Operability Strategy Report

December 2023

ESO

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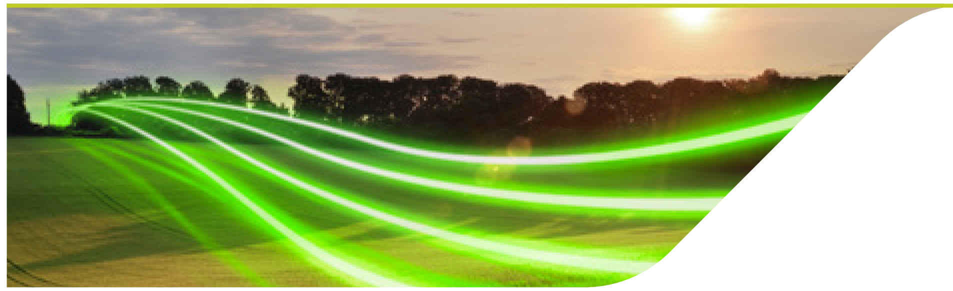

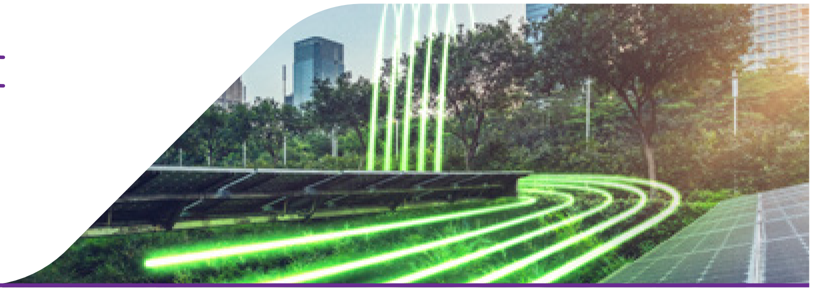

ESO Publications

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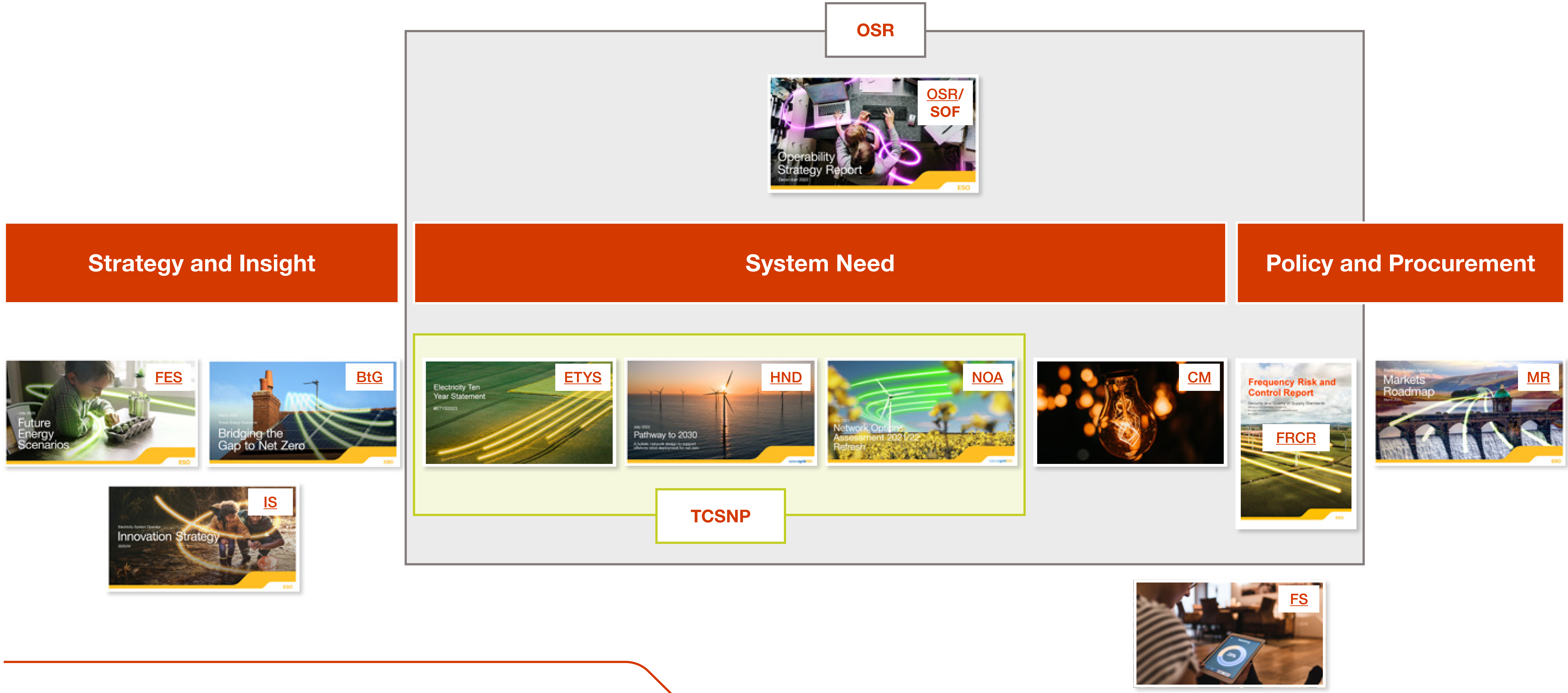

Foreword

Welcome to our annual Operability Strategy Report (OSR). The OSR explains the operability challenges we expect to face as the electricity system and industry continues to decarbonise. The report outlines our strategy for meeting these challenges as we progress to operating the electricity system at zero carbon for short periods of time in 2025, moving towards a zero carbon electricity system all of the time by 2035, in line with UK Government targets.

During 2023, we achieved periods of record high zero-carbon operation, with 90% of the generation mix provided by zero carbon sources. We managed both the lowest level of power provided by fossil fuel generation as well as the lowest carbon intensity on record.

Julian Leslie
Head of Networks and Chief Engineer, Electricity System Operator (ESO)

This year's report highlights the excellent work being delivered across the ESO and in collaboration with industry, ensuring we'll be ready to operate the transmission system with 100% zero carbon for short periods in 2025. Achieving this ambition requires two key deliverables. Firstly, the market must provide a zero carbon generation mix. Secondly, we must ensure we have the technical capability to operate a zero carbon generation mix. Our continued programmes of work will widen the operability envelope, enabling us to operate periods of zero carbon more frequently. In 2024, we'll start sharing regular information on the progress towards both our 2025 and 2035 targets.

We are already developing new tools, processes, strategies, and services that will identify system needs, increase capability, deliver operational tools and implement procurement routes. The Centralised Strategic Network Plan (CSNP) is evolving our network planning process to consider a wider range of operational scenarios and more system requirements. We're expanding the Frequency Risk and Control Report to provide a multi-year view of risks and controls. A new Flexibility Strategy is being developed to manage variability in supply and demand and we need to ensure there will be sufficient non-weather dependent technology to meet electricity demand.

Taking this wider system view is a key part of our new role as we transition to the Future System Operator in 2024 and we look forward to working with industry as we progress to a zero carbon electricity system.

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Zero Carbon Operability

Zero Carbon Operability

Progress to Zero Carbon Operability

Great Britain continues to be one of the fastest decarbonising electricity systems in the world and we are on track to operate a zero carbon electricity transmission system for short periods in 2025.

Our plans to deliver new services, policies and processes are enabling us to get closer than ever to Zero Carbon Operation (ZCO) of 100%. The Loss of Mains Change Programme, Frequency Risk and Control Report (FRCR), Voltage and Stability Pathfinders, and Dynamic Containment (DC) have led to new maximum PV and Wind generation levels, minimum carbon intensity from electricity generation and a new maximum ZCO%. Individual records aren't the only story, in Q2 2023-24, 10% of all settlement periods had a higher ZCO% than the maximum ZCO% for the same quarter in 2022.

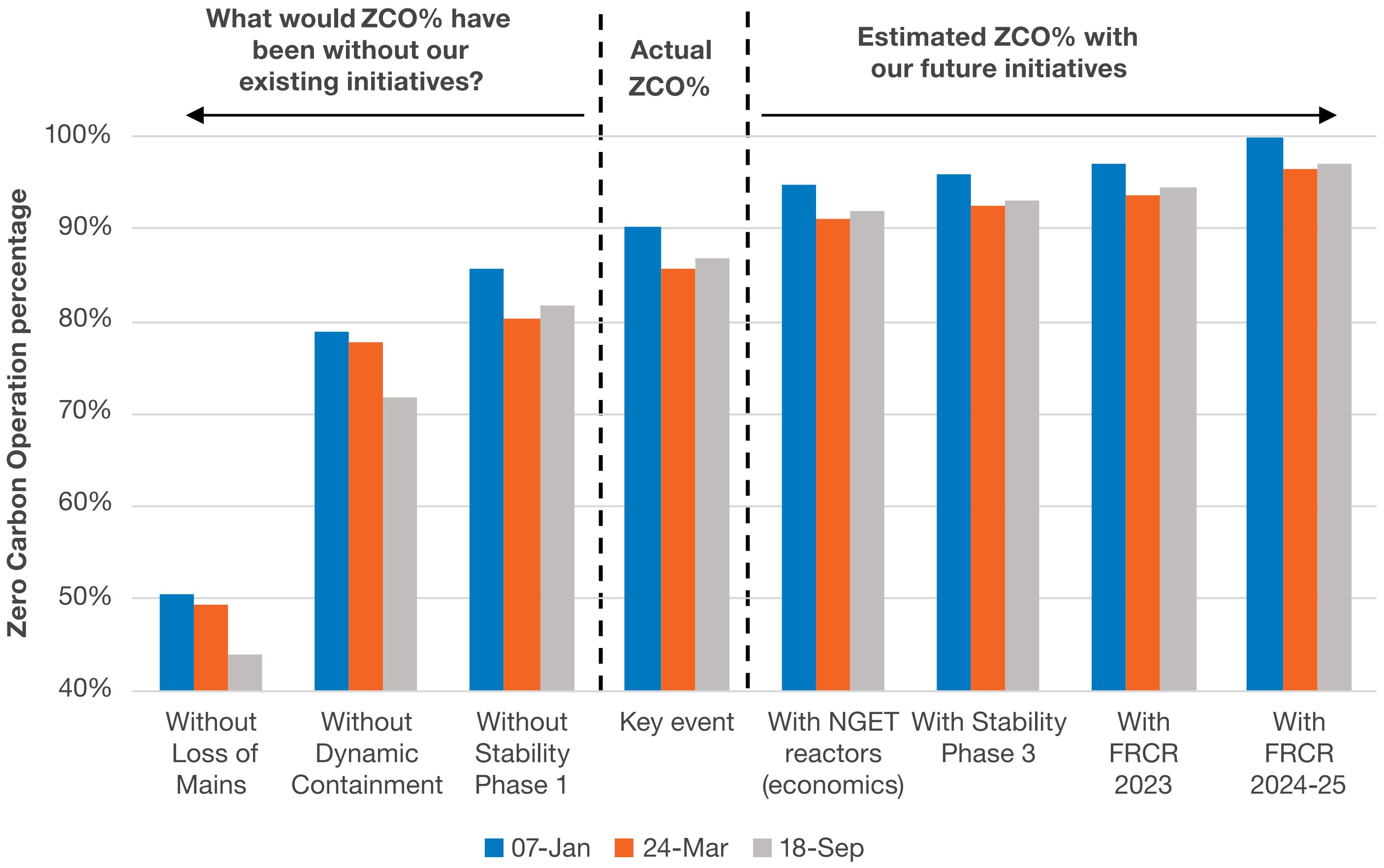
The remaining programme of work will close the gap to 100% ZCO and extend our ability to operate a zero carbon transmission system across more market and system scenarios. These programmes include further locational services across Voltage, Stability and Thermal, delivering reactive power, short circuit level and constraint intertrip services respectively. Development of FRCR policy has reduced the minimum inertia requirement for system operation and we expect to reduce it further by 2025.

The table shows key events from 2023 which show our progress towards 100% ZCO.

Date and Settlement Period	Event	ZCO%	Carbon Intensity (gCO_2/kWh)
7 Jan 2023 – 40	Maximum ZCO	90%	42
24 Mar 2023 - 22	Lowest generation from fossil fuel (1567MW)	90%	36
18 Sep 2023 - 31	Lowest Carbon Intensity	81%	27

For each of these events, the graph shows what the ZCO% would have been without the projects delivered so far, and what the theoretical ZCO% would have been once future projects are delivered.

Illustration of impact of ESO initiatives on ZCO%



When is Zero Carbon Operation likely in 2025?

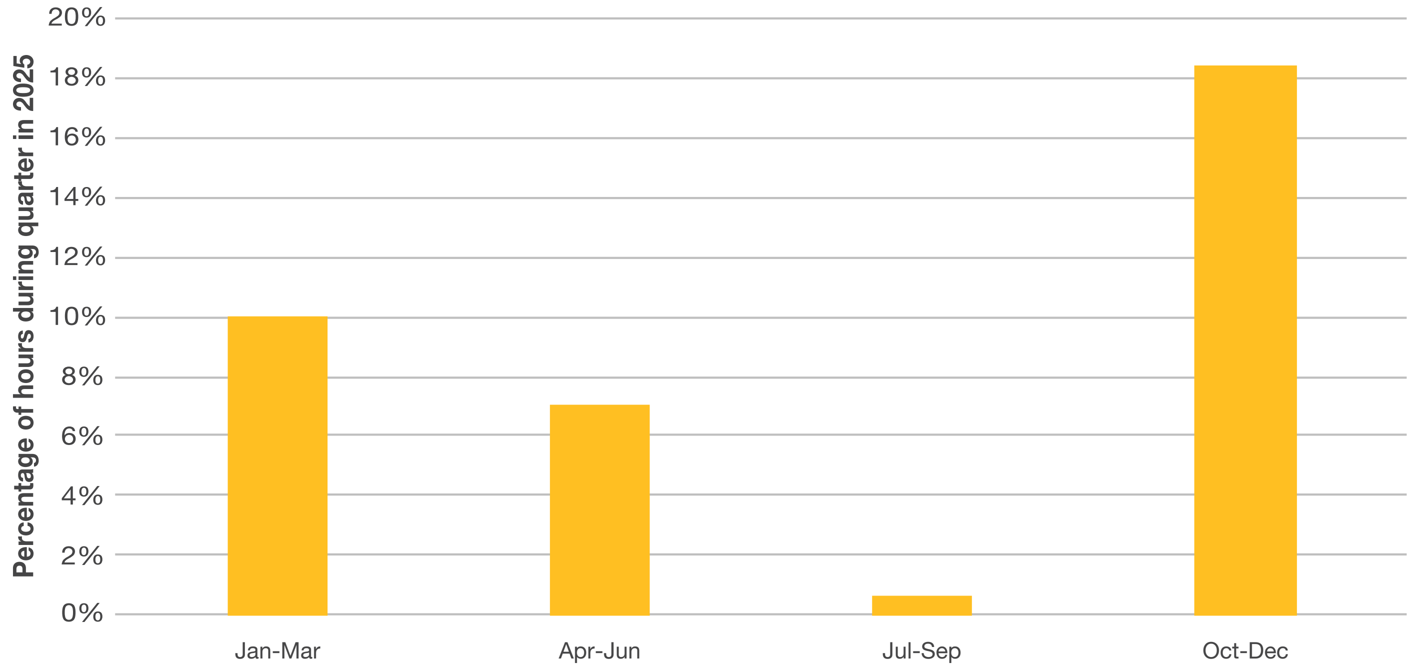
Our zero carbon ambition in 2025 is to be able to operate the transmission system for short periods when the market delivers a zero carbon generation mix. Whilst the market has yet to offer a 100% zero carbon solution, it came close in June 2022, offering 98.4%. It continues to regularly offer a generation mix greater than 90% and we expect significant periods of zero carbon generation to be provided by 2025.

