Operability Strategy Report

March 2025

NESO
National Energy System Operator

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Introduction

Executive Summary

The National Energy System Operator's (NESO) annual Operability Strategy Report (OSR) outlines our strategy for ensuring an operable electricity system in Great Britain as we transition to clean power by 2030 and net zero beyond. This report explores how NESO is proactively overcoming the challenges that Britain expects to face during a typical weather year to achieve the UK Government's ambition of clean power by 2030.

Following independent and comprehensive analysis by NESO, the UK Government's "Clean Power in 2030 Action Plan" (December 2024), outlines how Great Britain will ensure that, over the course of a year by 2030:

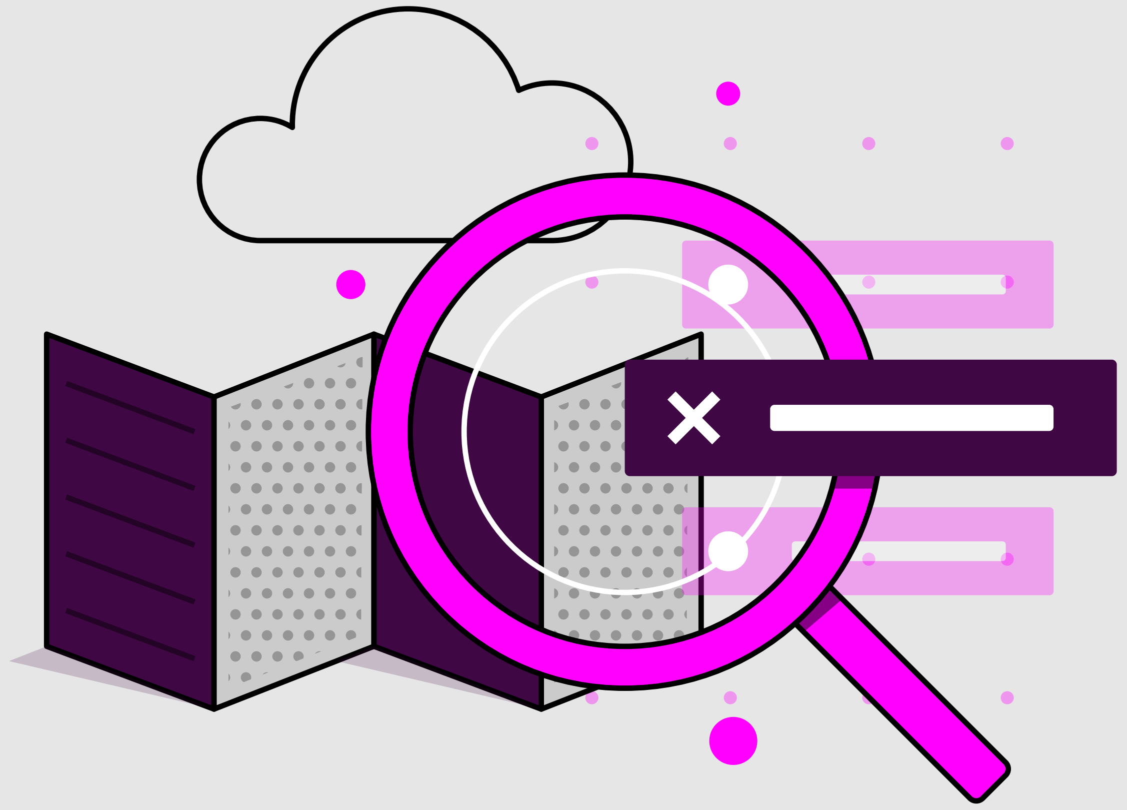
- Clean sources produce at least as much power as Great Britain consumes in total,
- Clean sources produce at least 95% of Great Britain's generation, and
- Average carbon intensity is <50 gCO_2/kWh.

Operating a clean power electricity system in 2030 will be a step change in our decarbonisation ambitions and presents several operability tests that NESO are already well underway with proactively addressing.

In 2024, NESO successfully ran the electricity system at 95% zero carbon for a short period of time. This was a significant milestone in NESO's ambition to run the electricity system carbon free for short periods of time in 2025, when the market delivers a zero carbon generation mix. We have demonstrated that the necessary operability services for a zero carbon system can be provided through innovation, and sourced at a lower cost than the alternative gas-fired power station solution. It is testament to the collaboration between NESO and industry to overcome technical challenges in running a low carbon electricity system, and develop new markets which enable new zero carbon technologies to deliver clean power and ancillary services.

Achieving clean power in 2030 will require operating the electricity system for longer periods of time using only clean power sources, reserving use of unabated gas generation for managing periods of insufficient clean power to meet demand and ensure it is within 5% of Great Britain's total generation. We are building on the work NESO and industry have collectively delivered in the last five years, ensuring the electricity system can run efficiently and economically on clean power sources, most of the time, by the end of this decade. NESO will continue to work with industry to develop the new tools, processes, strategies and capabilities needed to achieve our shared decarbonisation ambitions.

- In **2025 we expect to have the capabilities** to operate the electricity transmission system using only clean power sources and expect to do this over a few hours where the market delivers clean power generation.
- NESO have **created new voltage and stability markets** to procure new innovative services to meet additional needs that may emerge as we refine our analysis between now and 2030. The electricity Markets Roadmap sets out our progress in developing these markets to date, including the announcement of our first mid-term stability market contracts to procure zero carbon inertia.



- The **forward look analysis conducted** by NESO on frequency needs, risks and controls ensures we optimise our frequency event risk management and efficiently procure sufficient frequency management services. The Frequency Risk and Control Report details our methodology and proposed management of frequency risks.
- We will **enable flexibility resources** to contribute to meeting the operability needs for a clean power system. We set out our plans in the electricity Markets Roadmap to allow participants to operate seamlessly between markets, respond to transparent, effective market signals, and deliver whole electricity system value to consumers whilst supporting the transition to net zero.
- NESO's new suite of strategic network planning products will ensure we are better able to transition to a net zero energy system beyond 2030, with transitional products, such as tCSNP, bringing the **benefits of strategic planning** forward for 2030.

Decarbonisation of the electricity system is increasingly recognised as a whole energy challenge. The future energy system will see far greater interactions across energy vectors - heat and transport will play greater roles in providing electricity flexibility by shifting demand, and we will look to new technology types such as hydrogen or gas carbon capture and storage (CCS) for low carbon dispatchable power. As part of NESO's new responsibilities, we will be providing whole energy strategy, planning and expert advice. While this report remains focused on electricity system operability, we also examine how electricity interacts with the wider energy system, with particular emphasis on the challenges and opportunities that whole energy interactions will present for electricity system operability.

This Operability Strategy Report sets out key challenges, illustrated through some system conditions, the quantification of system needs, and the activities NESO will progress to ensure the clean power system commitment by 2030 is met. It is a key step in the journey to a clean power system and should be read in conjunction with the electricity Markets Roadmap. Together they provide our view on future operability challenges associated with a clean power system and how they will be overcome.

