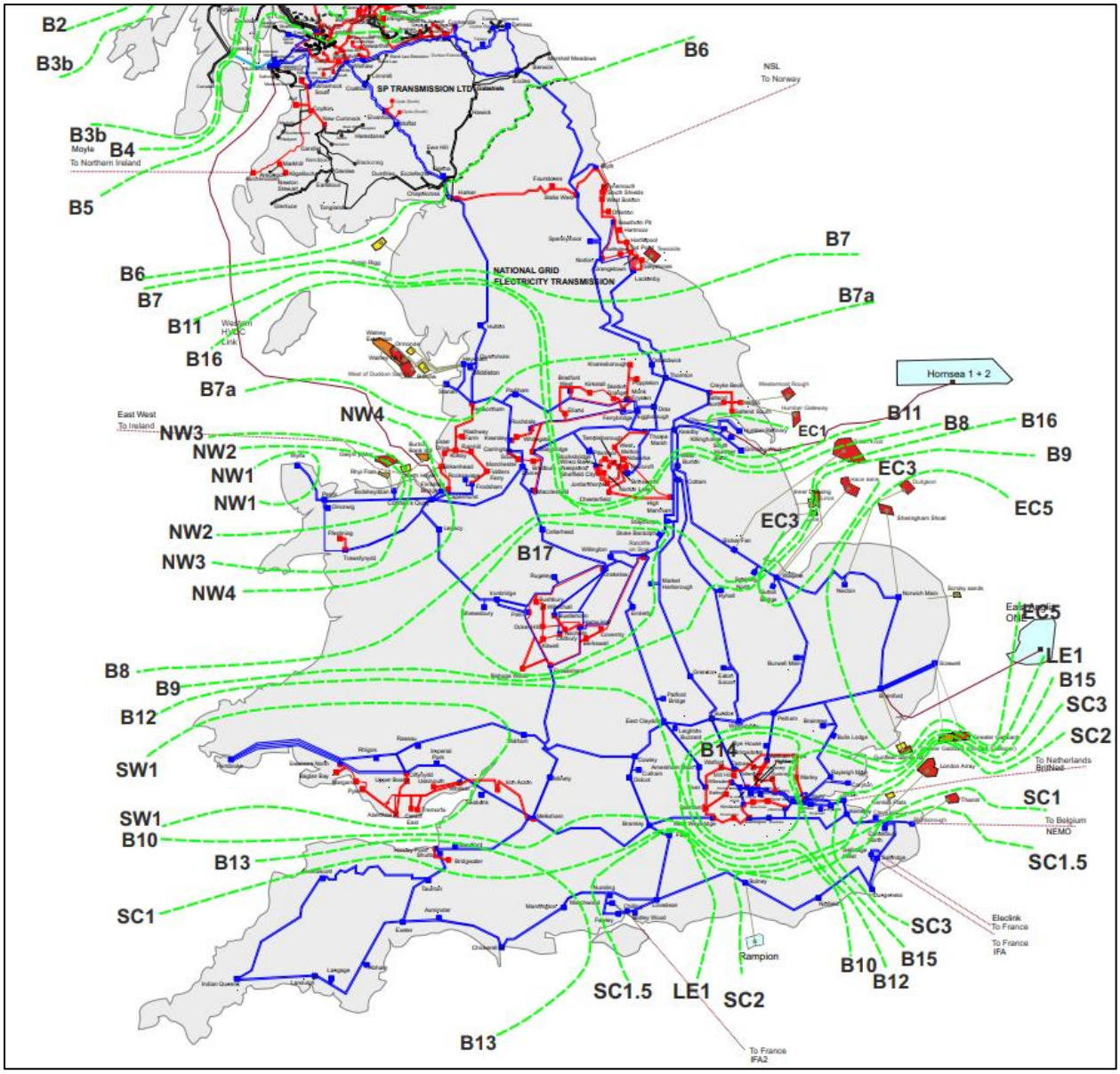


Figure 4 - UK Planning Boundaries

3 Projects

3.1 Introduction

The Office of Gas and Electricity Markets (OFGEM) is the government regulator for the electricity and downstream natural gas markets in Great Britain. OFGEM is responsible for setting out price controls on the companies that run the gas and electricity networks in Great Britain. To ensure that current and future consumers receive the network services they require at a fair price, OFGEM uses a RIIO model.