When the market does offer a zero carbon solution, there will be times where our ability to manage that solution will be limited to wider system conditions. We expect to be able to operate a zero carbon system when demand is greater than 27GW as this provides sufficient inertia to meet minimum requirements and power flows are high enough to maintain voltage levels. The maximum solution is limited by the market meeting demand with zero carbon generation. Data from our Future Energy Scenarios suggests these conditions could be presented in ~13% of hours in 2025. After we have resolved constraints, we believe there could be approximately 9% of 2025 where we will be able to operate a market provided zero carbon generation mix. These system conditions suggest that the first periods of Zero Carbon Operation are likely to be during average periods and seasons rather than at extremes. For example this could be as demand ramps up in the morning or down in the afternoon during spring or autumn. The graph reflects this view showing that a zero carbon generation mix is less likely during the summer months.

Zero Carbon Operation is defined as the total transmission generation from zero carbon sources, as a percentage of total transmission generation.

$$ZCO(\%) = \frac{\text{sum (zero carbon transmission connected generation)}}{\text{sum (total transmission connected generation)}} \times 100$$

Percentage of hours in 2025 where Zero Carbon Operation could be possible



Transmission connected generation is defined as generation directly connected to the transmission system and participates in the Balancing Mechanism. It excludes Interconnectors.

Zero carbon transmission connected generation is a subset of this generation and includes wind, hydro, pumped storage, nuclear, solar and batteries.

Innovation

Innovation

Improving our capabilities to conduct EMT studies

[RealSim](#): Developing real time simulations of the GB power system for EMT assessments.

[Practical Transition into wider EMT GB Modelling](#): enhance the GB network's EMT analysis by improving the models' computational efficiency.

Quantifying our within-day flexibility requirements

[QWID FLEXER](#): Developing a method to quantify how much within-day flexibility the system will need, to be the foundation for later analysis of how to get it.

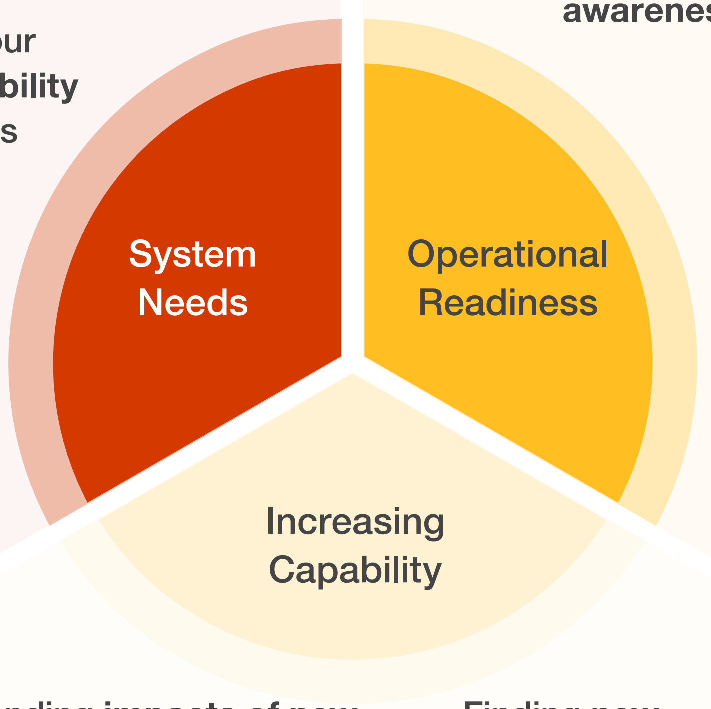
Optimising system strength metrics

[Strength to Connect](#): Developing a new method to measure grid strength as an alternative to short circuit level.

Improving overall system studies

[Reactive demands](#): Improved forecasting of reactive demand will reduce need to access/procure reactive power services leading to reduced costs for the end consumer.

[STARTZ](#): Reviewing and improving the current methods of calculating system stability needs for the GB network at a granular level, by implementing automation and machine learning techniques.



Developing tools to increase our operational awareness

[Inertia measurement optimisation](#): Analysing and verifying data from GE and Reactive inertia monitoring tools, comparing to our operational data with the goal of establishing a standardisation for inertia measurement.

[VoltaVisor](#): Developing tool to allow rapid provision of voltage management plans.

[Co-optimisation of Energy and Frequency-containment services](#): This project will develop a novel prototype software tool for achieving co-optimisation of energy and frequency control services.

Identifying methods for early oscillation detection and impacts

[DOME](#): Injecting a small high frequency signal at optimal locations on the GB system, to identify the root cause of oscillations and mitigate potential risks.

[CrowdFlex](#): Developing a model to understand the impact of consumer demand and domestic flexibility, increasing situation awareness.

Understanding impacts of new zero carbon technologies

[Hydrogen for constraints](#): Demonstrating how the large-scale production of green hydrogen can support the management of regional transmission constraints during times of high output from intermittent renewables generation.

[MinGFM](#): Investigating new methods and control strategies for grid forming converters without additional energy storage requirements.

Finding new capabilities

[Unlocking DER Reactive Power](#): Researching different options to address the technical challenges of gaining access to reactive power capability from DER.

[Distributed ReStart](#): Explores how distributed energy resources in Great Britain can be used to restore power in the event of a total or partial blackout.

NB. This is a non-exhaustive list of our innovation pipeline. For more details on ESO innovation or to get involved, visit the Innovation pages on our website.

Decarbonisation

ESO

Decarbonisation

What do we mean by decarbonisation?

Decarbonising the electricity power system in GB is critical to meeting the governments ambitions on the way to net zero. A sustainable energy system is something we are committed to enabling through all of our work. As the ESO, in our role of powering Britain, we want to ensure that we are ready to decarbonise the power system and this poses some challenges which, with industry, we intend to overcome. Here we explain what we mean by decarbonisation of the electricity system.

Decarbonisation of the electricity system is leading to changes in five key areas:

- Less dispatchable generation
- More asynchronous generation
- More variable sources of generation
- Generation moving to different areas
- More variable and unpredictable demand

Less dispatchable generation refers to the closure of traditional synchronous generators like coal and gas. These provided firm, flexible power and system services like voltage and stability. They were also typically used for restoration services.

More asynchronous generation refers to the increase in generators connected by inverter-based technologies, such as wind, solar and battery storage. These types of generators are less flexible than traditional synchronous generators and generally do not provide system services.

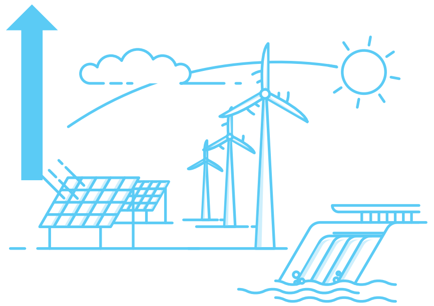
More variable sources of generation refers to the increase in generators which are more dependent on an input to generate, like sunshine or wind, and are more prone to variability in energy output due to input variability.

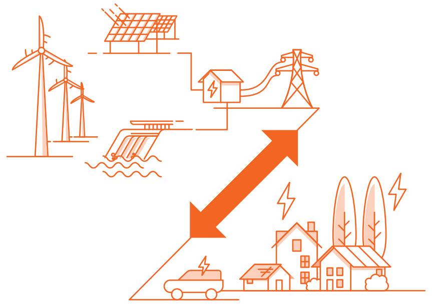
Generation moving to different areas refers to new generation locating at network extremities and further away from demand centres such as offshore, in Scotland and in South West England. It also refers to the increase in generation on the distribution networks.

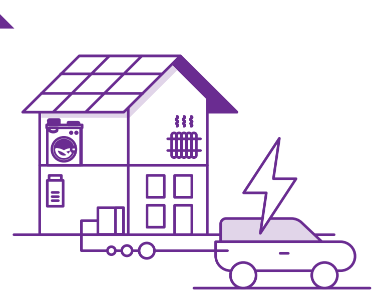
As we progress towards 2035, we expect to see an increase in the variability and unpredictability of demand. Here we refer to the increase in sources of demand responding to complex weather and price signals, such as heat pump use and electric vehicle charging during low prices or high renewable generation.


Less dispatchable generation


More asynchronous generation


More variable sources of generation


Generation moving to different areas


More variable and unpredictable demand

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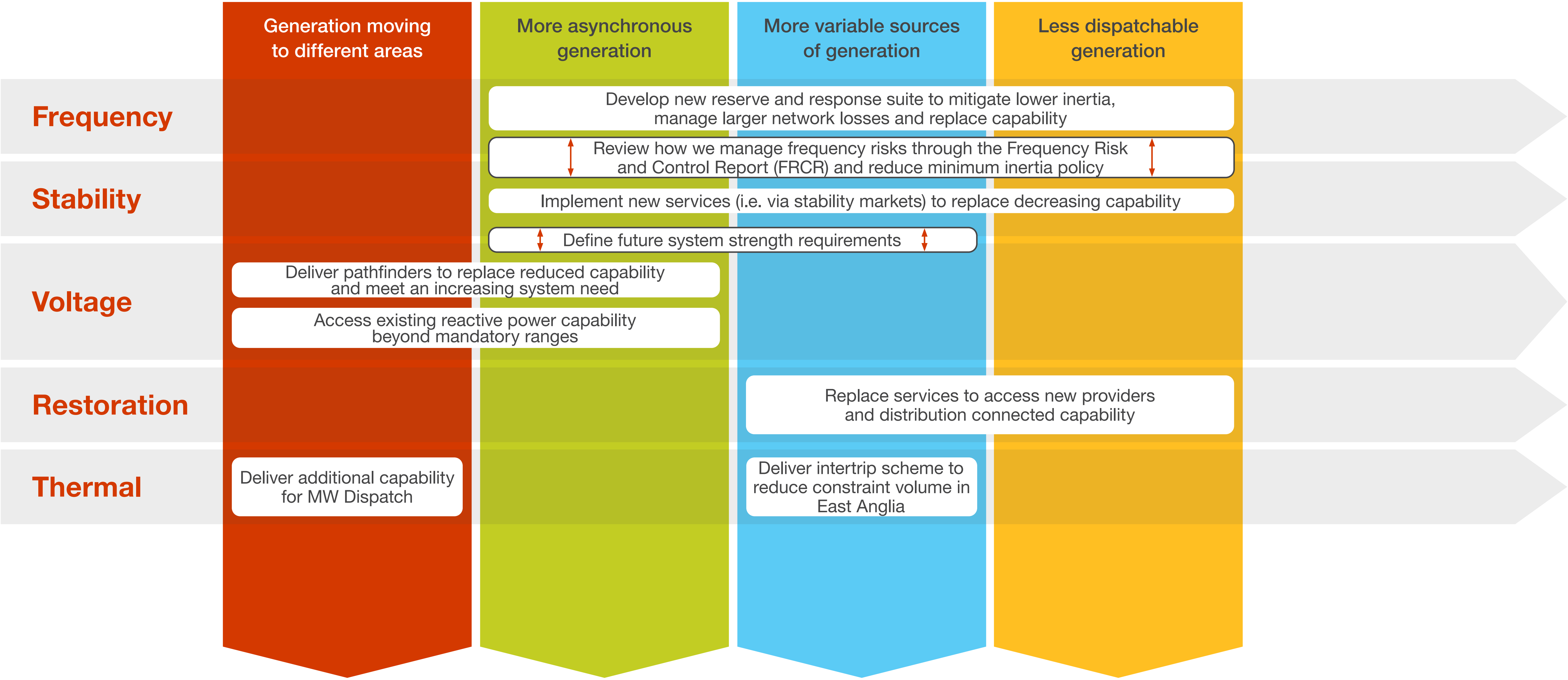
Zero Carbon operation in 2025

By 2025 our plans will enable us to overcome the decarbonisation challenges and operate the Transmission network carbon free for short periods.



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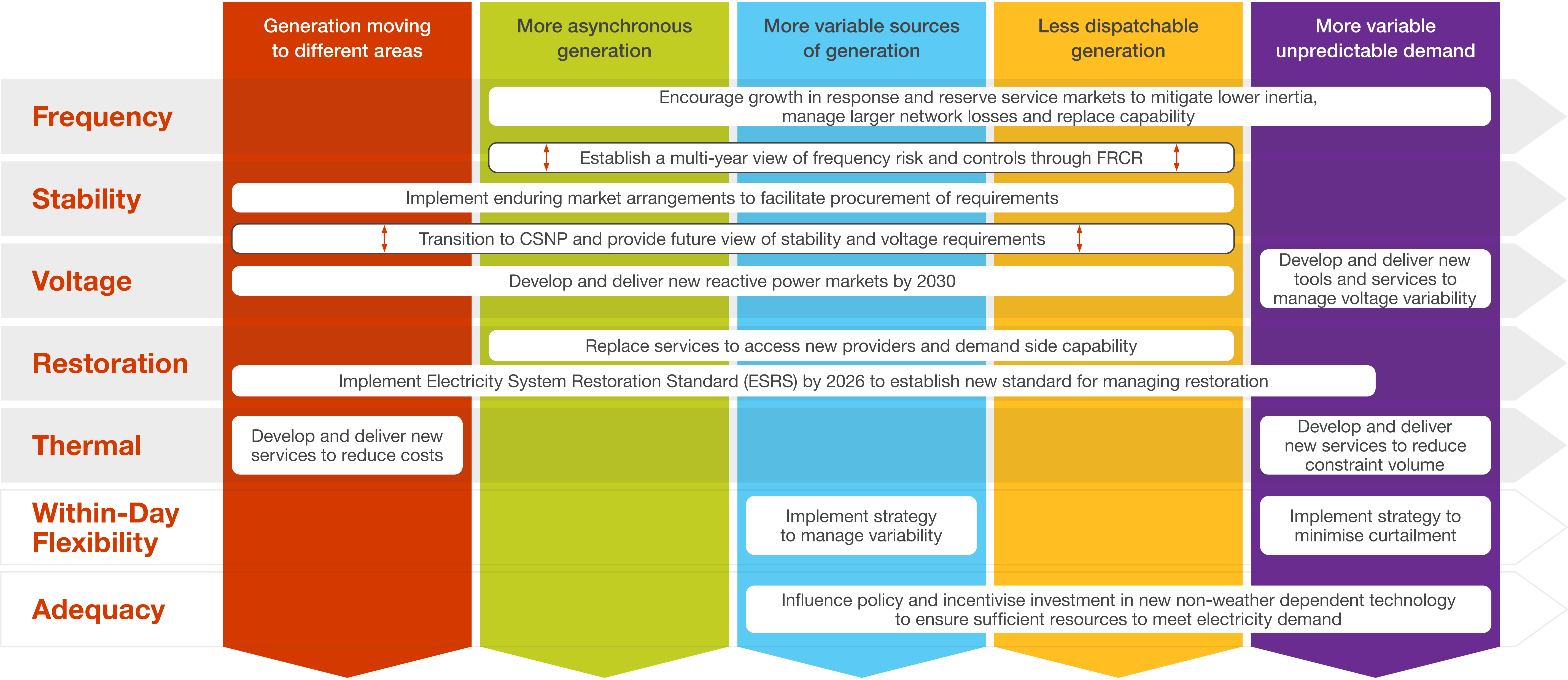
The gap to 2035

We are already identifying system challenges and needs for operating a net zero electricity system by 2035 and are developing the necessary strategies and services to deliver new flexible services and overcome over and under supply of energy.