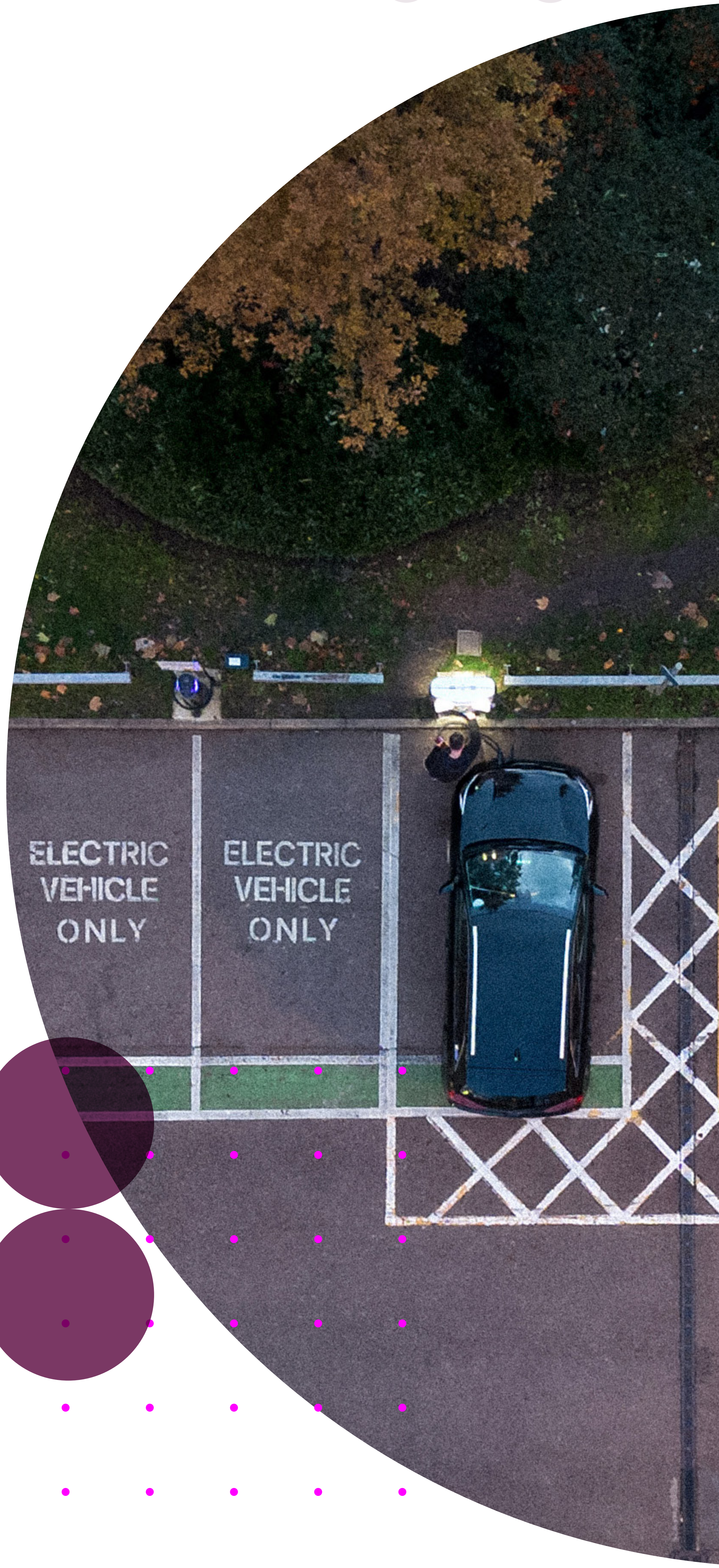
Decarbonisation of the Electricity System

2024 year in review

The electricity system continues to decarbonise at pace, breaking records again throughout 2024. We achieved periods of new record lows of carbon intensity at 19 gCO_2/kWh, maximum wind output at 22.5 GW and zero carbon generation meeting 95% of transmission demand. In September, Ratcliffe power station came off the system for the final time, marking the end of 142 years of coal power generation in GB. Across the year, zero carbon generation provided over 50% of the energy mix, contributing to the lowest average annual carbon intensity of 125 gCO_2/kWh.

The delivery of projects and programmes across NESO are enabling us to operate the electricity system closer to zero carbon. Last year we launched further frequency products, including Balancing Reserve and Quick Reserve, whilst reducing the minimum inertia requirement from 140 to 120 GVAs; this prepares us for managing larger network losses and reducing reliance on gas generation.

Further contracts were awarded for voltage and stability services, providing access to network services from zero carbon assets. The first grid-forming battery on the GB system has entered service in 2025 as part of Stability Phase 2, contributing to greater system security on a network with gas fired power stations running less often. Intertrips from our Network Services programme have also been extended, allowing for more renewable generation in the East Anglia region to meet demand across the wider network.



Clean power

In 2019 we set out our Zero Carbon Operation ambition to be capable of operating the GB electricity transmission system using 100% zero carbon power generation, when the market delivers a zero-carbon power mix. Five years later we were commissioned by government to provide independent advice on the pathway towards the 2030 clean power ambition. Our report concluded that a clean power system would be operable, but the right supply, demand, networks and flexibility all need to be developed and spearheaded by UK Government.

Our zero carbon ambition has already put in place some of the tools, processes, and strategies that are needed to operate the system using clean power. On that basis we are updating our definition of zero carbon operation to reflect those clean power technologies as set out in the Clean Power Action Plan. This means including biomass as a clean power source in our zero carbon generation definition. All other elements of our definition remain the same.

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

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

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

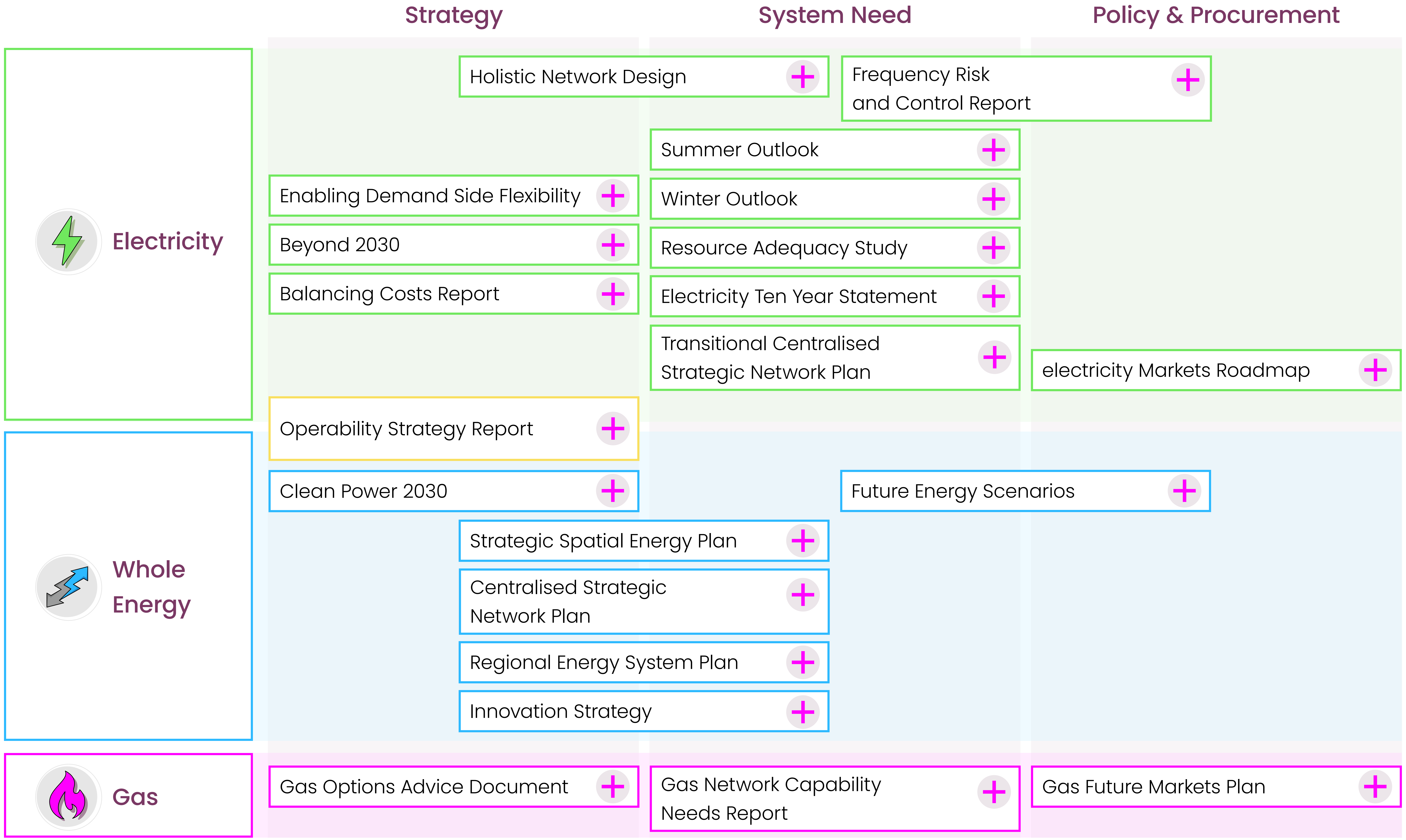
Domestic zero carbon transmission connected generation sources include power supplied from wind, solar, hydro, pumped storage, nuclear, biomass, and batteries. We will include other clean power technologies as they become operational.