The RIIO (Revenue = Incentives + Innovation + Outputs) model is a regulatory framework implemented by OFGEM. It sets out the framework through which revenue for electricity and gas transmission and distribution network operators, such as NGET, for a specific regulatory period. The key components of the RIIO process include:

1. **Revenue**: The RIIO framework determines the revenue that network operators are allowed to collect from consumers over the regulatory period. This revenue is intended to cover the costs of operating, maintaining, and investing in the network infrastructure.
2. **Incentives**: RIIO incorporates performance incentives to encourage network operators to deliver efficient, reliable, and high-quality services to consumers. Operators can earn financial rewards for exceeding performance targets and face penalties for underperformance.
3. **Innovation**: The RIIO framework promotes innovation by incentivising network operators to invest in new technologies, processes, and practices that enhance the efficiency, resilience, and sustainability of the energy network. This includes initiatives to support the integration of renewable energy, improve grid flexibility, and enhance cybersecurity.
4. **Outputs**: RIIO focuses on the outputs or outcomes delivered by network operators rather than the inputs or activities. This means that operators are incentivised to achieve specific performance targets and deliver tangible benefits to consumers, such as improved reliability, reduced carbon emissions, and enhanced customer service.

National Grid Electricity Transmission is currently working towards submitting a revenue proposal for the T3 price control between 2026 and 2031. The revenue proposal will encompass the work NGET will perform in the following price control period. The work will span across all NGET Delivery Vehicles and will require extensive coordination with internal and external stakeholders.

The work planned to be performed by each Delivery Vehicle is not mutually exclusive. Their implications on the network must be considered as a whole to ensure that resources and outages are bundled to maximise the efficient use of resources and minimise the cost to consumers without compromising on creating a network that is ready for net zero.

3.2 Regional Strategies and Whole System Planning

The extreme volume of work required to transition to a renewable power system means previous incremental approaches to planning and development cannot continue. Regional Strategies are documents created to bring together network and stakeholder requirements for the RIIO-T3 price control submission and beyond. Their intended purpose is to provide a view of the network that would allow the business to step back and access the network in the whole. This will enable NGET to determine the optimal path forward and surface more urgent key dependencies which require deeper analysis to ensure holistic, whole system decisions are made.

Many drivers can affect the outcome of individual interventions that NGET has planned. When combined, these drivers and interventions can also affect longer term network investment decisions. When building a Regional Strategy, the key decision-making drivers must first be collated to develop an understanding of the network. The NGET Delivery Vehicles (DVs) that have a significant effect on regional and site investment decisions were consulted. A brief description of the work performed by each consulted DV is provided below.

- The Customer Connections (CC) Delivery Vehicle is responsible for providing the means for customers to connect to the network. Accountable from contract negotiations through to generator commissioning, CC is also required to perform substation extensions to accommodate customers and construct or upgrade the transmission lines that directly serve customers. CC is planning and resourcing for around 1000 contracted connections.
- Asset Operations (AO) is concerned with managing and maintaining the aging NGET asset base. Covering both substation and transmission line infrastructure, AO must monitor, plan and price the work required for asset maintenance and replacement. Resilience and certain strategic initiatives such as SF6 removal are also headed by AO.
- Infrastructure Development and Delivery (IDD) is responsible for determining the outage and network investments needed to meet future requirements. Both external and internal forecasts are utilised by IDD to build a strategic network development plan that includes both onshore and offshore reinforcements. IDD is responsible for the delivery of smaller projects in the strategic network development plan such as line reconductoring, the installation of transformers and reactive plant. New overhead lines or HVDC projects are delivered by National Grid Strategic Infrastructure SI.
- Inputs from National Grid Strategic Infrastructure are crucial additions to the Regional Strategies despite being a separate entity to NGET. SI was created to take responsibility for the delivery of the largest, highest priority projects. These include both onshore and offshore transmission infrastructure developments. The timing and perquisite developments of SI projects must be considered in the Regional and Site Strategy documents to ensure projects run to schedule.

3.2.1 Customer Connections Drivers

Customer Connections are experiencing a very high volume of connection requests. While there are around 1000 customers contracted to connect, it is widely believed that the majority of these will be withdrawn. Although the Future Energy Scenarios can be used to underpin large network investments that can relieve the boundary constraints across entire regions, the uncertainty of individual customers makes it difficult to develop site specific plans. More clarity is needed so investment decisions can be made, cost and delivered.

Customer Connections have performed market analytics to categorise the connecting customers into a range of confidence based on a mix of quantitative and qualitative information to help guide network and resource planning decisions. The analysis performed by CC examines a range of factors that impact project confidence.