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Reliable Network

ESO

Reliable Network

Operating the national electricity transmission system to deliver power safely and reliably requires management of power system characteristics locally, right across the network. The Thermal, Voltage, Stability and Restoration workstreams ensure that we can:

- Manage power flows across constraint boundaries
- Maintain voltage within safe limits
- Ensure the system is stable enough to cope with faults
- Recover the power system in the event of a partial or total shutdown of the network

We operate the transmission system second by second, monitoring characteristics of a high voltage electricity system and taking actions to keep these characteristics within safe limits of operation. These limits and requirements are set out in the Security and Quality of Supply Standards (SQSS) and the Electricity System Restoration Standard (ESRS). The physics of a high voltage power system require certain system services to be delivered at, or near, the point of need. Historically, most of these needs were met by large dispatchable generation, delivering reactive power for voltage management, and short circuit current for managing faults. These generators were well spread around the network and near to demand centres, which made them well placed for restoring the network following a power outage. It also minimised the actions required to resolve thermal constraints.

The system services used, both historically and now, to manage the network are not directly valued by the energy market. We are the sole buyer of these services and currently must procure them to maintain a safe, reliable, and compliant network. Therefore, we are wholly responsible for the resilience of these services and ensuring that they are delivered effectively and efficiently for consumer benefit. As the electricity system decarbonises, we have access to less dispatchable generation but we are finding new sources to meet these challenges and locational needs.

- Power must be able to flow right across the network, from wind generation in Scotland to interconnector exports in South East England
- The network must be able to be restored using more variable sources of generation and assets on the distribution networks, whilst meeting the future restoration standard
- New sources and providers of reactive power and short circuit current are needed in the right locations of the network
- Grid Forming technology will be key to ensuring strength and stability of the future electricity system

These reliable network workstreams cover the challenges in more detail and the potential solutions available.

Further background on these workstreams can be found in the Appendix.

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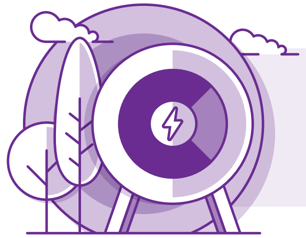
Thermal



Zero carbon operation by 2025

System requirement

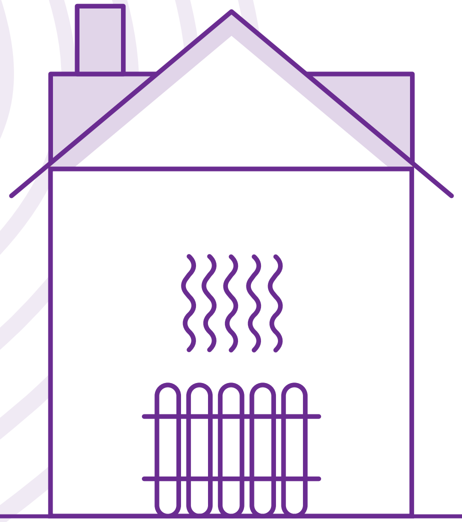
The transmission network plays a critical part to achieving both our 2025 zero carbon ambition and enabling a net zero system by 2035. It will help connect new zero carbon technologies and integrate them into system operation. It will facilitate the transport of renewable energy to where it's needed, or to storage for future use.

The electricity transmission system continues to face growing system needs primarily driven by the growth in zero carbon generation. These needs are mostly during the high demand winter period when power flows on the network are at their peak. Our network analysis, published in our Electricity Ten Year Statement (ETYS), continues to show that the areas with the greatest system need are in the South Scotland and North England regions.

Capabilities to meet our requirement

Achieving our 2025 ambition means minimising the actions we take to resolve constraints as they are predominantly on zero carbon generation, and the energy is balanced largely on carbon emitting generation. This can be done by increasing the capability of the network or reducing the volume of actions taken for a constraint.

The Network Options Assessment (NOA) balances network investment with the forecast costs to constrain generation behind a constraint boundary. Where new capability is recommended by NOA, it is delivered by transmission owners to increase the capacity of the network. The delivery of network investment by 2025 is well underway, providing the network capacity identified by our ETYS and NOA processes.



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Thermal

Operational readiness

Beyond network investment, our focus has been on ways to use the capability of the network more efficiently and reduce the volume of constraint actions. By 2025 we will have delivered these projects to help manage a zero carbon system:

1. **Constraint Management Intertrip Service (CMIS):** this service has now expanded to two key constraint boundaries. The intertrip service doesn't increase the capacity of the boundary, but instead it allows for increased flow across the boundary before a fault occurs. If a fault were to occur, assets connected to the intertrip service will reduce to 0MW very quickly, preventing the overloading of network assets. This service reduces the volume of constraint actions for the boundary, reducing costs to the consumer and increasing the number of periods of zero carbon operation. By 2025, we expect the service to expand to further boundaries, allowing for greater North to South power flows.
2. **Fault level reinforcements:** as more large synchronous generation closes the amount of support we have to support the system during and after a system fault reduces. This can reduce the capability of circuits and cables, resulting in reduced capacity of a network boundary. In some areas of the network, fault level reinforcement is being delivered to restore capacity to the system.
3. **Enhanced and dynamic ratings:** network assets have ratings which prevent them from being over-stressed. This is often linked to the environment, weather and temperature. We've worked with transmission owners to assess ratings more frequently allowing increased boundary capability when it would otherwise have been restricted.

Procurement route

Between now and 2025 we have no plans to implement any major changes to the way we manage constraint boundaries. We will continue to develop the Constraint Management Intertrip Service, whilst delivering further rounds for the B6 boundary on the Scotland-England border and a new scheme for the EC5 boundary in East Anglia. We will otherwise continue to use the balancing mechanism and trading options to efficiently manage constraints.

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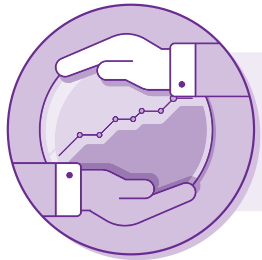
Thermal



The gap to 2035

System requirement

Understanding the required network investment and development is crucial to maintaining a safe and reliable network as we transition from single periods of zero carbon system operation to a year round net zero industry. Our 2023 Electricity Ten Year Statement (ETYS) highlights the increasing requirements on the network for the next 20 years. The rapid growth in zero carbon generation, including significant offshore wind to meet the 50GW government ambition by 2030, is driving the need for increased network capacity.

Over the next decade to 2035, changes to the generation mix and demand patterns will mean that winter peak demand is no longer the single worst case for network boundary constraints. We have developed tools which allow us to analyse system requirements year-round and ensure that as the more weather led generation and consumer led demand behaviour increases, we will be able to identify and communicate the resulting system needs.

Capabilities to meet our requirement

In 2024 the ESO will transition to a new Future System Operator, providing a whole energy system view across electricity and gas. We are developing our network planning processes as part of this transition into a Centralised Strategic Network Plan (CSNP). Ahead of the enduring CSNP, we are delivering transitional CSNPs. These are incorporating our existing ETYS, Network Options Assessment (NOA) and Holistic Network Design (HND) processes into a single plan. This will enable us to assess and communicate the needs of onshore and offshore networks, and assess the wider impacts of such investment on the environment and communities.

By 2035, we will need a network which has the capability to unlock the zero carbon generation potential, enabling demand to be met at all times of day, in all seasons. It will require sufficient new capacity to accommodate the growth in zero carbon generation, both in terms of connecting new assets and transferring power across the network. The transitional and enduring CSNP processes will enable us to assess, develop and accelerate the required capability for net zero system operation.

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Thermal

Operational readiness

Managing the transmission system will become more complex as power flows become more variable with a generation mix dominated by weather led supply. We need to ensure we have sufficient tools to forecast and monitor weather and variable generation to provide greater certainty to the control room. We want to minimise the need for ESO actions to resolve constraints where possible. We will therefore continue to develop commercial options for the control room to manage constraints.

Distributed Energy Resources (DER) continue to grow and, with limited visibility of DER, this makes system operation more complex. We are finding ways to increase DER visibility so the control room can plan and manage the system more efficiently, and harness the benefits of having DER available to manage system constraints.

Enduring procurement route

Managing the network efficiently means optimising investment and commercial options. Where investment is not deemed appropriate, we will develop commercial solutions to reduce the need for actions in the Balancing Mechanism and deliver value for the consumer. We expect more intertrip schemes to be developed for other key boundaries in future; the need for these is likely to be identified by CSNP. We continue to explore other commercial opportunities and work with industry to develop innovative solutions which reduce the impact of constraints and costs to the end consumer.

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Voltage

Zero carbon operation by 2025

System requirement

Maintaining voltage on the transmission system requires a minimum volume of reactive power capability to be spread across the network. Over the last few years we have developed our system studies to better understand the minimum requirements for 2025. These requirements are now well defined for 2025, including what is required to meet our 2025 zero carbon ambition.

System requirements are still largely dominated by the need to absorb reactive power and prevent high voltages. This is not limited to low demand periods during the summer, but rather experienced throughout the year. We continue to see declining reactive power demand and an innovation project will investigate the drivers behind this trend and develop forecasting tools and techniques to help with future system studies. We published the residual requirements for 2025 in the OSR2023 and following planned asset investment, these have reduced and are shown in the table. These residual requirements occur during the most onerous system conditions and can be met using existing assets including generation.

Region	OSR2023 residual requirement (MVAr)	OSR 2024 residual requirement (MVAr)
LONDON	500	300
W_MIDLANDS	600	200
S_WALES and S_CENTRAL	700	500
SW_ENGLAND	125	0
E_ENGLAND	300	300

Capabilities to meet our requirement

To reach our 2025 zero carbon ambition, we have sought new reactive capability to help us meet the future system requirements. These include:

- **Voltage pathfinders:** The Mersey pathfinder has been operational since May 2022. The Pennine pathfinder will start delivering assets in April 2024. Both pathfinders ensure those areas of the transmission system can be operated using zero carbon assets.
- **Stability pathfinders:** Our stability contracts deliver additional benefit in the form of reactive power from assets spread across the transmission system. As these contracts require operation at 0MW, they contribute to voltage management and our 2025 zero carbon ambition.
- **Planned investment:** National Grid Electricity Transmission (NGET) are working toward delivering seven new reactors by April 2025 to meet a mixture of compliance and economic needs, whilst getting us closer to zero carbon operation. We have worked closely with NGET to prioritise the right locations on the network for compliance, economic and zero carbon reasons.
- **Stability Markets:** Future markets will continue to deliver reactive power capacity as an additional benefit.

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Voltage

Operational readiness

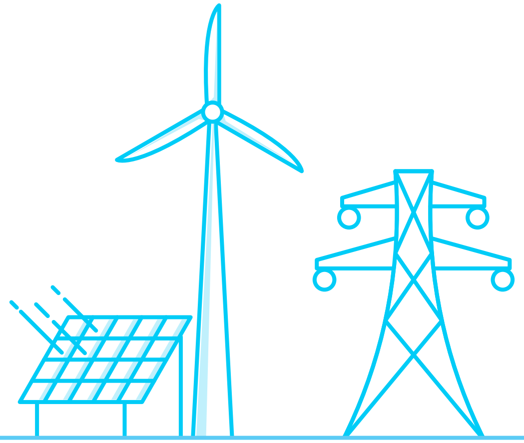
In addition to increasing reactive capability, we are also delivering additional capability, tools and services into the control room. This will enable them to operate a secure, efficient and zero carbon transmission system.

1. **Pennine pathfinder:** one of the successful parties from this pathfinder is an offshore windfarm. The contracted reactive capability is in addition to grid code requirements, so we are ensuring that the appropriate controls and dispatch systems are in place to utilise the contract, particularly when the wind farm is at 0MW.
2. **Commercial Service Agreements (CSAs):** there are many assets and providers who have more reactive capability than is required by the Grid Code. We are reflecting this additional capability in CSAs which are in addition to the Grid Code requirements set out in Mandatory Service Agreements (MSAs). This is an outcome from the voltage request for information (RFI) published in mid-2022. We are initially engaging with batteries and solar as they often have reactive capability at 0MW, which is beneficial to efficient zero carbon system operation. If you have additional reactive capability in addition to any Grid Code requirements, which we are not aware of, please contact us commercial.operation@nationalgrideso.com
3. **Managing GSP reactive transfers:** over the last decade there has been a downward trend in the MVAr balance across the Transmission-Distribution boundary, whereby falling demand on the distribution network for reactive power has meant more MVAr 'spilling' onto the transmission network. Excessive MVAr exports from certain GSPs are proving difficult and expensive for the ESO to resolve. The underlying cause of MVAr spill is to be studied and we will work with DNOs and DSOs to deploy appropriate mitigation measures.

Procurement route

Between now and 2025 we have no plans to implement any major changes to the way we procure reactive power. We continue to explore the possibility of introducing enduring reactive power markets. These may be introduced by 2025 but will not be available in operational timescales. We will continue to utilise the Obligatory Reactive Power Service (ORPS), including accessing this capability via the Balancing Mechanism as well as running ad-hoc tenders to meet any specific requirements identified. We are still exploring ways to reduce costs associated with reactive power ahead of 2025 and increase our ability to meet our 2025 zero carbon ambition. These include:

1. **A review of the ORPS default rate:** all providers of the obligatory reactive power service are paid the same rate for utilisation. This is regardless of generation technology type. The review aims to find whether the existing approach is still fit for purpose and, if appropriate, propose an alternative.
2. **Running a short-term tender in East England:** This region often requires carbon emitting generation to provide enough reactive capability to manage voltage levels. The region is due to get sufficient volumes of mandatory reactive power from new connections beyond 2025. In the interim we plan to tender for reactive power services in the region to reduce costs and potentially enable more periods of zero carbon operation.