Interconnectors, whether importing or exporting, are not included in the definition as non-domestic supply.

Achieving zero carbon in 2025

We continue to develop new tools, processes and strategies as we seek to achieve our zero carbon ambition in 2025. As we outlined in the last Operability Strategy Report, we require the market to first deliver a zero carbon generation mix, and then for us to have the technical capability to operate that mix. There will be times when our ability to operate a zero carbon system is limited by wider system conditions. We expect the likely periods for zero carbon operation to be possible are in the final quarter of 2025, when demand conditions are right, network service contracts are operational and more of our projects have delivered.

NESO Publication Map



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Electricity

Holistic Network Design

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Beyond 2030

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Centralised Strategic Network Plan

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Innovation Strategy

Gas

Gas Options Advice Document

Gas Network Capability Needs Report

Gas Future Markets Plan

Enabling Demand Side Flexibility

Cadence: Standalone

Enabling Demand Side Flexibility is a response to the urgent need for mobilising flexibility as Great Britain shifts towards a greener future. Our strategy aims to investigate the no-regret actions NESO, alongside other industry bodies, can take together to sharpen the market signals for flexibility in the medium term. It outlines our vision, the desired outcomes and associated activities needed in the next five years to unlock the flexibility required for achieving a net zero electricity system.

For more information click here.

System Operability

To ensure the safe, secure, economical, and efficient operation of a clean power system, NESO are proactively addressing potential future operability challenges across adequacy, within-day flexibility, frequency, stability, thermal constraints, voltage, and restoration.

Adequacy

Adequacy considers whether there will be sufficient available energy supply resources to meet electricity demand throughout the year. In Great Britain, this has traditionally meant having sufficient margins when demand is highest in winter. Moving to clean power means ensuring there is sufficient flexible capacity that can meet demand across weeks, months and years, to maintain frequency in real time. This will require large investment in clean, reliable technologies that are not weather-dependent. This could include: new nuclear, carbon capture utilisation and storage, hydrogen power generation, new electricity storage or other technologies that can deliver energy on a scale of TWh or tens of TWh.

Within-day flexibility

Flexibility is vital in a system with more variable renewables. 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 clean power, fossil fuelled flexibility will have to be replaced with new, low carbon solutions that move supply and demand through time. There are large opportunities to increase flexibility in both demand and supply, across residential and commercial applications, and in industry. We expect most of the within-day flexibility capability to be delivered through the wholesale market. However, markets and processes must be redesigned to remove blockers and unlock the value of flexibility.

Frequency

Maintaining the system frequency close to 50 Hz, by balancing real-time supply and demand, requires a quicker response due to impacts of the energy transition, such as the reduction of system inertia. NESO is delivering a new suite of reserve and response products to manage this transition. These services are pioneering, delivering the initial frequency response within one second following a system fault. These services are helping us better manage system frequency as we move towards clean power. As system volatility increases, there may be a requirement to increase the volumes procured of these services through our established frequency markets.

Stability

To ensure the system can securely and reliably withstand unplanned events, for example the loss of a generator or a fault on an overhead line, there needs to be enough inertia and short circuit level. With the move to renewable generation, NESO needs to increase the number of technologies that can provide these services, such as additional synchronous condensers, batteries, or renewable devices with grid forming inverters. Following the establishment of our network services markets, we have the mechanisms in place to procure the services we need.

Voltage

The voltage on the system must be maintained within acceptable operational limits using reactive power. All the new generation required to connect to deliver clean power must have a minimum range of voltage control; this includes battery energy storage and renewable sources of power. Voltage control in a clean power system does become more complex and further voltage control devices will need to be installed across the system to supplement the capability provided by new connections. Working with the transmission owners (TOs), we will identify and secure/source voltage control devices and services as required.

Thermal constraints

In operating an efficient electricity system, there are times when the physical capacity of the network cannot transfer the amount of electricity required. When this happens, generation output on one side needs to be reduced; this is called a ‘constraint’. Network development requires upfront investment, but brings benefit in reducing constraint costs. In addition to network development, other commercial and technical techniques can be used to reduce constraint costs. As we progress towards 2030, NESO will assess and deploy existing techniques as well as embracing new and innovative grid enhancing transmission solutions that increase the capacity of the network.

Restoration

NESO has an obligation to be able to restore 60% of British transmission demand within 24 hours and 100% within 5 days after a shutdown, by 31 December 2026. Clean Power 2030 pathways will not compromise this ability. The restoration strategy will include non-traditional generation for restoration services and an annual assurance framework to ensure compliance with the Electricity System Restoration Standard (ESRS).