A *Technology Score* was used as one of the key indicators of project confidence and differed based on the type of generator connecting. Generation types include batteries, solar, wind and gas turbines, etcetera. To determine the *Technology Score*, the generator type was assessed by analysing the following aspects:

1. Level of Oversubscription
   The FES, published by NGESO, set out the expected levels of generation by technology type in the coming years. These publications are intended to guide the market to achieve the correct generation mix. By comparing the total MW capacity of contracted connection requests with the capacity stated in the FES publications, an estimate can be made regarding the number of connections that will ultimately connect. Thus, technology was scored based on the level of oversubscription.

   For example, if a technology had 10GW of contract connection requests and an expected capacity of 1GW in the FES, the technology is 10 times oversubscribed and would receive a low score. An undersubscribed technology would receive a higher *Technology Score*.

2. Maturity of Technology
   Technology scores were also dependent on the maturity of the technology used by the connecting plant. More weight was given to connections with proven technologies like wind or solar compared to developing methods of electricity generation.

A *Company Score* was another key indicator of confidence and differed based on the parent company of the connection. Scores would be determined by analysing a range of public and sensitive information regarding the company. No further details can be provided.

Finally, a *Project Score* was given to a contracted connection based on project milestones. A milestone can include securing Power Purchasing Agreements (PPA) and Contract for Differences (CfDs).

The *Technology Score*, *Company Score* and *Project Score* were totalled and a confidence indicator was assigned to the connection. Connections with low confidence were discounted in further studies. The scores require constant updating as more information is obtained.

The Regional Strategy documents captured the generation volume, capacity, confidence, location and type. The information provided will be used to support network investment decisions.

3.2.2 Asset Operations Drivers

The transition to a renewable economy will test the resilience of a loaded network running on an aging asset base. At National Grid Electricity Transmission, Asset Operations is responsible for maintaining the delicate balance between managing asset risk and making the best use of the limited substation resources available. While there can be a need to replace an asset, NGET endeavours to align asset maintenance work with project work. Asset replacements triggered solely by asset health factors are performed only when absolutely necessary.

The timing of asset health triggers rarely aligns with other work requirements. As a result, some assets will require life extensions to reach the work date and in other cases, assets will be replaced with usable life remaining. National Grid has determined that this delivery model will ultimately result in lower costs and enable more customers to connect.

Assets Operations have been working to identify priority sites that require significant investment and coordination due to widespread asset health concerns. The assessment is mainly based on top-down analysis which evaluates the health and remaining life of all assets found in a substation. The ratings of individual assets are based on the CIGRE TB858 standard. The substation is then rated based on the condition of its constituent assets. I have attempted to explain the site rating process below:

1. Key assets are picked for assessment. These assets are generally long lead-time assets but may include assets that are resource intensive to replace. Examples include transformers, reactive plant and circuit breakers.
2. Each asset category is weighted. Assets may be weighted based on monetary cost, lead times, outage requirements, etc.
3. The asset category weighting is then multiplied by the number of assets in that category reaching end of life to find the *Substation Non-Linear Score* before penalties.
4. Substation penalties are then multiplied by the score to find the *Substation Non-Linear Score*. The application of substation penalties is intended to capture the added complexity of performing maintenance on significant elements not captured in Step 1. These can include civil asset issues, leaking SF6 assets or substation subsidence.