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Voltage

The gap to 2035

System requirement

As we have prepared for 2025, we have developed new processes for completing multiple voltage system studies and scenarios. During 2023 we have completed our high voltage system studies for 2027 and 2029. The residual absorption requirements are included in the table. Residual refers to the reactive absorption capacity required in a region to prevent voltage levels exceeding SQSS limits, after accounting for reactive compensation assets and self-dispatching generation. Residual requirements could be met by synchronising more generation, TO investment in new assets, procurement through a tender or market, or using operational actions. In future years, the upcoming Centralised Strategic Network Plan (CSNP) will provide the assessment of system requirements and will look further out, 10 years ahead.

Voltage pathfinders and system studies have so far identified static reactive requirements, focusing on a single snapshot in time. However, voltage must be managed constantly throughout the year so we need to understand and model the dynamic needs of the system too. We are developing tools to study these needs by looking at steady state voltage regulation. By 2035, consumer and market behaviour could more dynamically influence power flows across the network, in turn increasing and decreasing voltage levels.

Regions	2027	2029
	Total (Mvar)	Total (Mvar)
London	300	250
East England	550	-450
West Midlands	0	250
East Midlands	0	100
South Yorkshire	350	350
Humber	150	200
North Yorkshire	0	-50
Mersey	200	0
NW England	350	550
South Central Scotland	100	150
North Central Scotland	0	50
Totals	2000	2400

Capabilities to meet our requirement

By 2035, all our reactive power requirements need to be wholly met by zero carbon sources. The Centralised Strategic Network Plan (CSNP) will inform industry and Transmission Owners on the need for investment in new capability across the network. The CSNP will outline the roles and responsibilities of TOs and the Future System Operator regarding how a shortfall in capability to ensure a compliant network should be met.

Growth in new assets connecting to the transmission system will help to ensure there is sufficient reactive power capability on the network, however it may not be in the right location. Our existing Network Services Procurement (formerly Pathfinders) process will have transitioned to enduring market arrangements. The long-term market (likely to be 4 years ahead) will provide the market signals for new capability in regions across the network.

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Voltage

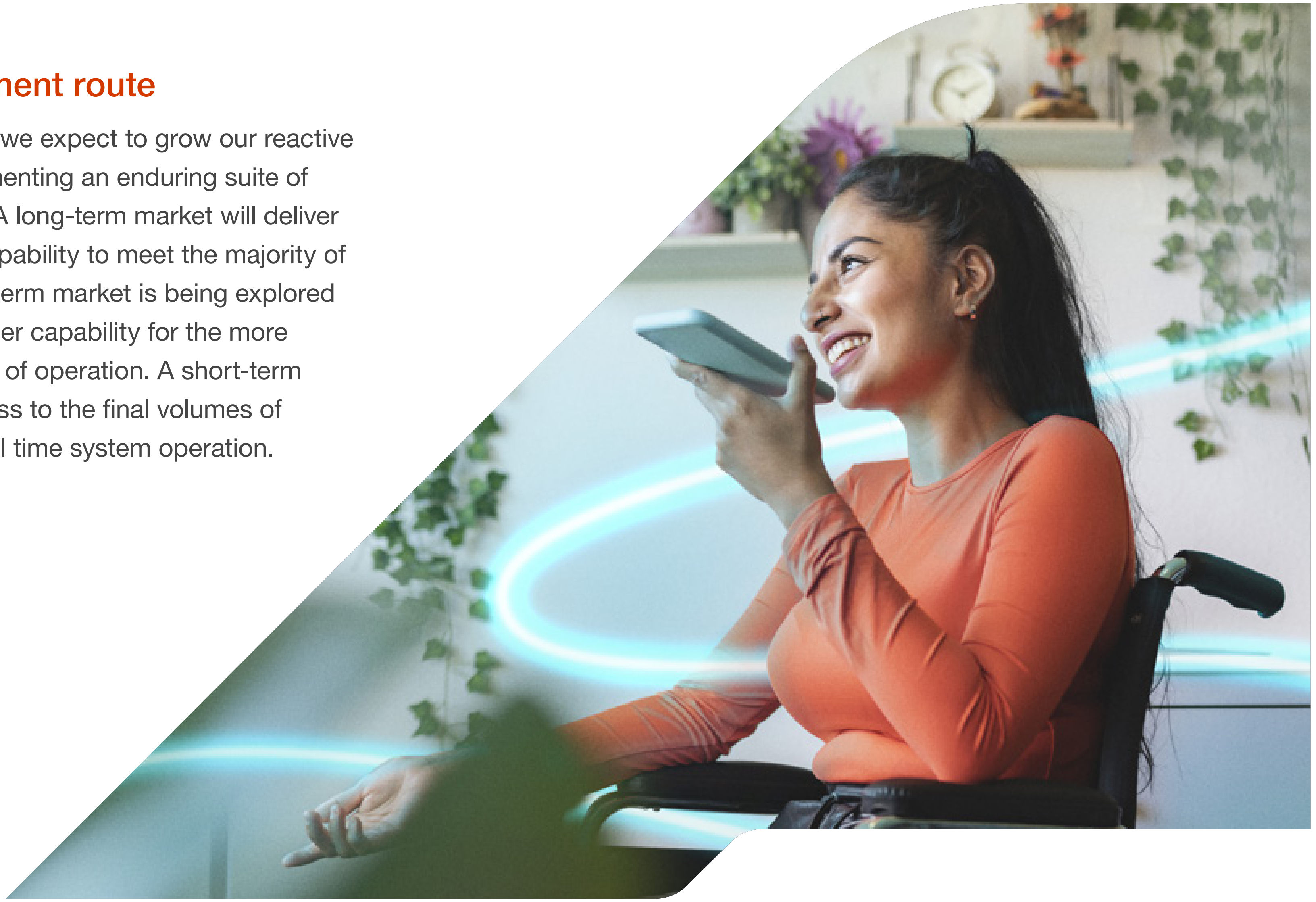
Operational readiness

After growing reactive power capability via long-term markets, we must then ensure there is sufficient capability accessible to the control room. Mid-term (likely to be at year ahead) and short-term (day ahead) markets could provide access to the extra capability when system requirements have greater certainty.

We will also need to develop operational tools to manage voltage on a system dominated by inverter-based resources providing reactive power services very differently to now. Unlike 2025, when we expect to manage short periods of system operation with zero carbon generation, by 2035 we will need to regulate steady state voltage on a network where power flows could change more dynamically than today, altering voltage levels more frequently and requiring greater levels of proactive management. New tools to forecast and manage this is crucial to 2035 system operation.

Enduring procurement route

Between 2025 and 2035, we expect to grow our reactive power markets by implementing an enduring suite of reactive power services. A long-term market will deliver the greatest volume of capability to meet the majority of our requirements. A mid-term market is being explored to provide access to further capability for the more onerous periods in a year of operation. A short-term market may provide access to the final volumes of capability required for real time system operation.



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Stability

Zero carbon operation by 2025

System requirement

Our system stability needs are underpinned by two key requirements – system inertia and system strength. We conduct regular studies to ensure we understand our requirement and, for 2025, this is well defined. For system inertia, our ambition is to reduce our operating level to our target of 102GVA.s by 2025 to help achieve our zero carbon ambition. Plans are currently in place to begin this reduction, with the implementation of FRCR 2023 which was approved by Ofgem in June 2023 to reduce our minimum operational inertia level to 120GVA.s. FRCR 2024 (which will be submitted to Ofgem in April 2024) will conduct a further assessment of system inertia and identify whether there is value in further reducing inertia towards our target operation of 102GVA.s.

Our system strength requirements are largely resolved through phase 2 and 3 of our stability pathfinder solutions delivering in 2024 and 2025 respectively. We are working towards the development of a near-time monitoring mechanism to ensure we have the capability for real time measuring of system strength. In addition, we have an ongoing innovation project 'Strength to Connect' which is investigating whether there are alternative indications of system strength and how these can be applied to the transmission system as it becomes dominated by inverter-based resources (IBRs). Learnings from this project will be used in future studies to assess the impact and behaviour of the IBRs connected to the system.

Capabilities to meet our requirement

Our stability pathfinders have paved the way to ensure we have plans in place to meet our stability requirements in line with our zero carbon ambition by 2025. In addition, we have recently concluded our Stability Market Design Innovation project, which recommended the implementation of three future stability markets (Long term Y-4, Mid-term Y-1 and Day Ahead):

- **Stability Pathfinders phases 1-3:** all of phase 1 assets are now operational, providing an additional 12.5GVA.s of inertia to the system, enabling us to move ever closer to our zero carbon ambition. Phase 2 units will start to deliver both inertia and SCL in the Scotland region from 2024 and the first of the stability phase 3 units begin delivery in Spring 2025.
- **Stability Mid Term (Y-1) market arrangements:** our stability market design innovation project recommended a blend of three future stability markets (Long Term (Y-4), Mid Term (Y-1), and Short Term (D-1). Based on our known requirement, we have launched the first Mid Term (Y-1) market which will award contracts for the provision of inertia for delivery from October 2025.
- **Future market implementation:** we are continuing to work towards the implementation of the remaining two market designs (Long Term and Short Term). This will be driven by our evolving system requirements and where we identify the largest value to consumers to be. At present our modelling does not suggest a need for additional long-term, new asset development; however, we are maintaining an option to procure new solutions as our requirements develop year on year.

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Stability

Operational readiness

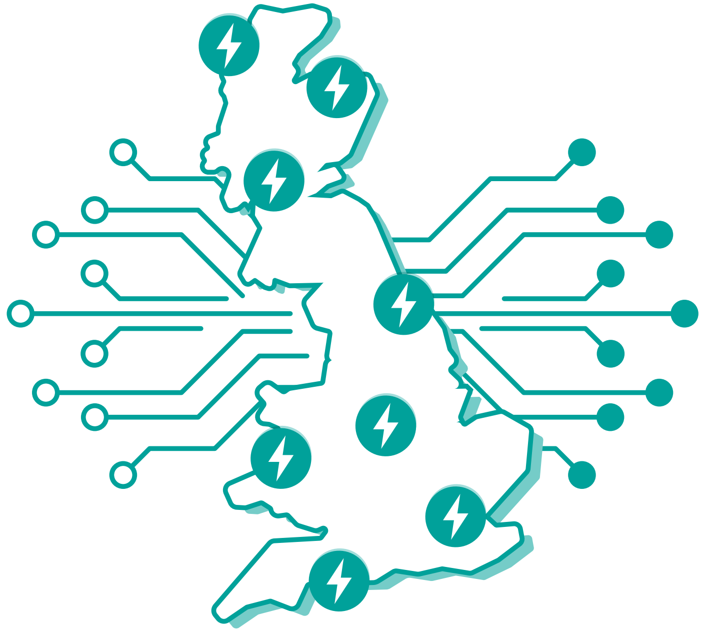
To ensure the additional capabilities can be utilised by our Control Room, we need to ensure we are delivering the right tools and processes to ensure we can operate a safe and secure system. For system stability in 2025 there are two key changes that will impact our operational readiness:

1. **Reduction of minimum inertia to 102GVA.s by 2025:** reducing our operational policy of minimum inertia holding will change how the control room manage system inertia. The models in place within the control room to calculate inertia requirements will be updated to reflect the new policies.
2. **Introduction of near term monitoring of short circuit ratio (SCR):** at present, we do not actively monitor short circuit ratio in operational timeframes. This is a useful metric for measuring phase locked loop (PLL) stability and so we are currently developing a monitoring tool to provide this insight and visibility to the control room, in light of declining system strength. This monitoring capability will increase our insights into areas of the network where system strength may be lower than our defined thresholds and enable us to implement proactive strategies to ensure we are prudently managing our requirements.

Procurement route

In October 2023, we launched the first of our enduring stability market solutions (Mid Term (Y-1)) and published an expression of interest (EOI) for participation in this service procurement. This market will procure system inertia for delivery in October 2025. In addition to the three stability pathfinder solutions, the future stability market arrangements represent our transition to procuring stability services through zero carbon solutions to help achieve our 2025 ambition.

Whilst we continue to grow our availability of such solutions, there may still be periods (typically during overnight, windy periods) where stability support from Balancing Mechanism (BM) solutions may be required in 2025. Our 2025 zero carbon ambition ensures that we have the capability to operate the network for periods of zero carbon generation. We will still choose solutions that meet our operability need in merit order, with cost as the driving factor. This may result in carbon emitting plant being utilised, if these happen to be the most cost effective, however if these solutions are zero carbon, we will also have the capability to ensure the network can still be operated safely and securely with such solutions.



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Stability

The gap to 2035

System requirement

We conduct regular system studies to ensure we have sufficient capability available to meet our requirements. Our current studies extend to 2038 and provide a view of our stability requirements for both inertia and system strength. These will be refreshed in early 2024. Currently our studies suggest that our inertia requirement to 2035 is an economic requirement, meaning any additional inertia procured will be to ensure we are accessing the cheapest service, rather than to meet a minimum compliance need. For system strength, we see additional requirements start to emerge in some regions of the network around 2030. Currently, we see this requirement as an economic requirement, to facilitate greater penetration of inverter based resources (IBRs) connecting to the grid. In order to manage low short circuit levels by 2035, we will need access to assets that have the capabilities to provide alternative solutions to our current approaches (which is often to curtail generation in areas where short circuit levels are low), and hence, our SCL requirement is currently an economic requirement, rather than compliance.

The upcoming Centralised Strategic Network Planning Review (CSNP) will provide a regular refresh of these studies from 2024 onwards. This will consider other requirement assessments such as thermal and voltage requirements and as such, a holistic, overall requirement can be determined across each of the operability workstreams, increasing coordination and maximising benefits to the consumer.

By 2035, our stability requirements should be met through zero carbon sources alone. Our pathfinder process will have transitioned to an enduring market arrangement though the long term (Y-4) market and we will have two additional market solutions in the Mid-term (Y-1) and Short-term (D-1) market. A combination of these markets will be our primary route to meeting our future stability requirements.

Capabilities to meet our requirement

In working towards our 2035 ambition, we need to increase our capability in modelling and increase our ability to conduct detailed dynamic (EMT) system studies. This capability will support with studying the increasing challenges regarding system stability and the need to complete further detailed analysis of areas of the network where stability issues may emerge. The decline of synchronous generation and increase in inverter based resources increases phenomena such as control interactions between generation, and power quality issues will need to be analysed more intensively and more intelligently. We are working with TO's to establish the correct modelling requirements and are sharing learnings through the Joint Planning Committee modelling subgroup.

Between today and 2035 we also plan to establish a strategy for the management and utilisation of Grid Forming capability in future. We foresee that this will be a fundamental technology in enabling us to meet our stability requirements, and zero carbon ambitions, in future years. We need to ensure that we are actively providing the right investment signals to the market whilst also ensuring we procure this service in the most economic manner.

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Stability

Operational readiness

By 2035, we envisage that the utilisation of grid forming technology will have increased significantly from today's levels. We need to ensure that this technology is integrated into control room operations so that the benefits can be realised in day-to-day operation of the system. This will include the establishment of processes to ensure such technologies are accounted for in planning timescales, and can be utilised in operational timescales to meet our system strength requirements. Our phase 2 stability pathfinder procured five grid forming battery solutions which will go live from 2024. We will take learnings from integrating these assets onto the system to ensure we are ready for the increased penetration of this technology in future years.