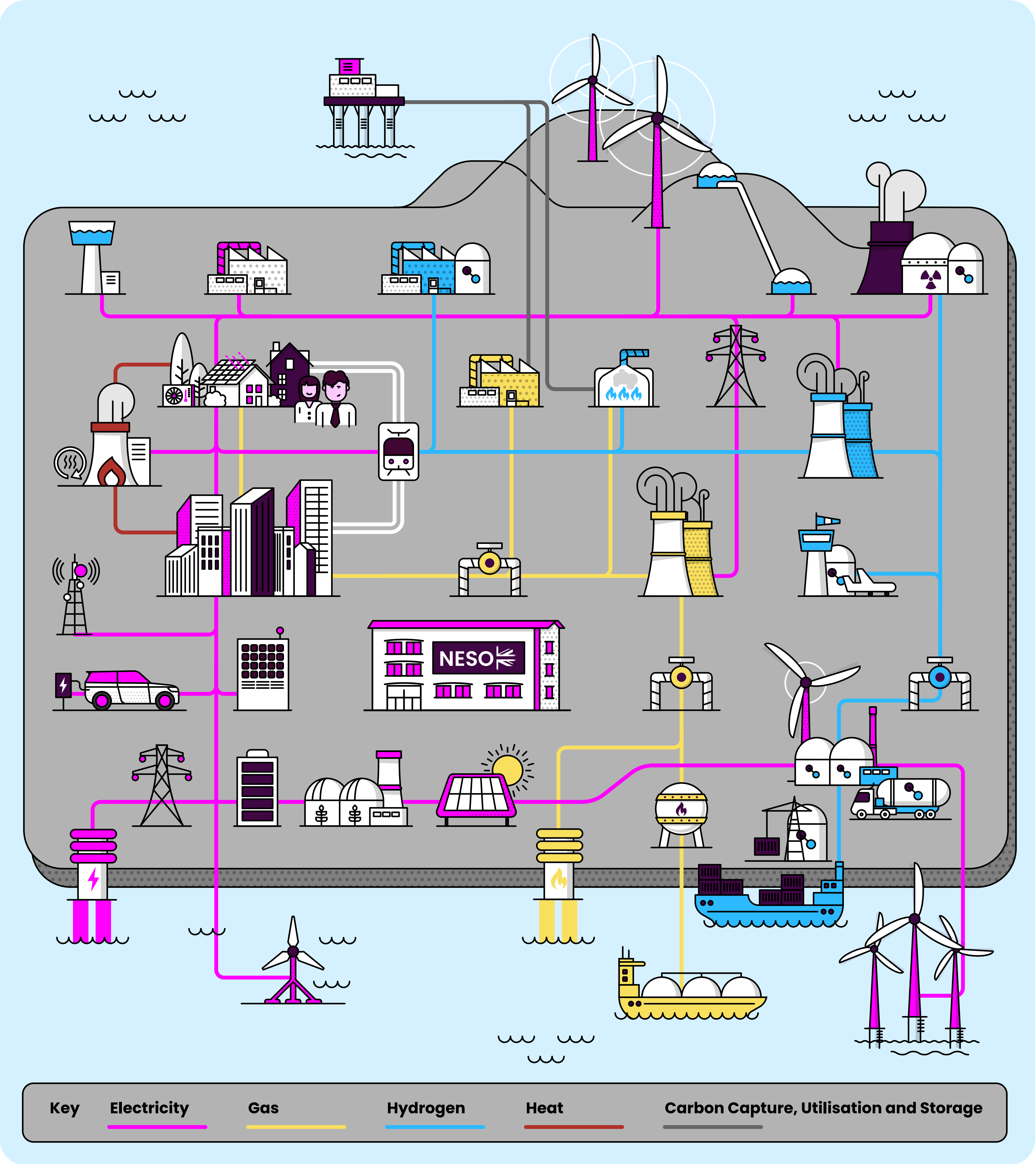
Beyond electricity

Since the last publication of the OSR we have transitioned from the Electricity System Operator (ESO) to the National Energy System Operator (NESO). Our role has expanded to include energy vectors beyond electricity, such as natural gas, heat, carbon and hydrogen. As we integrate multiple energy vectors, our focus will be on ensuring seamless and efficient planning across systems. This broader perspective enables us to better anticipate and address the complex operability challenges and opportunities associated with decarbonising the whole energy system.

In this OSR, the focus remains on electricity. We now consider the interactions between electricity operability and other vectors during different system conditions. As GB decarbonises, the interactions between different energy vectors will become increasingly complex. A change in operation of one vector's system can have a significant impact on another. We need to consider these impacts to avoid unintended operational consequences and drive the best overall solution. A fully integrated energy system presents many opportunities to optimise energy usage and support system operation.

Methane reduction

The pace at which some uses of methane are decarbonised through electrification will impact the scale and shape of demand on both the electricity and gas networks, impacting how they are operated. To decarbonise power, the electricity generation from unabated gas fired power stations will need to significantly reduce over the coming years, with gas plants moving from running frequently, to being used as a backup source of generation when the weather is unfavourable for producing renewable power.



This visual is intended to tell an illustrative story of a hypothetical future energy system. It is not intended to be comprehensive, nor does it define NESO's view of the future energy system.

Energy efficiency and flexibility

Energy efficiency is an important part of the transition to net zero, with our recent Clean Power 2030 advice to Government highlighting that energy efficiency is expected to reduce a typical household's electricity consumption by 5-10%. Certain types of electricity demand may decrease with others shifting their time of use. Over the longer term, electricity's contribution to the decarbonisation of sectors like heating and transport will significantly increase the demand on the electricity network. This transition will change the way in which the electricity system will interact with other developments, such as heat networks and new fuel types.

Hydrogen

The balance between which energy uses are decarbonised using electricity and which are decarbonised using new fuel types, such as hydrogen, will impact the operation of both networks. These different pathways are illustrated in our Future Energy Scenarios 2024 (FES24). Hydrogen power generation can offer a flexible source of clean power, but how hydrogen is stored and transported are important factors that need to be taken into consideration when assessing what level of flexibility can be offered. Hydrogen production via electrolysis may have a large impact on electricity demand and could be a potential future source of flexibility. Blending of hydrogen with gas could also be a stepping stone toward decarbonisation but the impact on the operation of existing CCGTs and the gas network needs to be considered.

Carbon capture utilisation and storage (CCUS)

The development of CCUS has the potential to offer a flexible source of low carbon power. The introduction of CCUS on some electricity generation will establish an interaction between the electricity network and the design and operability of carbon networks. When determining the type of flexibility that generation with CCUS could offer to support operation of the electricity system, the impact of the carbon capture process on the generators' operating capability and the wider pipeline for the use and storage of carbon need to be considered. These factors are likely to change over time as we move from first of a kind development to CCUS becoming a more established technology.

02

System Conditions

Introduction

Operating a clean power electricity system involves proactively managing new and evolving challenges associated with a changing generation mix, demand behaviour, increasing electrification of heat and transport, and greater interactions between energy vectors. Throughout the year, NESO will adapt to different system conditions, making informed operational decisions as we progress from short periods of zero carbon operation in 2025, to clean power in 2030, and net zero by 2050 and beyond.

To explore how a clean power electricity system can be operated, we are using illustrative system condition examples in this report, that highlight future operability challenges, and the associated tools, capabilities and system needs necessary for secure operation that NESO is already implementing. These include:

- **A typical day** where there is sufficient clean power generation to meet demand. Wholesale market dispatch largely covers the system requirements with renewable generation contributing to the majority of supply.
  - Minimal redispatch actions are required to manage thermal constraints, with reactive power, inertia, and short circuit level requirements met by our enduring stability and voltage markets.
  - Energy storage plays a significant role in maintaining frequency, by storing excess renewable supply during the day and discharging to meet evening demand.

- **Low demand** periods where actions are required to lower supply. These include where demand is low overnight, on a summer's day, or where downward margin needs to be managed.
  - Low transmission demand and high levels of distribution connected generation can result in high volts and lower inertia, which will be managed by forecasting requirements further into the future in our Centralised Strategic Network Plan (CSNP), improved tools, and procuring network services through enduring markets.
  - Periods of excess wind may require curtailment to manage network constraints, or to create margin to dispatch generation for inertia or voltage management. Where excess generation is from firm supply, such as distribution connected solar, it can result in limited operational margins available to manage frequency through low availability of dispatchable generation.
  - Improved forecasting for demand and weather dependent renewables is important for procuring sufficient reserve volumes. The Transformation to Integrate Distributed Energy (TIDE), formerly the distributed energy resource (DER) visibility project, amongst others, is helping improve forecasting and visibility of distributed connected resources.
- **High demand** where peak demand exceeds generation, or where generation is limited due to a network constraint. This typically occurs during cold, dark, winter evenings, where there is a high domestic heat usage and wind is low.
  - Unabated gas will be needed in 2030 and beyond to meet demand where there is insufficient clean power, demand response and bidirectional flexibility from storage and interconnectors. Deployment of hydrogen to power and carbon capture and storage generation will reduce reliance on unabated gas, yet these options will be dependent on gas, carbon and hydrogen transport and storage network development.
  - Weather dependent renewables will, at times, be constrained by network capacity, requiring replacement energy to come from clean power sources closer to demand centers. General flows are from North to South, meaning replacement clean power sources are needed in the South of GB.
- **Supply and demand ramps** that result in actions taken to maintain energy balance and system operability, typically where supply and demand are moving in opposite directions.
  - Changes in weather or energy prices can lead to changing energy output and demand, potentially leading to frequency management and inertia challenges. Our suite of response and reserve products, alongside stability markets, will ensure there are sufficient options available to maintain system frequency and inertia levels.
  - Enhanced forecasting and situational awareness will help improve our operational capabilities and preparedness to manage supply and demand ramps.