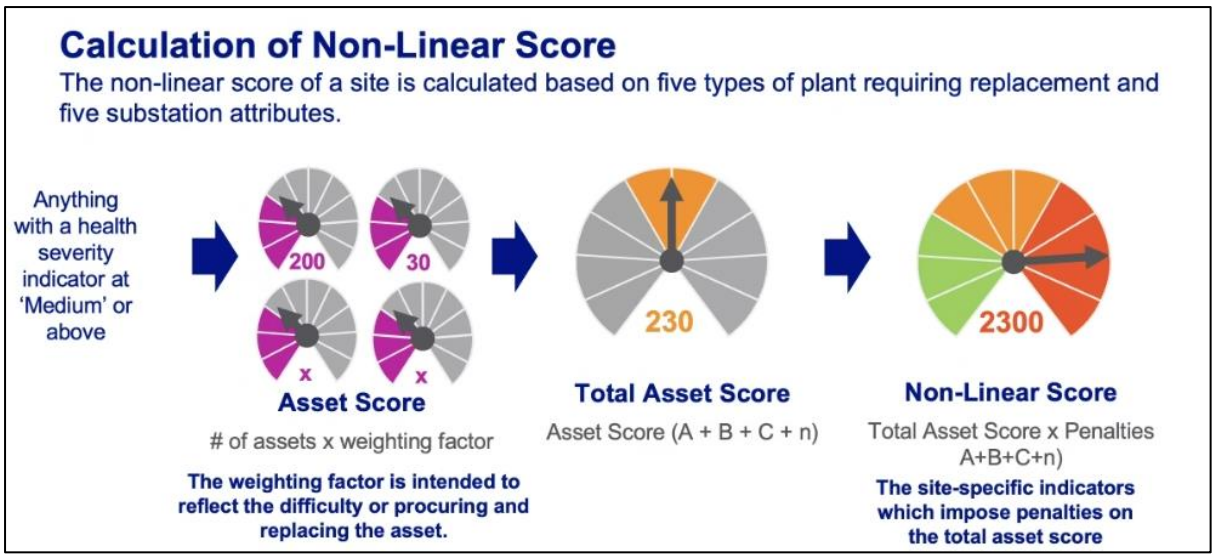


Figure 5 - Asset Score Infographic

An example calculation table is shown below.

Table 1 - Example Substation Rating

Key Asset Description	Transformer	Capacitor	Circuit Breaker
No. Reaching EoL	1	2	5
Key Asset Multiplier	10	2	1
Substation Penalty	10		
Substation Non-Linear Rating	190		

Performing asset replacements on an aging site can be challenging due to long outage requirements. For sites with multiple work drivers, the best option may be to replace the site completely. To help coordinate site works, substation and transmission line health data are important inclusions of the Regional Strategy documents.

3.2.3 Strategic Infrastructure and Infrastructure Development and Delivery Drivers

SI and IDD drivers can be bundled as they are in place to meet demand or strategic requirements.

3.2.3.1 Demand

The ESO has not yet provided a clear picture of the demand outlook for the UK. While DNOs have begun publishing Distribution Future Energy Scenarios, developing a clear and consistent understanding of the demand future will require significant stakeholder engagement and analysis to ensure that the network is developed accordingly. IDD utilises a variety of tools that help determine the investment required to meet the upcoming needs of the distribution networks.

Neptune is a program used by NGET that models growth in generation and demand at bulk supply points to identify upcoming network investments. New transmission infrastructure is considered once the distribution network is saturated. The requirement can be a result of growing demand or from the need to support the export of power from embedded generation. New distribution lines, transformers or even substations that serve as a new entry point into the distribution network are possible interventions. Neptune is considered to be the first of two stages and is responsible for identifying areas of the network that require further reinforcement stemming from the distribution network.

An image of Neptune has been captured below. The network is separated into areas based on the configuration of the transmission and distribution networks. Stage one establishes the demand growth within each area.

Figure 6 - Neptune, Separation into Grid Supply Groups

National Grid utilises a separate program to determine the optimal site for new transformers to be installed. Not much information was gathered regarding this program. However, it is understood that the program uses the outputs from Neptune and is part of a coordinated effort with distribution companies to determine the optimal transformer locations.

3.2.3.2 Infrastructure Developments

The information provided so far in the Regional Strategies set the backdrop for the network investments that have been planned. Although readers of the Regional Strategies do not require an understanding of the network to the depth of planning engineers, the information in the documents must still provide the reader with high-level explanations for upcoming network investments.

The network investments have been defined in a number of joint planning studies between NGESO and the three TSOs in the UK. An extensive range of onshore and offshore investments have been planned to make the UK network capable of delivering net zero by addressing the upcoming system requirements. The Network Options Assessment (NOA) publications typically define a range of onshore projects whereas the Holistic Network Development (HND) reports describe a combination of onshore and offshore projects.

NOA projects are typically aimed to address potential constraints in the UK power system. A boundary becomes constrained if more electricity is forecasted to cross the boundary than its capacity can handle. Stemming from Future Energy Scenarios, NGESO identifies and presents a set of system requirements to which the transmission owners assess and respond with a set of network reinforcement options. NOA is an economic analysis of these options.