We are currently designing monitoring tools to increase our operational insights into levels of short circuit ratio (SCR). This capability is being developed today and we will begin monitoring system strength in Q4 2023, into 2024. This near time monitoring will increase our insights into system strength across the network and help to identify any areas which may require additional studies or benefit from additional service procurement. Initially, this capability will be implemented via offline tools, however by 2035 it is our ambition to integrate these functions for monitoring SCR (or any other appropriate metrics) into online tools to provide an ongoing, live status of network system strength.

Procurement route

By 2035, all stability services will be procured through our enduring stability markets, utilising zero carbon solutions to meet our requirements.

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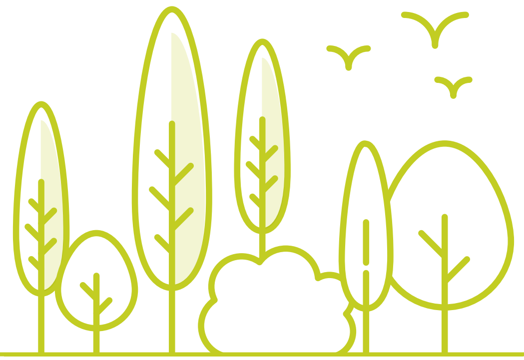
Restoration

Zero carbon operation by 2025

System requirement

Our system restoration requirements remain largely unchanged from last year's report. We have a requirement to ensure we have the ability to restore the system in the event of a total or partial shutdown. Traditionally, this has been dependent on large, dispatchable generation, however as we move towards our 2025, and 2035 zero carbon ambitions, this presents opportunities to develop radically different approaches to system restoration. The greater diversity in the provision of restoration services and our reduced reliance on traditional sources, will improve resilience and increase competition leading to reductions in both cost and carbon emissions.



Capabilities to meet our requirement

Our restoration strategy no longer requires the warming of coal plant and our procurement strategy has removed blockers for zero carbon restoration services. We are now able to utilise zero carbon assets in the restoration process if required. Our requirement for restoration service providers across the country is known, and we have established a rolling restoration procurement strategy to procure services in each of the regions on a regular basis.

The Distributed ReStart project has proven the restoration capability of distributed energy resources (DER), increasing our pool of restoration capable providers. In addition, we launched wind-only tenders in August 2022 as a one-off initiative to encourage a range of participation in restoration procurement and increase our capability of meeting our zero carbon ambition in 2025. This tender also demonstrates that offshore or onshore wind generation can meet the technical requirements for restoration services at a transmission level and we expect these services to go live by 2028.

Operational readiness

We are working towards increasing our range of restoration capable providers from a range of technologies, improving system resilience and increasing our capabilities in working towards our zero carbon ambition. These technologies are currently available to be utilised by our control room and as we enhance this pool of different technology types, we will ensure all control room processes are amended accordingly to enable all technology types to be used by the control room in the event they are needed for restoration services.

Procurement route

We have established an annual process within which our restoration requirements are modelled. This determines the volume of procurement needed which is run on a cyclical basis within each of the regions across the transmission system. Our procurement strategy and approach is detailed on an annual basis in our annual assurance framework, which is approved by Ofgem.

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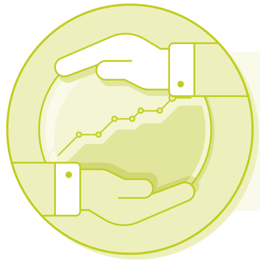
Restoration



The gap to 2035

System requirement

For 2035, the major change for restoration will be the implementation of the Electricity System Restoration Standard (ESRS) by the end of 2026. This requires the ESO to ensure and maintain an electricity restoration capability and maintain a restoration timeframe which is set at:

- 60% of electricity demand restored within 24 hours in all regions
- 100% of electricity demand restored within 5 days nationally

We will ensure the ESRS can be met by implementing a combination of the traditional top-down approach and using learnings from Distributed ReStart which is a world-first, bottom-up restoration approach. The implementation of ESRS also comprises numerous code changes, placing requirements on the ESO to ensure timely restoration of the system as well as increasing the obligations on generators and networks to be increasingly resilient.

Capabilities to meet our requirement

From 2026, there will be a significant increase in the number of Restoration Service providers, and it is our ambition to procure a variety of different technology types across each DNO licence area that make up the seven regions, creating uniform restoration across GB.

In addition, following industry wide engagement, there are a variety of new technical requirements on TO's, DNO's, ESO and CUSC parties to support the restoration process, requiring changes to various codes including (but not limited to) Grid Code, Distribution Code, STC and SQSS. Other recent Industry Code changes have reinforced our ability to restore the system, including the implementation of GC0137 (Grid Forming) which was introduced into the Grid Code in February 2022. This provides a vehicle for renewable plants (such as wind) to contribute to restoration services and increases our pool of available restoration service providers.

Operational readiness

As part of the implementation of ESRS, we are developing a restoration decision support tool to be used within the control room, with the aim that this is implemented by 2025. This tool will recommend optimised restoration routes to Control Engineers for implementation, provide real-time restoration progress on both Transmission & Distribution Network, and will log critical decisions during the restoration process.

Procurement route

Through the implementation of ESRS, we will launch more tenders to secure additional Restoration Service Providers as well as adopting a parallel regional approach to restoration procurement, through the implementation of at least one Local Joint Restoration plan (LJRP) in each region. We will maintain our rolling restoration strategy to ensure we are regularly reviewing our restoration requirements and available providers in each region.

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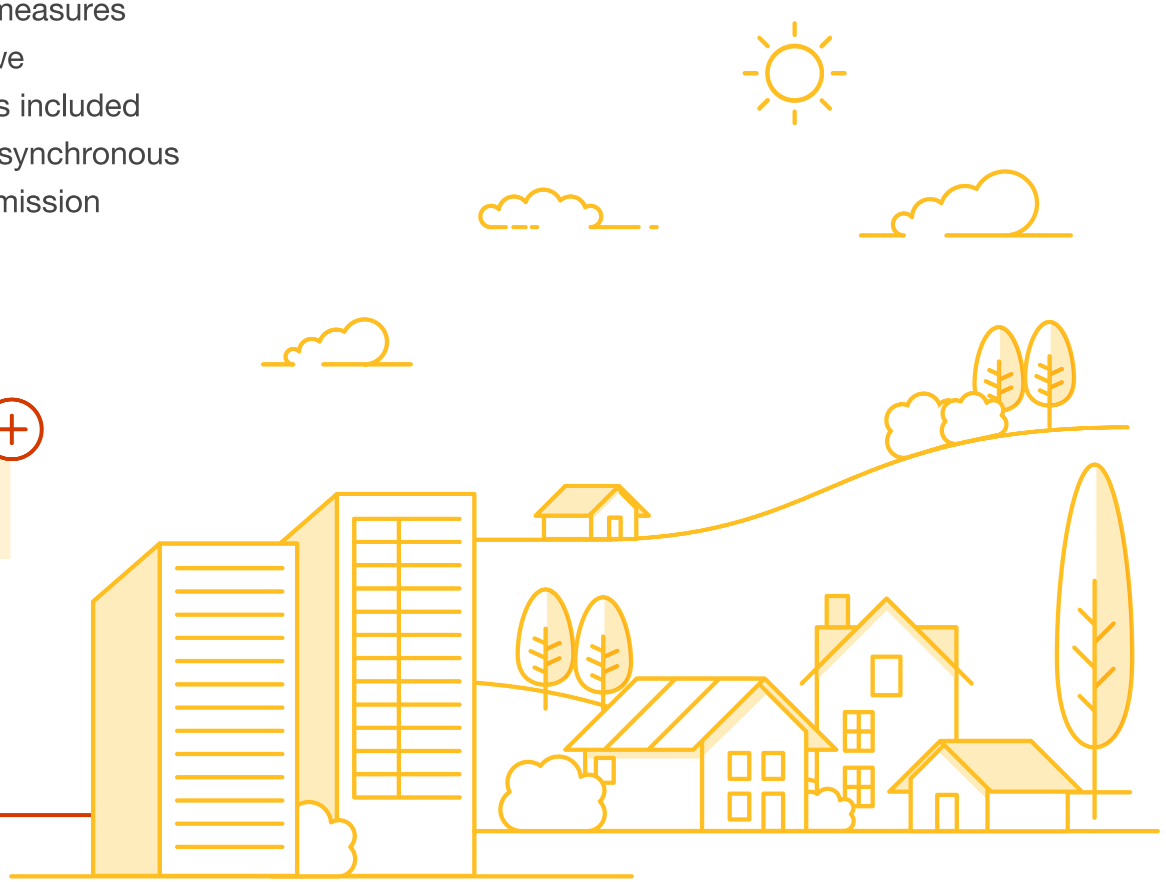
Scotland Sub-Synchronous Oscillations

During June and July 2023, 8Hz Sub-Synchronous Oscillations (SSO) occurred on five separate days, centred in the Scottish network. The SSO events caused disturbances on the power system which included the tripping of generation, an interconnector, a HVDC link, and a transmission circuit.

We worked closely with asset and transmission owners, technology providers, industry, academia and overseas partners to carry out a systematic investigation. The investigation analysed system conditions across all the events to determine any consistent factors. This analysis showed that the background system conditions varied across the events with differing levels of inertia, demand, wind levels, generation mix and system flows. There was no link identified between any system conditions and the oscillations events. Analysis of Phasor Measurement Unit (PMU) data at substations that had high dissipated energy flow during the oscillations showed the presence of very high reactive power (MVAr) oscillations at one site during the events in comparison to other similar devices.

Following the initial SSO event, numerous tactical measures were put in place to mitigate further events whilst we investigated the cause of the SSO. These measures included holding increased levels of response, reserve, and synchronous generation. In collaboration with the Scottish transmission owners, we returned assets and circuits into service and optimised the network configuration, increasing the Short Circuit Level (SCL).

What are sub-synchronous oscillations?



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Scotland Sub-Synchronous Oscillations

DEF Analysis

The DEF analysis has limitations in that the analysis requires for Phasor Measurement Unit (PMU) data to be available for many substations or circuits to provide a reasonable level of accuracy. As there are only a limited number of substations with PMUs, this evidence was only used to highlight areas for further investigation.

EMT Modelling

Building a detailed picture of the SSO events was challenging as there was limited availability of electro-magnetic transient (EMT) modelling data and high sample rate monitoring capability on the network. EMT modelling has become a key requirement to understand equipment interactions due to the increase in power electronic devices. Following an innovation project led by SSEN Transmission (Project TOTEM), we have a network EMT model, but it is limited to the use of generic models for some network elements. Grid Code modification 141 will provide the ESO with EMT models from Users connecting since September 2022. We are working on getting EMT models from Users connected before that date and all Transmission Owners' equipment. This will be critical for understanding the interaction of controllers on the network when carrying out network analysis.

Compliance and Control

The investigation found that multiple assets tripped during the SSO events for varying reasons. Those that tripped due to voltage protection were found to have operated as per their design and no compliance issues were identified. The voltage protection operated due to abnormal automatic voltage control elsewhere on the network. A resolution has been implemented to prevent any future abnormal voltage response at that location.

Numerous assets were tripped by their rate of change of frequency (ROCOF) protection. Embedded assets are permitted to have ROCOF protection within set requirements and limits. All asset owners confirmed compliance with the G99 DNO code and demonstrated their protection operated as per design. Transmission connected assets that had tripped due to ROCOF protection were instructed to disable or remove such protection as it is not a requirement for directly connected plant under the Grid Code. No other compliance issues were identified at those assets.

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Scotland Sub-Synchronous Oscillations

Next steps

The SSO events demonstrated a need to improve real-time situational awareness to provide real-time monitoring and alarms for any future oscillation events before they become significant. Phasor Measurement Unit (PMU) based Oscillation monitoring tools are also needed and the ESO is running two innovation projects currently linked to this. We are working with Reactive Technologies, to implement a proof of concept which will display dominant oscillation frequency and damping. The initial version will monitor Scotland, with scope to extend to cover all of GB.

We will be reviewing our compliance process to understand how a generator can demonstrate the ability to dampen oscillations, considering the learning from key assets which tripped for different reasons. We will publish more information to help new generators connect to the system and mitigate further oscillation events. We will also review how certain equipment can be tested or simulated to show no abnormal response to system oscillations.

Conclusion

Our extensive investigation found no evidence to suggest that the cause of these events is directly linked to system inertia, short circuit levels or any specific type of generation. The wider network conditions such as fault level and inertia were always within acceptable limits during the events and the reductions in both values due to increasing renewable generation did not have an impact.

We have worked with multiple parties following the events and some system configuration settings have been changed to ensure that the oscillations risk is minimised.

There are already improvement activities underway around Electro-Magnetic Transient (EMT) Modelling and Real-Time Situational Awareness which will improve our ability to model the power system in detail for oscillatory or transient modes.

We will work with affected parties from the SSO events to review the wider system actions, the mitigating actions and share relevant learning and recommendations. We will share these recommendations with industry and provide lessons learned for other TSOs.