The illustrative examples of system conditions in this report use data from our recent Clean Power 2030 publication. Please note, modelling data used in this chapter are for illustrative purposes only and has maintained the existing national wholesale pricing model. In chapter 4, we quantify what these system conditions mean in an overview of system needs, and set out the programmes of work NESO are already progressing and have planned for the future.

A Typical Day

On a typical day in 2030, market dispatch meets most of our demand needs with renewable generation contributing the majority of supply, with interconnectors, demand and energy storage providing the main sources of within-day flexibility. Solar generation during the day contributes to an excess of supply, much of which is stored to manage the expected supply shortfall in the evening. Nuclear will continue to provide a consistent baseload, with biomass, combined heat and power, and energy from waste consistently dispatched throughout the day. Minimal redispatch is required to manage constraints, as the transmission network has near sufficient capacity to transfer supply to demand.

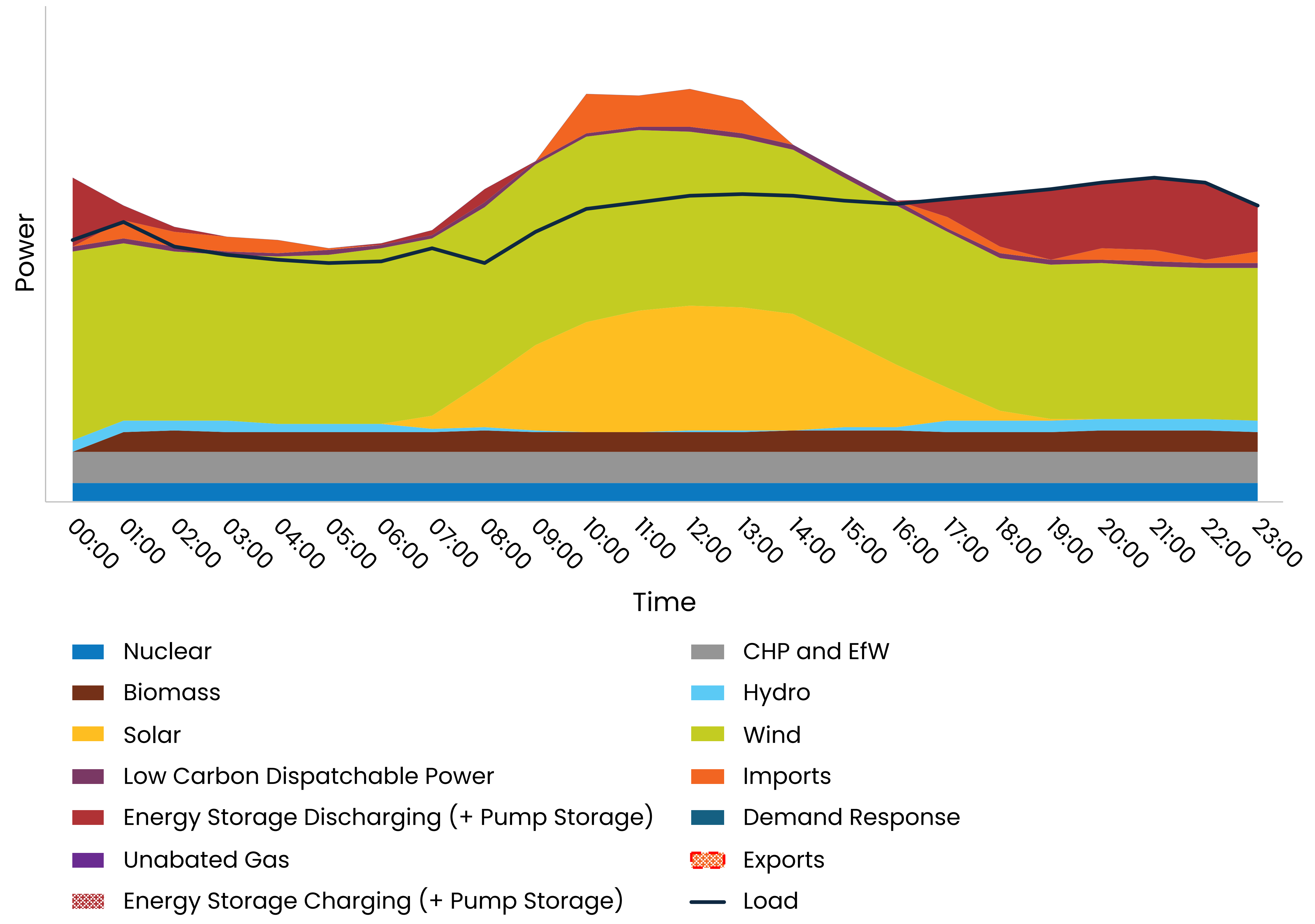
Maintaining energy balance

Throughout our example day there is both significant excess supply during periods of high renewable generation, and clean supply shortfall during periods of reduced renewable generation and increased demand. System/Bidirectional flexibility plays an important role in moving energy through the day to maintain energy balance. This within-day flexibility is mainly provided by interconnectors, energy storage, and pumped hydro. This is demonstrated by storage assets charging during the periods of excess supply then discharging in the evening (see Figure 1).

We expect demand side flexibility to respond to dynamic time of use tariffs (ToU) to smooth demand throughout the day, reducing required system balancing actions as consumers and smart appliances respond to price signals. Storage options, including batteries and vehicle-to-grid, take advantage of low electricity prices in the overnight period to charge and higher prices to discharge during the evening demand peak. Our example uses data from the further flexibility clean power pathway, as such does not include low carbon dispatchable power, such as hydrogen to power, or gas CCS. However, we would expect low carbon dispatchable power to dispatch in a similar manner as storage in our example.

In our typical day example, minimal redispatch is required to manage thermal constraints, as the transmission network has near sufficient capacity to transfer supply to demand (see Figure 2).

Figure 1: **A typical day market dispatch**



+ **Supply only**

+ **Plus bidirectional flexibility**

More information +

In reality, network outages are likely to create some constraints on the system, and it's our role to optimise these in collaboration with transmission owners (TO)s. Our transitional Centralised Strategic Network Plan (tCSNP) will be a key enabler in ensuring we have sufficient network to reduce actions taken to manage thermal constraints for a clean power system in 2030 and our enduring CSNP will look at the network needs beyond 2030.