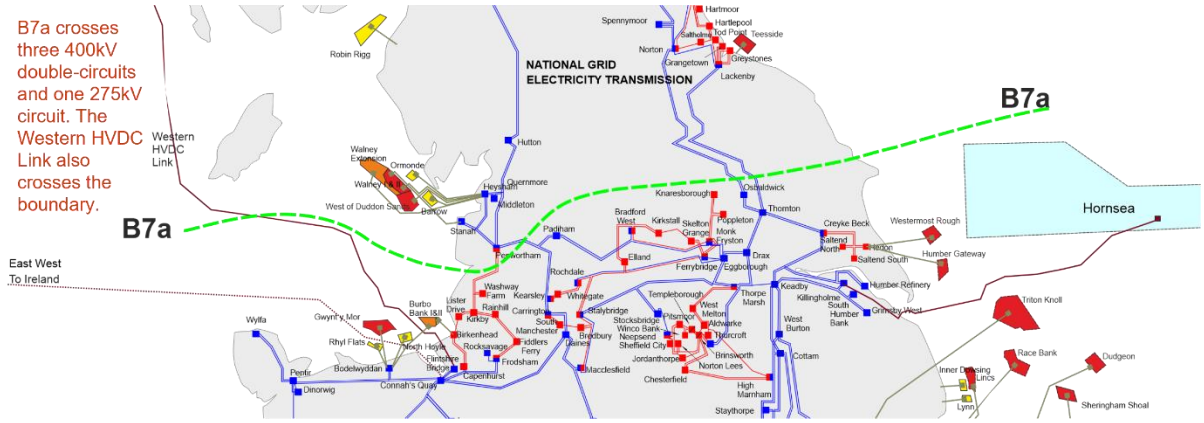


Figure 7 – Example Boundary B7a

NOA makes economic recommendations by comparing the cost of managing system constraints against the cost of reinforcing the network. Typical NOA investments include:

- New AC transmission line infrastructure;
- New transformers;
- Installing power flow control devices to manage power flow;
- Installing reactive plant to balance system voltage;
- Circuit capacity upgrade by reconductoring.

The NOA outcomes are grouped into four categories.

- **HND Essential** – Onshore reinforcement options that must be delivered by 2030 to facilitate HND and the connection of a significant level of offshore wind.
- **Proceed** – The optimal delivery date falls on or is earlier than the Earliest In Service Date (EISD) and there is value in the delivery of the investment.

- **Hold** – The optimal delivery date falls after the EISD and there is value in the delivery of the investment. TSOs must continue to keep the option deliverable on its optimal date.
- **Do Not Start/Stop** – Solution not optimal, or no need seen.

HND was conducted to facilitate the connection of 50GW of offshore wind generation by 2030. The HND is made up of several individual recommendations to develop the onshore and offshore networks. Most notable in the HND publication was the recommendation for an offshore network to be constructed. An offshore network, which includes offshore substations, is said to reduce undersea cables, minimise network constraints and provide billions of pounds of savings when compared to radial connections. A recommended offshore network design is shown below in Figure 8.