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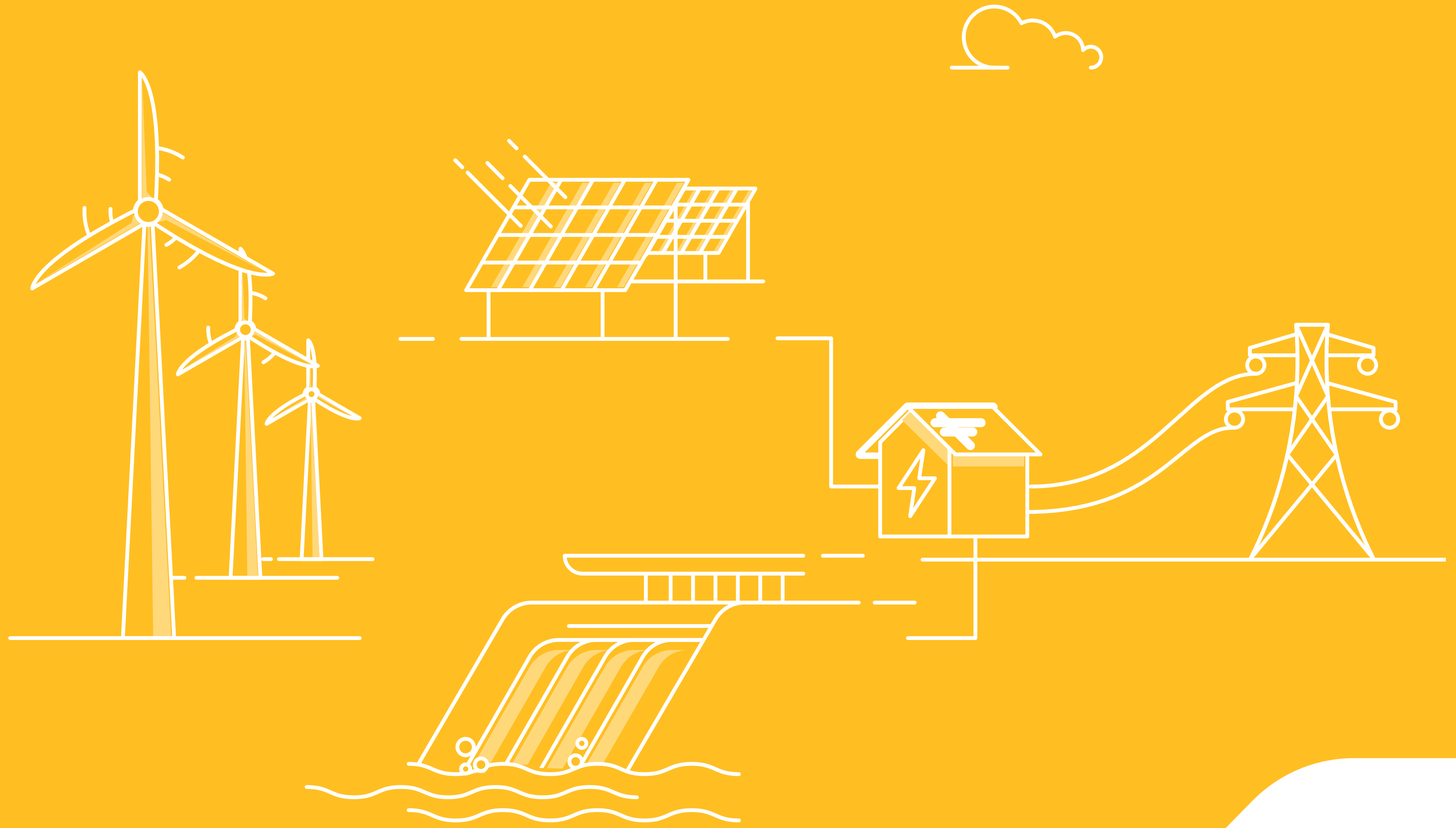
Balancing the System



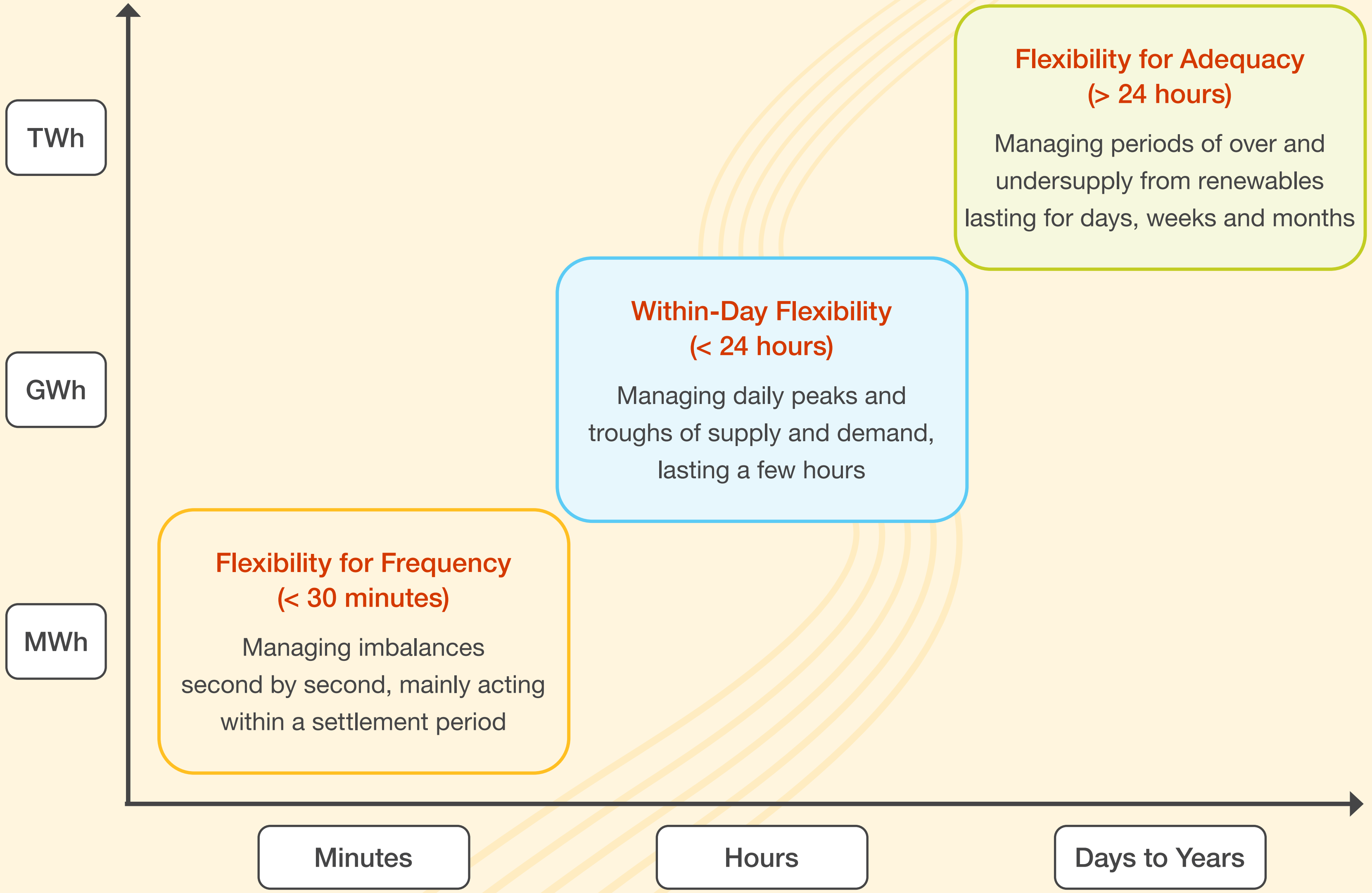
ESO

Balancing the System

The Great Britain electricity system operates at close to 50Hz. This is a measure of balance between energy supply and demand which is fundamental to safe and reliable system operation.

The balance of energy supply to meet demand is mostly met by the wholesale market. The ESO balances any residual difference between supply and demand, in real time, to maintain the frequency of the system at or near to 50Hz. The assets used today to balance the system, effectively have an unlimited source of energy from other vectors. As the system decarbonises, the technologies that replace the current assets will likely have time limited durations, such as storage or demand side response. There is a requirement to highlight where those technologies are best suited to deliver whole system value. The Frequency, Within-Day Flexibility and Adequacy workstreams all contribute to maintaining the energy balance in real time but operate across different time horizons and deal with differing magnitudes of energy volume.

Further background on these workstreams can be found in the appendix.



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Balancing the System

As we progress towards net zero system operation by 2035, we expect energy imbalance to grow to larger volumes and longer in duration. This is largely driven by an increase in variable supply as we move to a system dominated by weather-dependent generation. Seasonally driven demand e.g. electrified heat, and changes to wind generation driven by long lasting weather patterns, could lead to energy imbalance lasting days, weeks and months. Adequacy ensures capacity will be available to manage these long periods of over and under supply.

Within-day energy imbalance is driven by variability in both demand and weather-dependent generation. As we progress towards 2035, we expect to see an increase in unpredictable and variable demand as consumers respond to price signals and vary their domestic energy use. We also expect to see an increase in supply variability through growth of weather-dependent generation e.g. solar and wind. Within-day flexibility will provide the ability to manage flexible generation and demand throughout the day to meet the inflexible elements of supply and demand, lasting a few hours to a day. Our QWID FLEXER innovation project will help us to quantify the volumes of within-day flexibility required to manage the energy imbalance.

Frequency is the most mature of these three workstreams and enables the system frequency to be maintained second by second within a 30 minute settlement period. Energy imbalance in this timescale is largely driven by faults, forecast errors and other unexpected events; but we must also ensure that the system frequency does not change or vary too quickly as a result. Frequency will provide the necessary services to maintain system frequency, secure it for unexpected events and balance system reliability with operational costs.

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Frequency

Zero carbon operation by 2025

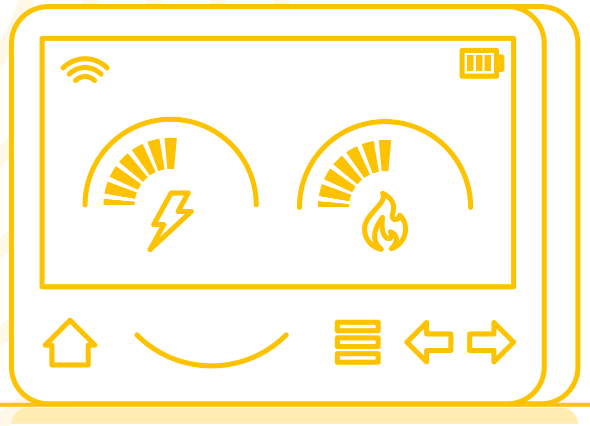
System requirement

Frequency must be managed during normal system operation (steady-state) and following faults on the network (transient). The Frequency Risk and Control Report (FRCR) interprets the Security and Quality of Supply Standard (SQSS) to determine how we manage transient frequency – defining which events and deviations we secure for based on the system impact and the cost to end consumer. The FRCR also determines the minimum inertia holding on the system, which largely impacts the volume of response needed to keep frequency within limits. Between now and 2025 the minimum inertia policy will be continually reviewed to achieve the 2025 goal of 102 GVA.s.

By 2025, the Dynamic Reserve Setting (DRS) project will be live on the system, using machine learning to determine our daily reserve requirement. It will consider the impacts of wind, solar, interconnector flows, temperature, time of day and year, as well as other factors to ensure we are procuring the optimal volume of reserve. By recalculating our reserve requirements on a daily basis, we can use new data as soon as it becomes available and better calibrate our reserve requirements to the changing energy system. This results in a reduced number of units being synchronised to the system to provide this reserve - this will result in lower carbon emissions and a lower cost to the end consumer.

Our frequency requirements can differ depending on external factors. We continue to see a decline in the traditional sources of inertia on the system, meaning that system frequency will change more quickly when subject to an event. New connections on the network, both generation and demand, continue to grow in capacity – causing an increase in the largest loss size that we need to secure for. An increasing number of variable renewable resources on the system means that we see greater fluctuations in frequency during normal operating conditions. These factors result in frequency moving more quickly than it has historically. To manage this, our new services need to be fast enough to restrict this sudden change in frequency, both pre-fault and post-fault.

To meet our 2025 zero carbon ambition, steady-state frequency services must be provided by zero carbon sources in 2025. However, as our ambition is not year round in 2025, but limited to short periods, delivery of post-fault services will not necessarily need to come from zero carbon sources.



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Frequency

Capabilities to meet our requirement

Maintaining frequency on the transmission system requires capabilities provided by a variety of response and reserve services. We are designing services that meet our obligations, can be delivered by zero carbon sources and that help us manage frequency on a highly renewable, lower inertia system. Many of our new response services, including dynamic containment, dynamic regulation, and dynamic moderation, are live on the system to help us meet both our obligations and our 2025 ambition.

- **Dynamic Containment:** preventing frequency deviations outside of limits following losses.
- **Dynamic Moderation:** helping keep frequency within 0.2Hz during more volatile conditions.
- **Dynamic Regulation:** helping keep frequency close to 50Hz during normal operating conditions.

Our new reserve services are expected to launch before or during 2025. We do not expect to reach our 2025 ambition during periods of system stress, so any post-fault services (both reserve and response) are not expected to be utilised during our 2025 zero-carbon periods.

- **Quick Reserve:** recovering frequency back to 50Hz mainly during normal operating conditions (within 60 seconds).
- **Slow Reserve:** recovering frequency within 0.2Hz following losses (within 15 minutes).

We are looking to introduce another service before 2025 to help in meeting our zero carbon ambition and reduce cost for the end consumer.

- **Balancing Reserve (BR):** securing regulating reserve (real-time reserve to correct energy imbalances) at day-ahead.

Balancing Reserve should reduce cost to the end consumer by securing reserve in advance, preventing the price being determined by potentially expensive bids and offers in the Balancing Mechanism (BM). BR should encourage increased participation from zero carbon resources due to procuring reserve in shorter windows.

We are committed to working collaboratively with industry to unlock additional capability within our suite of response and reserve services. Work is ongoing with the Energy Networks Association, as part of their Open Networks Programme, to ensure that the right level of standardisation is present; aligning service procurement, settlement, baselining, products, interfaces, as well as data across the industry. Primacy, stacking and distributed energy resource visibility are some priorities of the Open Networks Programme, ensuring we work collaboratively to unlock volume and reduce cost to the end consumer.

- **Primacy:** ensuring that services are procured in a coordinated manner, that any conflict of service can be managed appropriately, and the suitable market action can be taken. Achieving coordination and having effective primacy rules would help for more efficient procurement of these services, as well as increasing liquidity in markets, and reducing the overall cost to the end consumer.
- **Stacking:** understanding and removing the barriers associated with stacking across DSO and ESO services to improve overall coordination of services. This will aid us in meeting the overall balancing service requirements in the most efficient manner to help optimise provider participation and unlock savings for the end consumer.
- **Distributed Energy Resource (DER) visibility:** large volumes of distributed generation and flexible consumer energy resources (CER) are connecting to the distribution network. We are engaged with the DNOs to initiate an industry-wide transformation to increase visibility of these assets, which will improve our forecasting ability and the real time monitoring and dispatch of these assets. As visibility of these assets grows, we expect to see increased participation of DER in balancing services, resulting in increased competition and decreased cost.

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Frequency

Operational readiness

We are implementing appropriate tools and controls within our control room to ensure these balancing services are available when required. Work is underway to ensure the control room can operate a secure, efficient and zero carbon transmission system.

- **Closer to Real-Time Response Procurement:** ahead of real-time we experience uncertainty around the volume of renewable generation output on the system. This leads to ambiguity in the level of response required to manage the frequency volatility that occurs with increasing variable renewable resources on the network. This drives a need for a method to increase response holding closer to real-time. Mandatory Frequency Response (MFR) is the current tool used by the control room to access intra-day response, however MFR has several derogations in place. We are working on a strategy to ensure that after these derogations end there is an optimal solution implemented to access the response required closer to real-time.

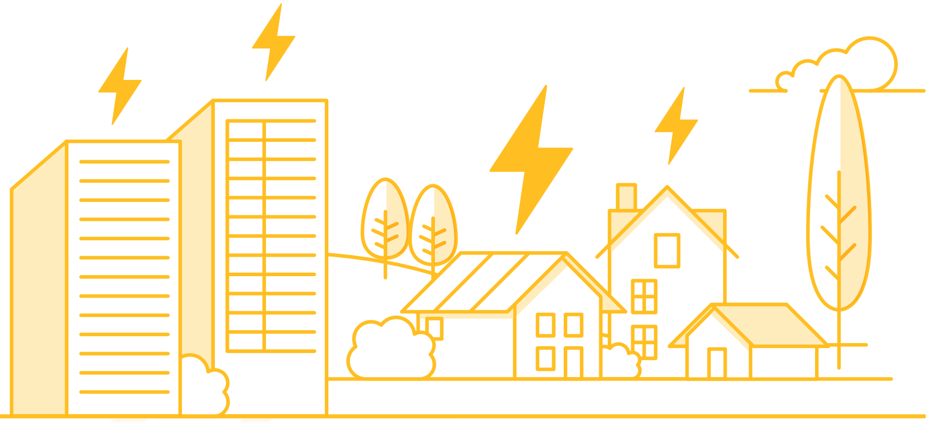
Procurement route

All new response and reserve products are procured at day-ahead, complying with the Clean Energy Package (CEP). The new response products that are live on the system are all procured in EFA blocks through a daily pay-as-clear auction process. Between now and 2025 we have no plans to change the way we procure these response products.