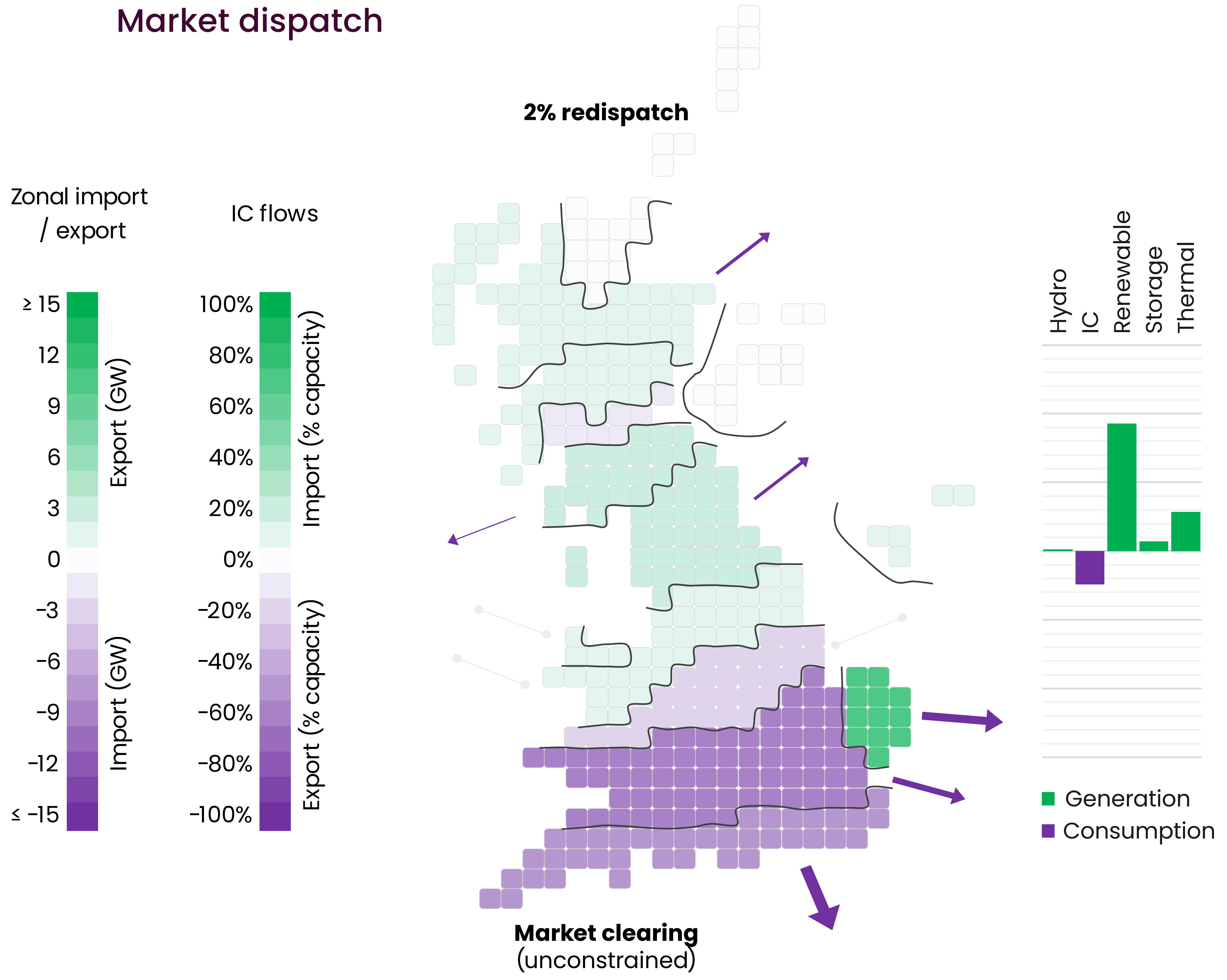
New stability capabilities

Asynchronous generation (including onshore and offshore wind, solar generation and batteries) comprises over half of the total generation in our study day and are the technologies that replace the synchronous unabated gas used on today's system. In order to achieve the 2025 zero carbon ambition, we need to be less reliant on synchronous generation for the provision of network services; inertia and short circuit level (SCL) (stability), and reactive power (voltage). We have begun to tackle this by procuring zero MW network services and redesigning our suite of frequency response and reserve products. This has allowed us to reduce the minimum system inertia operating level from 140 GVA.s to 120 GVA.s. Our studies indicate that we can reduce the minimum system inertia operating level further to 102 GVA.s. This is expected to be implemented in 2025, subject to Ofgem approval. Current analysis indicates that a minimum inertia operating level of 102 GVA.s will be sufficient for clean power operation in 2030, yet will be reviewed annually as part of the Frequency Risk and Control Report (FRCR).

Whilst overall system inertia levels are reducing, additional capabilities will be required to meet system inertia requirements to 2030 and beyond, where shortfalls could be as high as 35 GVA.s, as outlined in our Clean Power 2030 report. Additional inertia and SCL capabilities will be procured through the long-term (Y-4) and mid-term (Y-1) stability markets, formally the stability pathfinders and outlined in the electricity Markets Roadmap. Further capabilities may be procured through the short-term (D-1) stability market, which is still within its design phase, as such is subject to approval.

Figure 2: Typical day single period redispatch

Market dispatch



SCL is a measure of the electricity system's fault response capability and is essential for transmission protection systems to detect and isolate faults quickly.

We are currently working with industry to explore a Grid Code modification that would require newly connected Type D Generation Modules (50 MW and above and/or connected at 110 kV or above) and HVDC Systems to have grid forming capability. This is a control technique that allows asynchronous resources to mimic the behaviour of traditional synchronous machines to provide SCL and inertia, benefiting system security.

Our redesign of frequency services

The transition to a clean power system means a reduction in inertia alongside an increasing largest loss, and greater uncertainty in demand and generation output. NESO has worked with industry over the last five years to redesign our frequency services which enable the transition to clean power providers and efficiently manage associated challenges.

Largest loss is the measure of the largest supply, or demand unit, connected to the system that could trip, resulting in an instantaneous frequency deviation. By 2030, we estimate that response and reserve volumes will increase when compared to 2025 by:

- Response increase from 4.2 to 4.8 GW, including 2.1 to 2.2 GW for high frequency, and 2.1 to 2.6 GW for low frequency events.
- Reserve increase from 6.8 to 12.9 GW, including 4.4 to 6.4 GW of positive reserve to replace generation loss, and 2.4 to 6.5 GW of negative reserve to replace demand loss.

Delivering clean power in 2030 will require further decarbonisation of some of our frequency reserve services, such as Mandatory Reserve and Short-Term Operating Reserve (STOR), which is primarily met by unabated gas generation. Frequency reserve changes are covered in more detail in our Supply and Demand Ramps section and for further information, please refer to the electricity Markets Roadmap, or the frequency response services page on our website.

Meeting future voltage needs

We will manage regional high and low voltage using TO network assets (e.g. shunt reactors and static var compensators), synchronised clean power generation, and the utilisation of assets contracted through voltage markets. We can also reconfigure the network to help manage voltage levels, including altering substation layouts and switching out transmission circuits. However, excessive use of these actions increases wear and tear on assets. To date, we have concluded three network service tenders to provide additional reactive power capabilities across regions in England. Our enduring reactive power markets will allow for more effective procurement of reactive power and help reduce voltage management actions. The CSNP will identify future voltage requirements, that could be delivered by network owners or via our reactive power markets (formally pathfinders), supporting our efforts to meet long term system needs.

NESO has launched the Connections Reform programme which is focusing on reducing and reordering the connections queue to ensure it prioritises 'ready' projects that align with strategic energy plans. This will reduce connection timescales and will also free up connection bays for voltage and stability network service assets. Identification and acceleration of connections that are critical for system security or operability have been included as key Clean Power 2030 enablers.

Low Demand

Overnight Minimum

Historically, transmission demand falls overnight as businesses shut and consumers go to sleep. In 2030, increasing volumes of wind generation can lead to supply exceeding demand during these periods, prompting interconnector exports and energy storage assets to charge in preparation to discharge during any potential day-time supply shortfall. Excess wind supply drives prices down and reduces the diversity of generation technologies active overnight. Figure 3 shows how we might manage system constraints during an overnight period. This involves increasing interconnector exports from the North of England and reducing some thermal generation; whilst offers are issued to decrease charging and increase discharging of storage assets.