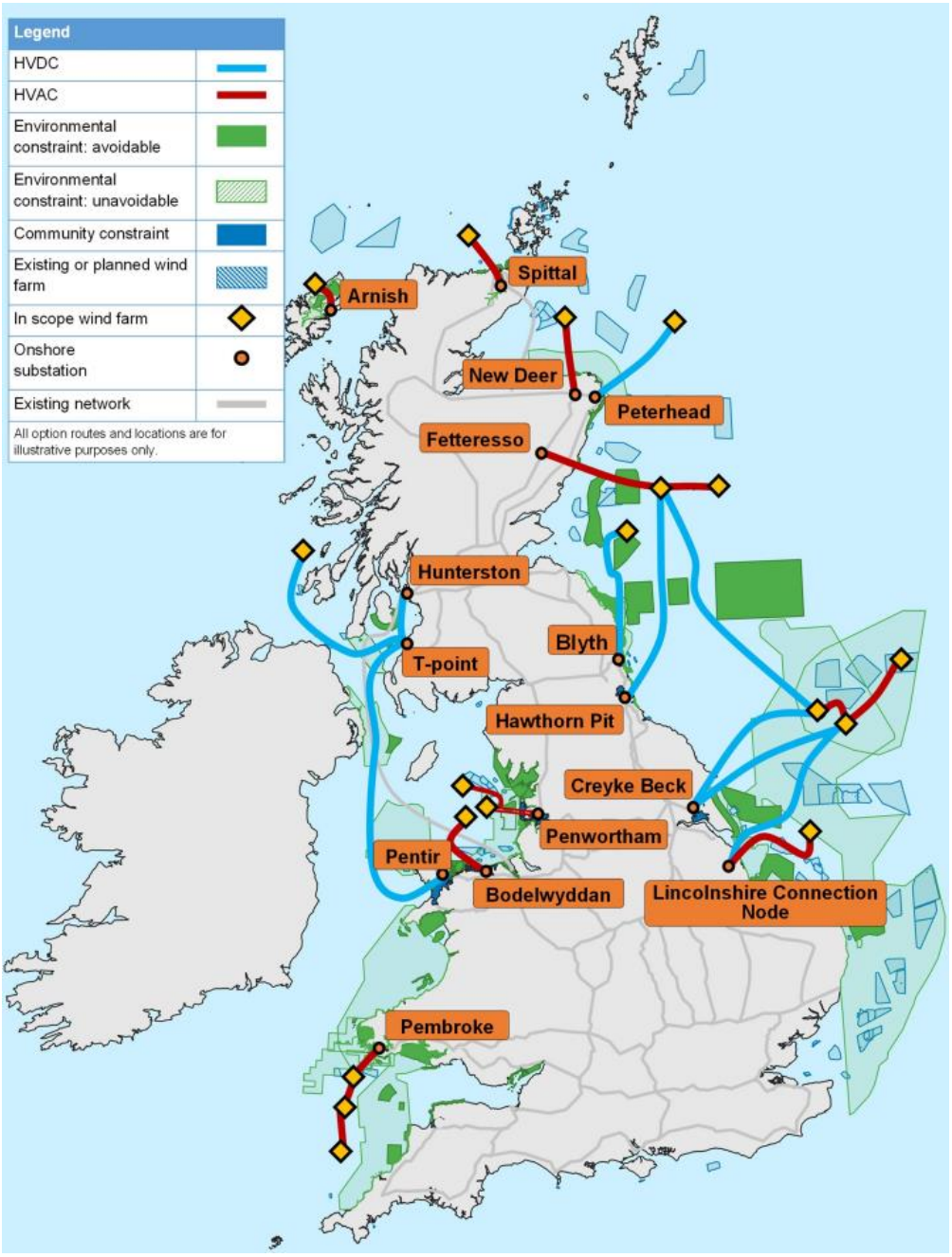


Figure 8 - HND Recommended Design

The NOA and HND projects were linked to the existing portfolio of works and graphically depicted in the Regional Strategies. By establishing a combined portfolio of work mapped geographically, the Regional Strategies provided an opportunity to align and bundle work in the region.

3.2.4 Regional Strategies Closing Thoughts

The collation of investment drivers and planned network investments in the Regional Strategies provides an accessible way for all staff members to gain an understanding of relevant projects in their region. The Regional Strategies remain in development as the structure is reviewed and feedback is received from internal stakeholders. Before the submission of the RIIO-T3 draft in March, the Regional Strategies will be expanded to include sustainability, planning, resilience and external stakeholder information.

The Regional Strategies were created in part to bridge gaps formed when NGET was restructured in 2021. However, there is a greater enduring need in the business to have an up-to-date portfolio of works that accurately describes the work and its timing to enable the design and delivery of optimal solutions. National Grid Electricity Transmission utilises an outage optimisation program called Copperleaf. It is believed that Copperleaf will be one of the enduring processes NGET will adopt to maximise the use of resources. Copperleaf ingests a portfolio of works and a set of user written constraints to create an optimised outage plan. The accurate description of the required work and available resources among other inputs, are vital to the quality of the program outputs. It is hoped that Regional Strategies will establish some of the processes that will allow Copperleaf to be utilised effectively.

Regional Strategies can lack the granularity required to make informed investment decisions at the substation level. This is especially apparent for complex sites with multiple investment drivers. Consequently, NGET has set out to create a set of Site Strategies.

3.3 Site Strategies

It is estimated that National Grid Electricity Transmission will be required to perform up to four times more work in the next price control period compared to the previous. Consequently, there is a need to plan for and maximise the use of construction resources now, before the demand for resources increases further. At select sites, NGET will perform substation upgrades as a single comprehensive project rather than through incremental changes and upgrades. These substations will be updated to meet future requirements of the site. The work performed at these sites may involve:

- Uprating sites from 275kV to 400kV or rationalising a 275kV site into a neighbouring 400kV site;
- Reconfiguring meshed corner sites to double bus;
- Installing the highest rated primary equipment, currently 63kA with the potential for >80kA in the future;
- Installing spare bays or at the very least, have sufficient substation space left to accommodate upcoming requirements.

Although upgrading sites to meet future specifications will require significant capital investment up front, NGET considers many of these investments to be on the core pathway of no to low regret options.

The phrases “Enable Net Zero” and “Do it once, Do it right” are common phrases at National Grid that come to mind when NGET is willing to take on risk. The responsibility of NGET to develop a network capable of transitioning to and supporting net zero weighs heavily in the investment decision-making process. This sentiment is largely in line with stakeholder feedback. Furthermore, there is a belief within the business that new infrastructure will be fully utilised eventually. Consequently, NGET is willing to invest now to ensure that any constraints or delays arising from limitations in transmission infrastructure are minimised, even if the cost of doing so is greater.

National Grid have established three primary approaches that the business takes when performing the substation upgrades described.

1. **Upgrade and Extend** – Keeping the existing site and opting to maintain and extend the infrastructure.