The Enduring Auction Capability (EAC) went live in November 2023 to deliver co-optimised procurement for our day-ahead response products. The EAC system consists of an auction clearing algorithm that helps meet our frequency requirements in the most efficient manner to help optimise provider participation and unlock savings for the end consumer. Our live response products have been co-optimised on EAC since the systems launch, with the reserve services expected on EAC after they go-live. We will continue to monitor the performance of EAC and make improvements where possible.

Several new reserve products are expected to launch before or during 2025, Slow Reserve (SR), Quick Reserve (QR) and Balancing Reserve (BR) and will be procured at day-ahead. SR will consist of both low and high frequency products (Positive Slow Reserve and Negative Slow Reserve respectively), unlike its predecessor Short Term Operating Reserve (STOR) which we procure as a low frequency service only. QR will be contracted as a firm service, unlike its predecessor Fast Reserve which is optional only. We don’t expect any procurement changes for these services between now and 2025.

Between now and 2025 we will continue to procure closer to real-time response using Mandatory Frequency Response (MFR) and intra-day regulating reserve from within the Balancing Mechanism. Access to these services in intra-day timescales is necessary to ensure system security and to prevent over procurement and excess cost to the end consumer.



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Frequency

The gap to 2035

System requirement

We expect the frequency requirements currently stated in the Security and Quality of Supply Standard (SQSS) and System Operation Guidelines (SOGL) to remain unchanged between 2025 and 2035. FRCR will continue to determine how we manage transient frequency deviations, striking the balance between system reliability and the cost of operating the system. We expect FRCR to cover multiple time horizons, potentially looking several years into the future. Depending on future iterations of FRCR and associated consultation with industry, FRCR may consider securing different events and loss risks, such as generation connections, and the impact of potential system events, such as high frequency deviations.

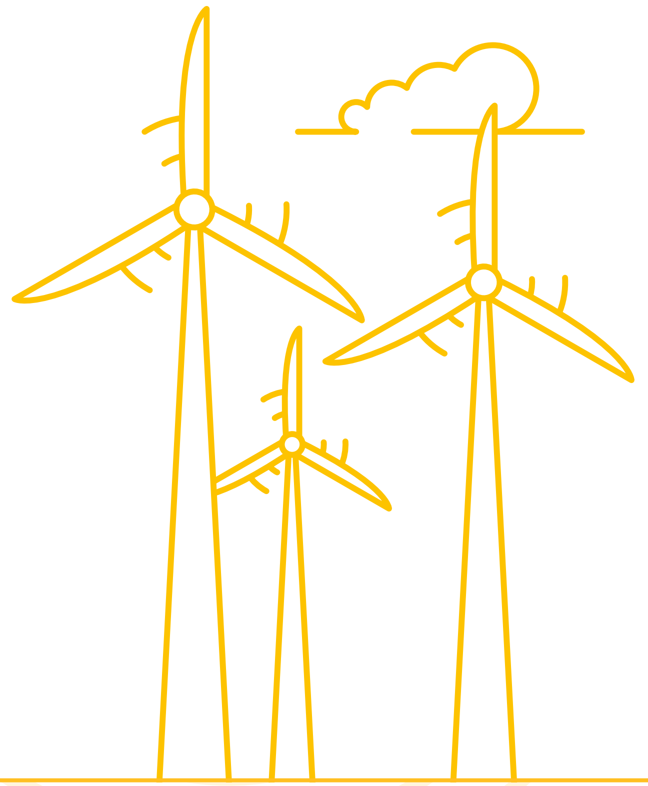
The Dynamic Reserve Setting (DRS) tool will continue to provide our reserve requirements, having used machine learning to determine more accurate reserve volumes as the tool continues to learn and processes data.

Capabilities to meet our requirement

Between 2025 and 2035, we will evolve our current secondary static response service. This updated service should deliver a set volume of response to recover frequency to limits within 60 seconds following large losses. This will be necessary for 2035 to ensure participation from zero carbon sources and comply with EU legislation.

By 2035, the new response and reserve suite will be live on the system, ensuring our obligations are met and we can securely manage a highly renewable, lower inertia system. These new services will largely be provided by zero carbon sources, helping realise our 2035 ambition.

Our work with industry will continue into this time horizon, to ensure the continued evolution of standards developed under Open Networks and to ensure that we have a robust set of market rules. The work will ensure that there is a cohesive vision for ESO and DSO services, helping maximise participation in balancing services. We will look to improve data quality and availability to ensure that the system can be managed in an optimal manner.



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Frequency

Operational readiness

After developing balancing services to meet the current and future needs of the system, we must ensure there is sufficient capability accessible to the control room.

- **Closer to Real-Time Reserve Procurement:** by 2035, day-ahead and closer to real-time procurement of reserve will be in place. Our Balancing Reserve service will create a day-ahead market for reserve which could be co-optimised with Quick Reserve and Slow Reserve. Variable renewable resources may have difficulty participating in day-ahead markets, therefore we are looking to understand the impact and benefits associated with opening up reserve markets closer to real-time, for example intra-day reserve auctions.
- **Locational Procurement:** localised procurement of response is being considered due to both a potential localised inertia requirement and network constraints increasing the risk of response units being unavailable to deliver. Network constraints also impact the availability of reserve units on the system, potentially restricting access to services when required. We plan to investigate this potential requirement as part of our frequency strategy to determine if regional frequency products are required in future.

Procurement route

From a procurement perspective, we expect minimal change between 2025 and 2035. The Enduring Auction Capability (EAC) will likely develop over this time horizon as our services continue to launch and develop. The algorithm may need to be modified to include changes such as auction timing if intraday services are implemented.

We are looking to potentially procure certain products in smaller services windows, such as half hourly windows, to allow us to procure more efficiently as well as allowing participation from providers who can offer volumes for shorter time periods. This would increase the number of zero carbon providers participating in services while decreasing the cost for the end consumer. This is currently under review and will be analysed as part of our future frequency strategy.

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Within-Day Flexibility

Zero carbon operation by 2025

System requirement

Within-day flexibility describes the operational need to adjust the flexible parts of supply and demand as the inflexible parts vary over a day. As we continue to decarbonise, we will see increasing numbers of inflexible, variable sources of generation on the network and a decrease in the volume of flexible fossil fuelled plant. This decrease in flexible fossil fuelled generation largely drives the need for within-day flexibility for energy balancing purposes. However, there may also be a requirement for locational ESO and DSO within-day flexibility services, to shift energy within-day, to manage the transmission and distribution networks.

To ensure the system remains balanced throughout the day, without using fossil fuelled generation, we must understand the energy balancing requirements and have access to the necessary volumes of zero carbon within-day flexibility.

We are running an innovation project named Quantifying Within-Day Flexibility Requirements (QWID FLEXER) to better understand our within-day flexibility need, for the purpose of national energy balancing. QWID FLEXER aims to provide the method and tools for calculating this requirement, allowing us to repeat the studies for differing uncertainties and scenarios.

External factors can also influence our system requirements. During winter 2022/23 we saw a global energy shortage and high wholesale prices due to a reduced supply of natural gas following the start of Russian-Ukrainian war. These events highlighted a requirement for within-day flexibility to help avoid the use of emergency actions during times of high demand and system stress - this led to the development of a within-day flexibility service to reduce demand.

Capabilities to meet our requirement

Currently, within-day flexibility is mostly delivered by the wholesale market and Balancing Mechanism (BM). The flexibility in supply mainly comes from dispatchable generation and the flexibility in demand mainly comes from industrial and commercial customers. Currently, the majority of domestic consumers are not exposed to the varying wholesale price; they tend to face a flat electricity rate and are often not metered or settled on a time of use basis, so have little incentive to provide flexible demand. Interconnectors are an additional source of within-day flexibility capability, acting as supply or demand, by altering their flow when required.

Outside of the wholesale market and BM, the demand flexibility service (DFS) is our primary flexibility service for use as an enhanced action during times of system stress. DFS was introduced during winter 2022/23, providing access to additional flexibility during high demand, winter days. During our first live event for winter 2023/24, more than 450MW of demand flexibility was procured. The service incentivises consumers to alter the time in which they use energy, moving the demand to a lower period of the day. DFS was established to aid our control room in managing a challenging winter when there was a higher risk of gas supply scarcity.

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Within-Day Flexibility

Currently, only small volumes of zero carbon within-day flexibility are available on the network. However, between now and 2025, we expect battery storage volumes to continue to grow significantly, with up to 12GW of capacity by 2025, making it the largest source of within-day flexibility during this period.

To unlock zero carbon within-day flexibility volume, the appropriate technology and rules must be in place. We are committed to working collaboratively with industry to unlock this additional capability.

- **P415:** a Balancing and Settlements Code modification named P415: 'Facilitating access to wholesale markets for flexibility dispatched by Virtual Lead Parties' is currently awaiting implementation. This modification will allow Virtual Lead Parties (VLP) to trade consumer flexibility in the wholesale market. This modification should incentivise more VLP's to enter the market (wholesale and BM) increasing the volume of flexibility available on the network and driving down the cost as a result.
- **Connections:** we understand the challenges associated with connecting zero carbon assets to the network and appreciate the need for a long-term strategy to reform the connections process. To help address this in the short-term, we have created our five-point plan which contains initiatives to speed up the connections process. This plan should aid us in connecting zero carbon assets to the network that will help in providing the within-day flexibility required.

Operational readiness

To ensure that we can operate the network securely, it is essential that we have visibility of where the flexibility is located, that appropriate forecasting systems are in place, and the necessary tools and systems are available to instruct flexibility and monitor system impact. We are working alongside industry, in a learn by doing manner, to overcome barriers to accessing flexibility on the system.

- **Small Aggregated Asset Balancing Mechanism (BM) trial:** the current metering standards act as a barrier to entry for small scale aggregated units, leading to flexibility from these assets being unavailable. This trial allows us to understand the benefits and impacts of small-scale aggregated assets within the BM if new proportionate operational metering standards were to be introduced – this will assess the capability of these assets to meet the requirements of the BM. The trial outcomes will help assess how we overcome barriers in our markets, ensuring we maximise the volume of assets that can provide capability, while aiding visibility and situational awareness to the control room.
- **Operational metering review:** reviewing operational metering requirements to enter the Balancing Mechanism (BM), with the aim of applying proportionate standards for smaller-scale aggregated assets. This will open our markets to smaller units that were previously unable to provide flexibility to the ESO. Visibility of new types of assets will better the control room's situational awareness, improving both dispatching and demand forecasting, ultimately resulting in a lower cost for the end consumer.
- **CrowdFlex:** the innovation project is focusing on understanding the statistical nature of flexibility and developing this into a reliable model to understand the impacts of consumer demand and domestic flexibility. The models developed through CrowdFlex will provide us with situational awareness to better understand the impacts of domestic flexibility of the system, as well as improving our forecasting ability. Understanding the locational impacts of flexibility will be crucial to ensuring the correct volumes are procured, in the optimal location, to reduce cost to the end consumer.

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Within-Day Flexibility

- **Enhancing Energy Storage in the Balancing Mechanism (BM):** we are liaising with industry to create a plan and develop capabilities that will improve the use of storage assets within the BM. This will allow for efficient dispatching of these units, utilising additional volumes of within-day flexibility, as well as reducing balancing costs for the end consumer.

Procurement route

Within-day flexibility is predominantly delivered through the wholesale market and Balancing Mechanism (BM). The price for power changes every half hour, driving a variation in supply, and to a lesser extent, demand.

This winter, the Demand Flexibility Service (DFS) is procured closer to real-time to allow us to understand the impact of different lead times on the volume of flexibility available. DFS is utilised in service windows of varying length, depending on the time duration of the system requirements.

Over this time horizon, we will continue to explore new methods of accessing within-day flexibility capability – more information will be shared through the Markets Roadmap and the soon to be published Flexibility Strategy.

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Within-Day Flexibility

The gap to 2035

System requirement

Between 2025-2035, we expect a significant increase in the need for zero carbon within-day flexibility as we continue to decarbonise. By 2035, all within-day flexibility should be provided by zero carbon sources to ensure the government target is met.

The tools and methodology provided through QWID FLEXER will continue to help determine the national balancing requirements based on varying levels of uncertainty and different scenarios. In this time horizon, technology will be growing at a fast pace, and it is important that we understand these changes and their impact on our system requirements. Before 2035, we want to better understand the need for locational within-day flexibility, including locational balancing requirements, to understand the impacts beyond national energy balancing. With increased experience and access to better data, we will set increasingly accurate requirements that will be published through the relevant forums.

Capabilities to meet our requirement

Flexible domestic consumers will be a key resource for accessing within-day flexibility. We expect that a large proportion of within-day flexibility will be provided by new technologies, including battery storage, electric vehicle (EV) smart charging and vehicle to grid technologies, smart appliances and smart heating. The largest growth is expected to come from EVs, with the Future Energy Scenarios estimating up to 13GW of smart charging capability and up to 14GW of vehicle to grid capability over peak demand by 2035.

To access consumer flexibility in the wholesale market, the following programmes are underway:

- **Smart meter rollout:** as variable tariffs become more readily available it will become increasingly beneficial for homes to have a smart meter, to ensure that all consumers can alter and understand their energy usage as prices change.
- **Market-wide half hourly settlement (MHHS):** this programme will be implemented late 2026 to allow suppliers and aggregators to settle domestic demand half hourly. Following this momentous change, we expect the majority of domestic consumers to have the opportunity to alter their usage based on price signals, such as through variable tariffs that expose these consumers to these varying prices throughout the day.

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Within-Day Flexibility

Operational readiness

Currently, work is being done to understand the impact of small-scale flexibility units within the Balancing Mechanism (BM) and create reliable flexibility models. We are also working alongside industry to overcome additional internal barriers to accessing flexibility on the system.

- **Distributed Energy Resource (DER) visibility:** large volumes of distributed generation and flexible consumer energy resources (CER) are connecting to the distribution network. We are engaged with the DNOs to increase visibility of these assets, to ensure accurate real time monitoring and dispatch of these assets for within-day flexibility, as well as improving our forecasting ability. We are working to initiate an industry-wide transformation to help enable more efficient, closer to real time flexibility markets, avoiding over-procurement and over-dispatch of DERs.

Our vision for 2028 is to enable DERs and CERs, providing a route to market and removing the barriers for these resources. These current projects will help form our strategy for enabling DERs and CERs that will be published in the upcoming Flexibility Strategy Roadmap.