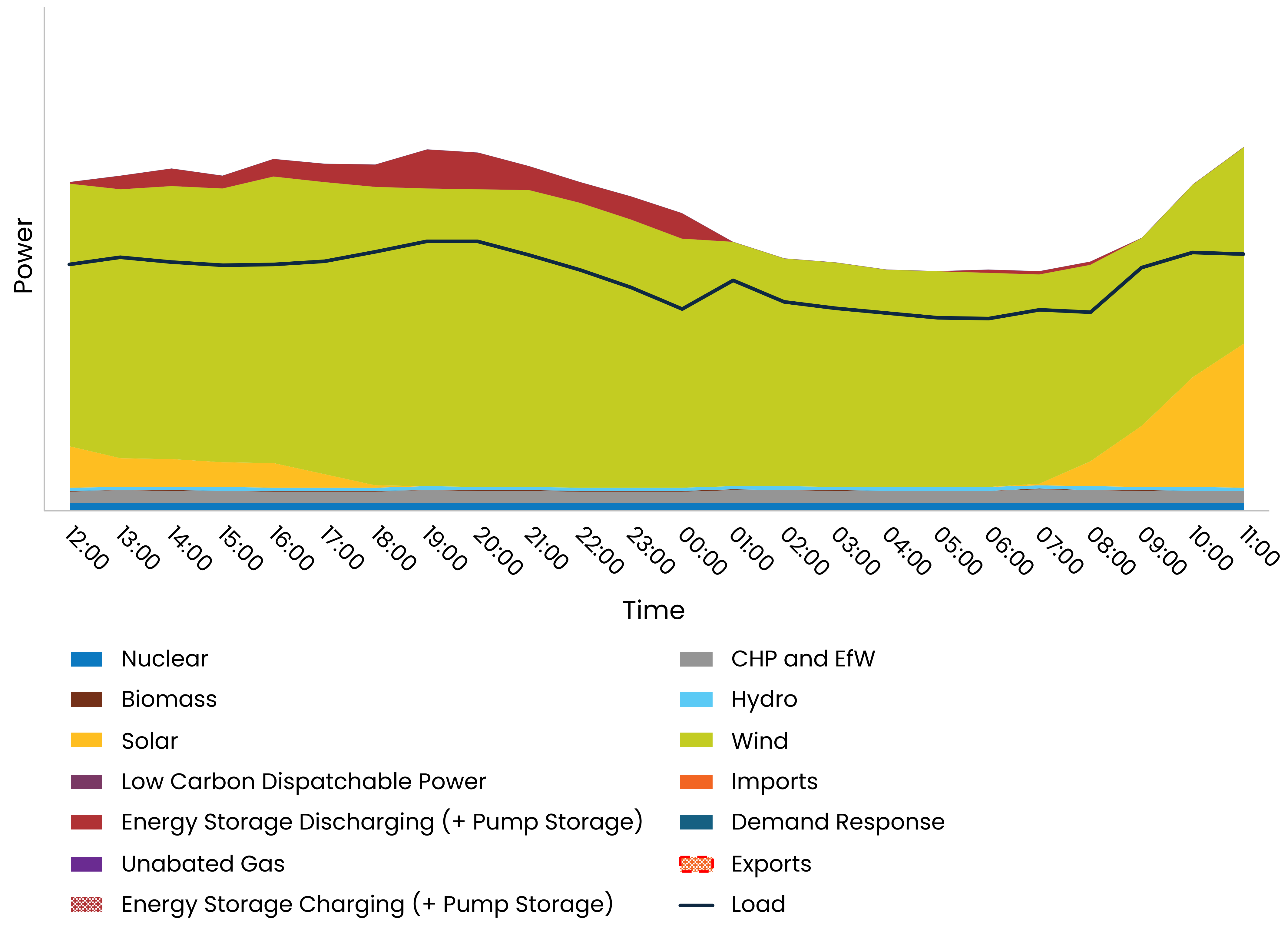
Changing demand behaviours

Periods of high wind supply and low transmission demand (see Figure 3) can drive wholesale electricity prices down and present new commercial opportunities for flexibility. As we move towards and beyond 2030, we expect domestic smart appliances (e.g., electric vehicles, domestic batteries, and heat pumps) and other energy vectors (e.g., heat and hydrogen) to increase nightly demand, as they react to lower prices.

This behaviour is expected to reshape overnight demand profiles as demand moves away from supply shortfalls to times of excess. The combination of a higher volume of smart meters, and Market-wide Half Hourly Settlement (MHHS) will enable easier access to time of use (ToU) tariffs and unlock greater levels of flexibility. Automation is expected to play a key role in enabling flexibility from domestic consumers and distributed energy resource (DER) control systems, particularly overnight.

Additional market flexibility will help align demand with supply, reducing NESO actions required to manage imbalances and lower associated costs.

Figure 3: Low demand overnight minimum market dispatch



+ Supply only

+ Plus bidirectional flexibility

More information +

Greater frequency control

High wind output during low demand periods can amplify the impact of wind volatility on grid frequency, increasing response and reserve requirements to manage deviations. Procuring sufficient response and reserve volumes during the nightly period can itself be challenging due to lower availability of frequency response service participants.

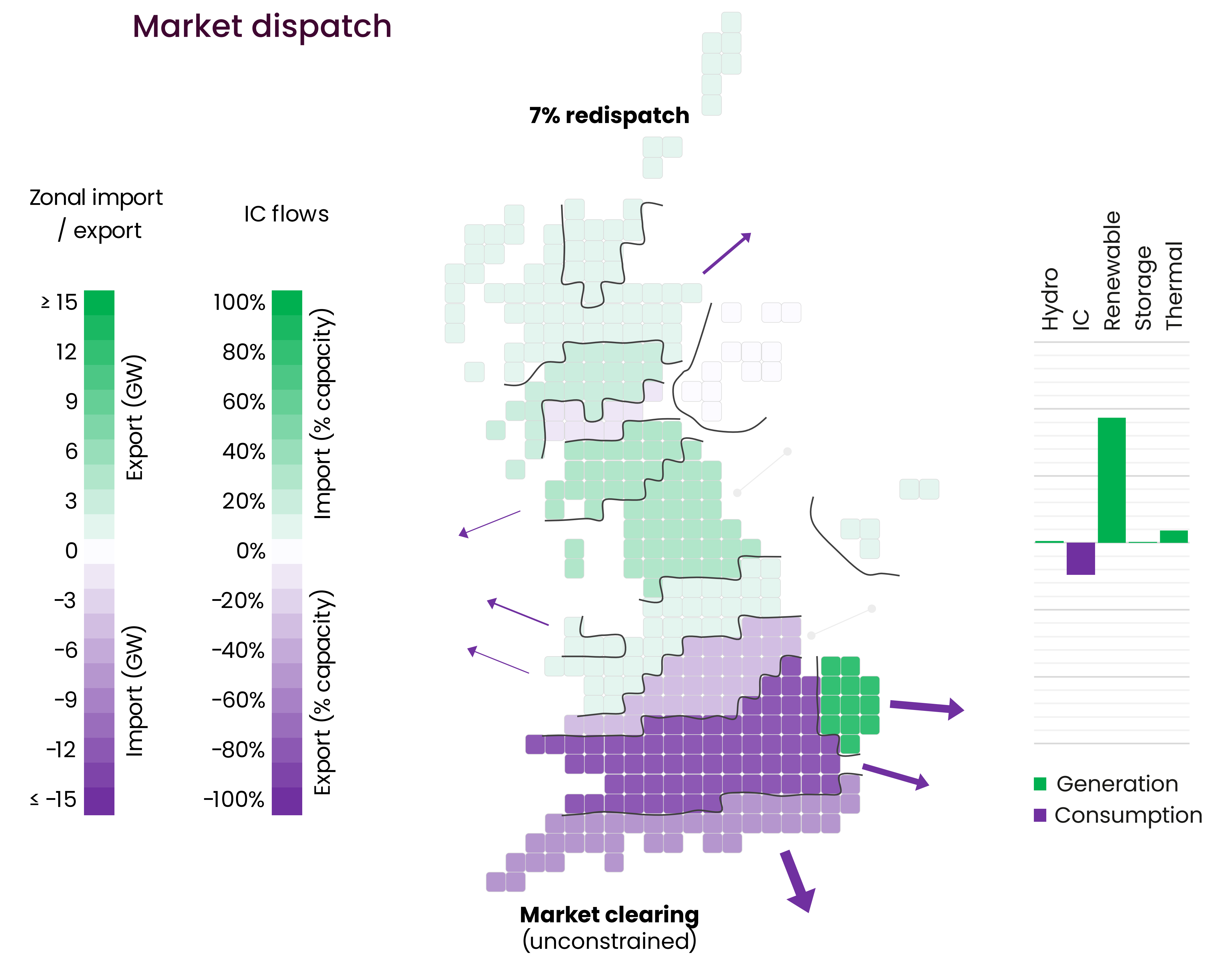
Our suite of dynamic response services and new Quick Reserve and Slow Reserve products will ensure we have sufficient access to frequency control to manage periods of high wind. Please see the electricity Markets Roadmap for further information.