2. **Site Rebuild** – Building a new site near or next to an existing site up to future specifications to replace the old substation. After the circuits are transferred, the original substation is decommissioned.

3. **New Site** – Building and connecting a completely new site to the power system. The construction of a new site is expensive, resource intensive and can be subject to lengthy land and stakeholder consultations.

Each option will have unique benefits and drawbacks and it can be a difficult process to understand all requirements at a site. NGET have been developing Site Strategies as a process of grouping drivers to determine the optimal investment decision for a substation.

Site Strategy is a term used by National Grid to describe the process of determining investment decisions for a substation. At the time of writing, a formalised method of determining site investment decisions has yet to be captured. However, it is known that a range of drivers are gathered from across the business before the options are considered. Extensive consultation with key NGET personnel across all Delivery Vehicles is required for each step of the process to ensure the concerns of all parties are accounted for.

By observing the challenges from a whole system perspective, it is hoped that optimal planning, investment and resourcing decisions can be made.

4 Summary of Learnings

Index	**Learning**
1	In 2021, National Grid Electricity Transmission (NGET) restructured their business into multiple Delivery Vehicles (DVs). Each Delivery Vehicle was equipped with their own planning, project, finance and human resource teams which, in theory, allow the business groups to operate autonomously and thus deliver efficiency through vertically integrated processes. Furthermore, DVs provided clear lines of accountability up to executive management and allowed risk to be controlled within the business. The control of risk was achieved by balancing work portfolios between DVs. Under the Delivery Vehicle structure, employees have noticed a reduction in workplace collaboration following its inception. This business structure necessitates the need for regular cross-divisional meetings to fulfil informational needs
2	Regional Strategies are documents developed to bring together the network and stakeholder requirements across all Delivery Vehicles. Their intended purpose is to bridge the business silos to provide a view of the network that will allow the business to step back and assess the network in the whole. This will enable NGET to determine the optimal path forward and surface more urgent key dependencies which require deeper analysis to ensure holistic, whole system decisions are made. The key decision-making drivers are collated in the Regional Strategy to develop a broad understanding of the network. There are many drivers that can affect the outcome of individual interventions that NGET has planned. When combined, these drivers and interventions can also affect longer term network investment decisions. The information captured includes: • Connection volume and confidence broken down to site level; • Asset health summary of substations and transmission line infrastructure requiring intervention; • Demand Data pertaining to substation investment requirements up to 2050; • Network investments planned in the region. The Regional Strategies help bridge information gaps between the silos and have been useful in uncovering alignment opportunities between projects. Where possible, geographical information pertaining to the drivers should be captured in Regional Strategies. The Regional Strategies remain in development and several additions have been planned. Sections detailing sustainability, resilience, external stakeholder and internal planning information will be added to the documents.
3	NGET have been developing Site Strategies as a process of grouping drivers to guide substation investment decisions. Currently, based on extensive consultation with key personnel, a formalised method has yet to be captured.

4	NGET has taken an aggressive network development approach and is willing to assume the risk of doing so. The responsibility of NGET to develop a network capable of transitioning to and supporting net zero weighs heavily in the investment decision-making process. This is backed up by a belief within the business that new infrastructure will be fully utilised eventually. Consequently, NGET is willing to take on risks to ensure that any constraints or delays arising from limitations in transmission infrastructure are minimised, even if the cost of doing so is greater. Upgrades to sites can include: • Uprating sites from 275kV to 400kV; • Reconfiguring switched mesh sites to double bus; • Installing the highest rated primary equipment to avoid the need for rework; • Installing spare bays. NGET have established three primary approaches to perform the substation upgrades described. 1. **Upgrade and Extend** – Keeping the existing site and opting to upgrade, maintain and extend the infrastructure. 2. **Site Rebuild** – Building a new site near or next to an existing site up to future specifications to replace the old substation. After the circuits are transferred, the original substation is decommissioned. 3. **New Site** – Building and connecting a completely new site to the power system. The construction of a new site is expensive, resource intensive and can be subject to lengthy land and stakeholder consultations. For transmission lines, NGET are considering: • Reconductoring lines with the highest capacity conductors for lines that require conductor replacement or upgrades; • Performing line upgrades ahead of the need to release future resource capacity.
5	National Grid Electricity Transmission are experiencing a very high volume of connection requests. While there are around 1000 customers contracted to connect, it is widely believed that the majority of these will be withdrawn. National Grid have been performing market analytics to categorise the connecting customers into a range of confidence based on a mix of quantitative and qualitative information to help guide network and resource planning decisions. A *Technology Score* was used as one of the key indicators of project confidence and differed based on the type of generators connecting. Examples of generation types include batteries, solar, wind and gas turbines. To determine the *Technology Score*, the generator type was assessed by analysing the following aspects: 1. Level of Oversubscription The Future Energy Scenarios (FES), published by the UK Electricity System Operator, set out the expected levels of generation by technology type in the coming years. These publications are intended to guide the market to achieve the correct generation mix. By comparing the total MW capacity of contracted connection requests with the capacity stated in the FES publications, an estimate can be made regarding the number of connections that will ultimately connect. Thus, technology was scored based on the level of oversubscription.