To ensure we are enabling zero carbon within-day flexibility we are developing our first Flexibility Strategy Roadmap that will be published in Q1 2024. This 5-year roadmap is created in partnership with industry to set the vision and desired outcomes for 2028. It explains how we will achieve the activities required to help enable access to markets for low carbon flexibility, remove barriers for providers, coordinate across ESO and DSO markets, reform our markets and build the necessary digital infrastructure, while minimising cost to the end consumer.

Procurement route

By 2035, within-day flexibility will be mainly delivered by the wholesale market for the purpose of energy balancing, through mechanisms such as time of use tariffs (TouT). The energy balancing requirement that is not met through the wholesale market will be procured through the Balancing Mechanism (BM). There will also be a requirement for locational ESO and DSO services to shift energy within-day to manage the transmission and distribution networks.

More information will be shared through the Markets Roadmap and the upcoming Flexibility Strategy Roadmap.

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Adequacy

The gap to 2035

System requirement

Our first step to understand the potential risks and challenges with a decarbonised system started with our first report on Net Zero Resource Adequacy which was published in December 2022 in collaboration with AFRY. The study examines four different potential portfolios of resources – utilising different combinations of nuclear, Carbon Capture and Storage (CCS), hydrogen power generation and batteries. Some of the key system requirements coming out of this study are listed below:

1. There is no trade-off between adequacy and meeting net zero but we need to bring forward investment in clean technologies whose output does not depend on the weather. Even at times of low output from renewable generation, it is possible to operate a fully decarbonised power system and meet customer demand.
2. Weather patterns will be the dominant driver of stress periods in a fully decarbonised power system.

   This represents a change for the GB system, as tight periods have traditionally been driven by plant availability and high demand. Understanding risks due to weather patterns will become increasingly important to ensure adequacy in a fully decarbonised system with high levels of weather dependent generation.
3. The GB system is expected to evolve from one where tight periods are relatively short to one where they could be much longer. Even though the duration of tight periods increases, the LOLE of the system remains broadly similar. The inherent risk profile of the system is changing. This means that new modelling approaches and metrics will be required to assess risks to adequacy in a fully decarbonised power system.
4. It will become more important to consider adequacy in the context of developing the right markets, the right networks and future operability challenges to be confident that adequacy is ensured in a cost-effective way.

In working towards our 2035 ambition, we need to increase our modelling capabilities to conduct stochastic resource adequacy simulations. Recognising this requirement, we have built a new Net Zero Adequacy Modelling team in the ESO and begun deploying our new model (PLEXOS) to prepare for the next study. Unlike the previous study, the next study will be conducted with in-house capabilities which will enable us to cover more areas which are important for all stakeholders. We are aiming to publish our next study in summer 2024. The objective of this study will be to identify the resources needed to ensure adequacy in a fully decarbonised power system. It will incorporate improvements that build on the work we have already done, reflecting stakeholder input, considering different portfolios across a range of scenarios. The outcomes of the study could potentially lead to us making recommendations on the future resources needed, coinciding with our transition to the Future System Operator, and our new role in coordinating strategic planning for the whole energy system. We will be striving to ensure that the outcomes are robust such that it can support development of policy and investment in the GB energy system. We are also planning to continue this discussion on adequacy with our stakeholders through various spotlight studies which we are aiming to publish early next year.

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Adequacy

We have also set up a technical advisory group which includes around 20 experts representing a diverse range of views, backgrounds and interests. This group is expected to help us improve our assumptions, review our work, and provide feedback on areas such as adequacy modelling methods, assumptions for new technologies including costs, development of potential scenarios to consider including weather etc.

Capabilities to meet our requirement

Our study suggests that the GB system requires large investment in clean technologies that are not weather-dependent. This could include new nuclear, CCS, hydrogen power generation, new electricity storage or other technologies that can deliver energy on a scale of TWh or tens of TWh. There is uncertainty in relying upon new technologies. They typically have long lead times and some need to be proven at commercial scale. It is therefore important to identify barriers to delivering this capacity at scale ahead of 2035 and suitably address them to reduce dependence on unabated gas.

Following publication of our first adequacy study, we invited feedback from expert stakeholders, through an in-person event on 8 March 2023 and virtual round table events, as well as bilateral discussions, receiving input from over 40 individual stakeholders. A summary report of this feedback was published in July 2023. The feedback has been highly valuable in shaping our next study which is planned for publication in summer 2024. Further details of that study are discussed in the next section. Although there was feedback on several topics, most of these topics could be grouped into the following broad areas:

Demand Side Response (DSR)	The first study assumed high levels of DSR based on those in the Future Energy Scenarios, but what is the role of DSR in adequacy and what assumptions are we relying upon?
	What types of DSR in terms of the size, duration and frequency of the response is needed?
	How would the resources in the different portfolios change if we use different assumptions for DSR?
Extreme scenarios and weather	How do events like wind drought, Dunkelflaute and extreme summer heat in both Great Britain and Europe impact adequacy?
	How do we assess risks due to previously unseen, more extreme weather patterns? How does it impact availability of the different technologies?
	How does climate change impact adequacy?
Network development	The first adequacy study didn't assess the impact of network constraints. Given that we expect significantly more renewables on the system by 2035, what is the impact of network constraints on adequacy in the 2030s and can we consider this through a zonal model for Great Britain?
	The first study assumed over 20GW electricity interconnection with Europe by 2035. GB currently has 8.4GW interconnection with a further 4.7GW committed. How would the resources in the different portfolios change for different levels of interconnection?
Other Areas	What are the alternatives to Loss of Load Expectation (LOLE) as a metric for monitoring security of supply?
	How certain can we be in the mix of technologies in order to be confident of the soundness of investment decisions now? How would various storage technologies impact the adequacy? What assumptions are we making for emerging technologies?
	What is the impact of uncertainties and stochasticity in various parameters like fuel price or outages on resource adequacy and total economic costs?

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Adequacy

Operational readiness

Our analysis has focussed on how different resources ensure adequacy. It has not considered how the resources deliver energy to meet demand throughout the year, for example, in periods when demand is much lower and / or output from renewable generation is much higher. While the different generation technology mixes show similar outcomes for adequacy, the range of annual renewable curtailment due to there being excess supply across our different resource mixes from the dispatch modelling shows that the operability impacts throughout the year will need to be factored in. This means it will become increasingly necessary to consider the resources needed to ensure adequacy in the context of future operability challenges as well (i.e. we cannot consider adequacy in isolation).

Procurement route

The economic viability of the resources was not considered in our study. The market arrangements in which these resources operate in future could be very different to those that are in place today. The right market arrangements will need to be in place to bring forward investment in new resources that are needed to ensure adequacy. Further investigations are being done through the ESO's work on Net Zero Market Reform and the UK Government's Review of Electricity Market Arrangements (REMA).

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Appendix

ESO

What is Thermal?

What is Thermal?	The transmission network has limited capacity to transport power. The thermal workstream covers how we manage this capacity.
What are our obligations?	It is our responsibility to identify the future transmission network needs as we drive towards operating a zero carbon electricity system, and enable the transition to net zero. Planning the future transmission network starts with the Future Energy Scenarios (FES). We use these scenarios to determine generation capacity, peak demand and transmission network power flows. We can then identify where additional network capacity is needed and this is published in our Electricity Ten Year Statement (ETYS). We then undertake an economic assessment of options to improve network capacity and reduce constraint costs. Recommendations for these are published in our Network Options Assessment.
What are the future operability challenges?	As we move towards a net zero future, more generation must connect to the electricity network. Careful management of where this generation connects is required, or appropriate processes in place to plan a network fit for the future. If not, significant costs will be incurred constraining low and zero carbon generation because there isn't sufficient network capacity. Often, these costs are incurred as the ability to connect new generation occurs at a pace greater than delivery of new infrastructure. Therefore, future network planning will likely require a move to more strategic and anticipatory investment.
What capability do we need?	We need network capacity to accommodate the Government's ambition of 50GW of offshore wind by 2030. We published our recommendations for this network investment in our Holistic Network Design. We also need capacity which allows for connection of generation and new forms of large scale demand on the transmission network. Enabling the connection of renewable generation and flexible demand is key to reaching a zero carbon network in 2035 and net zero in 2050. We are working with stakeholders to achieve an improved connections process, in both the short and long term.

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What is Voltage?

What is Voltage?	Voltage must be kept within set limits all across the transmission system to maintain safe and efficient operation. The absorption of reactive power helps to lower the voltage, the injection of reactive power helps to raise the voltage.
What are our obligations?	We are responsible for managing voltage levels across the transmission system. We must ensure that the Security and Quality of Supply Standards (SQSS) for voltage management are met. We must ensure that there is sufficient reactive capability available on the transmission network to maintain voltage within an acceptable range. There are obligations on us and transmission owners (TO) to build, maintain and operate a network which meets voltage criteria in the SQSS. These criteria apply in planning and operational timescales, and in steady state and post-fault scenarios.
What are the future operability challenges?	The energy transition is having, and will continue to have, a significant impact on voltage management across the transmission network. The need for reactive power support continues to increase and new providers of reactive power are required, in the right locations, to meet this increase. The increase in reactive power needs is driven by many factors: transmission circuits which are transferring much less power than their capability produce reactive power and raise the voltage; more transmission circuits are put underground and these cables inherently produce reactive power; reactive power was historically consumed by assets on the distribution networks, but now reactive power is produced on and by distribution networks which must then be consumed and managed on the transmission network. Getting to zero carbon operation means removing our reliance on carbon emitting generation for the provision of reactive power services. It means attaining new capability and operating the system with fewer large synchronous assets with very large reactive power ranges.
What capability do we need?	Reactive power capability mainly comes from two main sources; assets owned by transmission owners (TO) and transmission connected generation, providing both dynamic and static reactive services. Generators typically provide a dynamic service by adjusting the volume of reactive production or consumption in response to changes in the system voltage. TO assets provide static or dynamic services depending on the asset type. We will need a balance of assets which can manage voltage dynamically, responding to fluctuations in voltage profiles and smooth voltage level variability, and those which provide static reactive power. An increasing amount of reactive capability will need to come from assets which can provide reactive power at 0MW output (decoupled from MW generation).

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What is Stability?

What is Stability?	Stability is the inherent ability of the system to quickly return to acceptable operation following a disturbance. The term is used to describe a broad range of topics, including inertia, system strength and dynamic voltage. If the system becomes unstable it could lead to a partial or total system shut down leading to the disconnection of consumers.
What are our obligations?	The Security and Quality of Supply Standard (SQSS) requires that we operate the system such that it remains stable following specific secured events. These obligations are enduring, and we are required to ensure they are met at all times even when system conditions change.
What are the future operability challenges?	Getting to zero carbon operation means removing our reliance on carbon emitting generation for the provision of stability services. We need to find new capability and learn to operate the system with fewer large synchronous assets, and operating a system with lower inertia levels.
What capability do we need?	We need more assets that are capable of providing inertia independently of their MW output, or zero carbon assets that can provide us with stability services. We need to learn more about the real-time operation of grid forming capability and further integrate this technology onto the system.

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What is Restoration?

What is Restoration?	In the unlikely event that the lights go out, the ESO has a robust plan to restore power to the country as quickly as possible.
What are our obligations?	The Electricity System Restoration Standard (ESRS) was introduced by BEIS in April 2021. This introduced a legal binding target for the restoration of electricity supplies in the event of a National Electricity Transmission System (NETS) failure. This resulted in a change to our licence, requiring us to ensure we maintain the capability to restore 60% of electricity demand within 24 hours and 100% of electricity demand within 5 days, in the event of a restoration event.
What are the future operability challenges?	We have removed our reliance on warming coal units for the purposes of restoration. We continue to develop a radically different approach to restoration compared to our historical reliance on large dispatchable generation. We continue to find new capabilities for restoration, from asynchronous, zero carbon generation and create the robust capability to restore the system using a ‘bottom up’ approach.
What capability do we need?	The Distributed Restart project has proven the restoration capability of distributed energy resources (DER). We need to continue to diversify our portfolio of restoration providers, improving resilience, increasing competition and leading to reductions in both cost and carbon emissions to meet our 2035 ambition.

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What is Frequency?

What is Frequency?	Frequency is a measure of the balance between supply and demand. We use response and reserve services to correct imbalances and maintain system frequency close to the target of 50Hz.
What are our obligations?	We ensure the SQSS is applied at all times by controlling frequency both steady-state and transient within the SQSS guidelines. SQSS also requires that we operate the network and avoid 'unacceptable frequency conditions' in a number of scenarios. As the GB system operator we are also required to abide by the System Operator Guideline obligations for all system operators in Europe.
What are the future operability challenges?	The largest loss size on the network continues to increase for both generators and interconnectors - the larger the loss the more actions need to be taken to protect the network both before an event and to recover post an event. Inertia levels continue to decrease on the network making the system frequency less resistant to change, meaning frequency will change more quickly when subject to an event.
What capability do we need?	Sufficient volumes of our fast acting suite of response and reserve products, predominantly provided by zero carbon sources, to ensure frequency stays within statutory limits and we abide by our obligations.

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What is Within-Day Flexibility?

What is Within-Day Flexibility?	Within-day flexibility means being able to adjust the flexible parts of supply and demand as the inflexible parts vary over the day. To achieve a zero carbon electricity system, fossil fuelled flexibility will have to be replaced with new, zero carbon solutions that move supply and demand through time.
What are our obligations?	We must ensure the system remains balanced. Within-day flexibility helps us meet this obligation by ensuring sufficient zero carbon capability is available to help balance supply and demand over the course of a day.
What are the future operability challenges?	Using within-day flexibility during high demand periods, such as winter peak, to shift demand to another period in the day, reducing system stress. Using within-day flexibility to increase minimum demand, potentially around noon on a summers day, to match renewable supply. This can also help alleviate voltage, stability and thermal challenges.
What capability do we need?	We expect the majority of within-day flexibility capability to be delivered through the wholesale market, driven by price signals. We are working with industry to understand and remove barriers to unlock within-day flexibility capability on the system.

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What is Adequacy?

What is Adequacy?	Adequacy measures whether there are sufficient available resources to meet electricity demand throughout the year. In Great Britain, this has traditionally meant having sufficient margins when demand is highest in winter.
What are our obligations?	We must ensure that the system remains balanced. Adequacy will help to ensure there is enough flexible capacity across weeks, months and years, to maintain frequency in real time.
What are the future operability challenges?	Weather patterns will be the dominant driver of stress periods in a fully decarbonised power system. Understanding risks due to weather patterns will become increasingly important to ensure adequacy in a fully decarbonised system with high levels of weather-dependent generation.
What capability do we need?	Even at times of low output from weather-dependent renewable generation, it is possible to operate a fully decarbonised power system and meet customer demand. It will require large investment in clean, reliable technologies that are not weather-dependent. This could include: new nuclear, CCS, hydrogen power generation, new electricity storage or other technologies that can deliver energy on a scale of TWh or tens of TWh.

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National Grid ESO
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