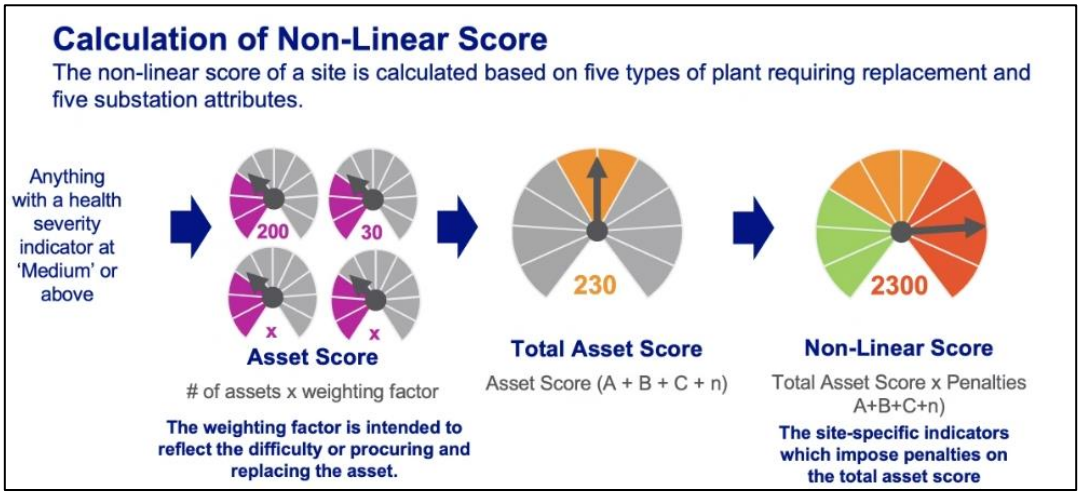
2. Maturity of Technology
   More weight was given to connections with proven technologies like wind or solar compared to developing methods of electricity generation.

A *Company Score* was another key indicator of confidence and differed based on the parent company of the connection. Scores would be determined by analysing a range of public and sensitive information regarding the company. No further details can be provided.

A *Project Score* was given to a contracted connection based on project milestones. A milestone can include securing Power Purchasing Agreements (PPA) and Contract for Differences (CfD).

6 The Assets Operations Delivery Vehicle at NGET has been working to identify priority sites that require significant investment and coordination due to widespread asset health concerns. The assessment is mainly based on top-down analysis which evaluates the health and remaining life of all assets found in a substation. The ratings of individual assets are based on the CIGRE TB858 standard. The substation is then rated based on the condition of its constituent assets. I have attempted to explain the site rating process below:

1. Key assets are picked for assessment. These assets are generally long lead-time assets but may include assets that are resource intensive to replace. Examples include transformers, reactive plant and circuit breakers.
2. Each asset category is weighted. Assets may be weighted based on monetary cost, lead times, outage requirements, etc.
3. The asset category weighting is then multiplied by the number of assets in that category reaching end of life to find the *Substation Non-Linear Score* before penalties.
4. Substation penalties are then multiplied by the score to find the *Substation Non-Linear Score*. The application of substation penalties is intended to capture the added complexity of performing maintenance on significant elements not captured in Step 1. These can include civil asset issues, leaking SF6 assets or substation subsidence.



5 Future Plans

At the time of writing, I have spent a little over three months at National Grid. My role is primarily strategic and provides the avenue for me to gain exposure to many parts of the business. However, due to the deadlines of the price control submission, there has been limited opportunity to gain exposure to items directly related to my ES Cornwall Memorial Scholarship topic. I have identified a number of relevant subjects that I intend to learn about over the next few months.

- NGET is undergoing a connections reform process that will enable the company to better manage the connection volume.
- As the Site Strategy process is formalised, I will attempt to capture how these site-specific decisions are made.
- Power controlling devices (quadrature boosters) can be found along many transmission roots. I will try to learn about how NGET utilises these devices.
- Performance standards for generators and demand are still areas that I am still to investigate.