Increased reactive power absorption capabilities

Low overnight demand can lead to elevated voltage levels due to low network power flows and low reactive power demand. The changing generation mix and move to clean power, means that there is less reactive power capacity available to meet the increasing locational needs of the network.

We have been developing tools and techniques to improve our forecasts of reactive power requirements further into the future as part of our transition to a Centralised Strategic Network Plan (CSNP). We have already procured reactive power services using these new techniques and will continue to do so. Enhanced reactive power forecasting will better enable the procurement of reactive power volumes in the right locations through our enduring voltage markets. This will reduce the need to take MW actions, such as curtailing renewable generation, to create room on the system for assets that provide voltage control.

Figure 4: Low demand overnight minimum single period redispatch



＋ Market dispatch ＋ NESO redispatch for constraints More information ＋

Post-fault control

Periods of low demand and high asynchronous generation can lead to a lowering of system strength and inertia. This can make the system more susceptible to frequency deviation, voltage fluctuations, slow post-fault recovery, and potential generation trips. As such, our mid-term and long-term stability markets will play an important role in identifying and procuring additional stability needs to ensure post-fault system resilience.

Grid-following asynchronous assets, such as wind, can be vulnerable to Phase-Lock Loop (PLL) instability in low SCL conditions. Procuring new grid forming technology through stability markets will provide additional system strength and the planned Grid Code mandate will ensure newly connected generation provide inertia and SCL, further mitigating system strength decline.

Summer Minimum

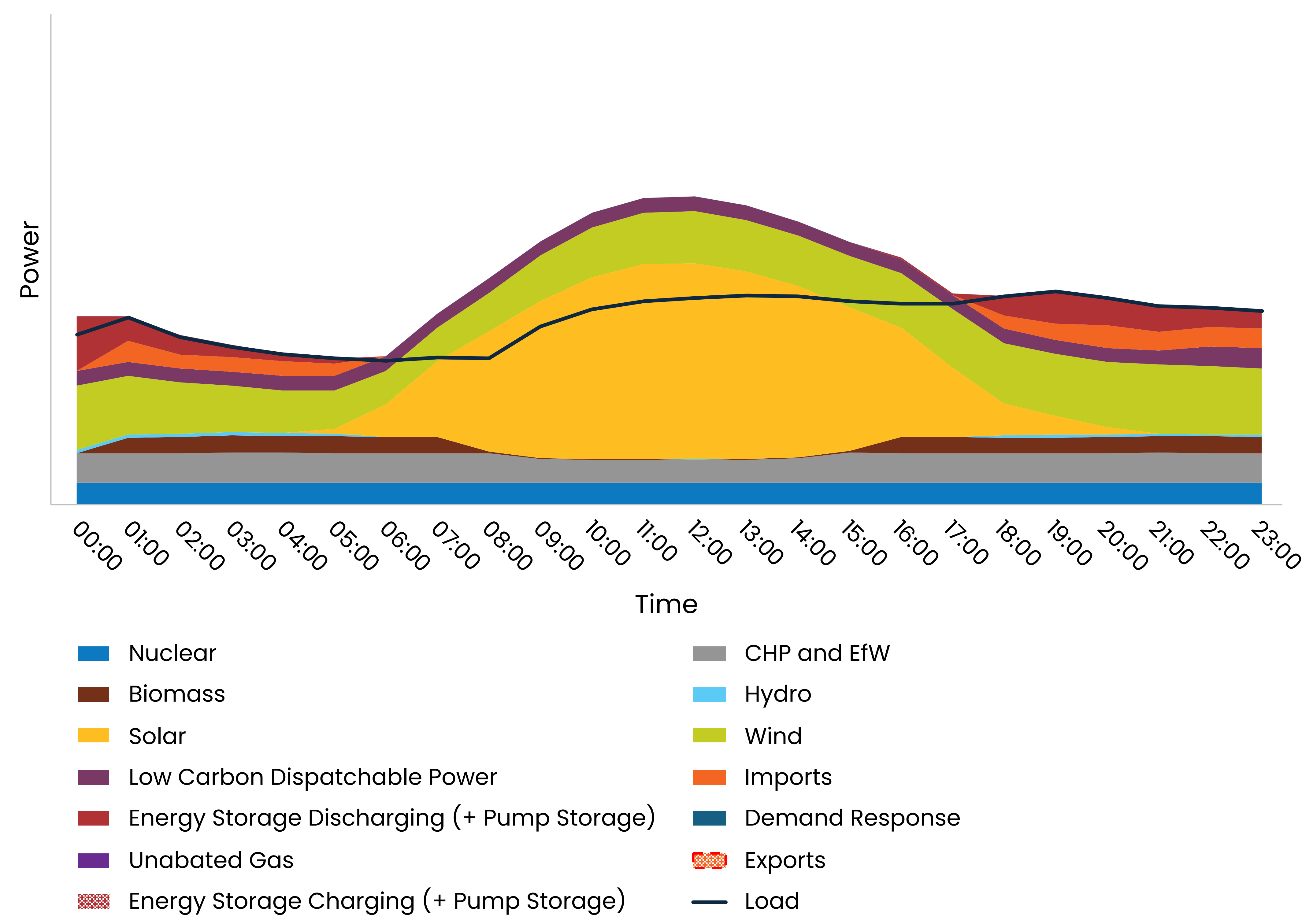
As higher volumes of solar PV generation are connected to the system, longer, sunnier, summer days can lead to periods of low transmission demand and excess supply. As solar PV ramps up in our example day, interconnectors switch from import to export and storage switches to charging, offsetting excess supply and keeping the system in balance during the daytime period. As solar PV volumes decrease through the late afternoon and ceases in the evening, interconnectors switch back to import and storage assets discharge to meet supply shortfall. There are North to South power flows across the network, with interconnectors and storage used to manage the minimal redispatch required.

Enabling deployment of distributed energy resources (DER)

By 2030 and beyond, Britain expects to see a continued increase in the volumes of distribution-connected assets, such as solar PV and domestic storage. This can lead to additional national system balancing considerations, particularly during periods of high distribution connected solar PV supply. National electricity system control has limited access to alter the output of DER assets, emphasising the importance of maintaining sufficient within-day flexibility to balance the system.

Higher volumes of weather dependent and distribution connected assets is changing supply and demand modelling requirements. It is increasing the volume, granularity and diversity of data inputs. In parallel, demand profiles change, as consumer uptake of time of use tariffs (ToU) increases following the completion of Market-wide Half Hourly Settlement (MHHS). Whilst this is expected to smooth demand and reduce NESO balancing actions, it will impact how we forecast demand. See the Supply and Demand Ramps example and our Situational Awareness section for more information.

Figure 5: Low demand summer minimum market dispatch



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To enhance visibility of distribution connected assets and demand behaviour, NESO is progressing the Transformation to Integrate Distributed Energy (TIDE) project, working with distribution operators improve data sharing. Greater access to distribution level data is a key enabler to increasing the accuracy of our forecasting and improving our situational awareness.

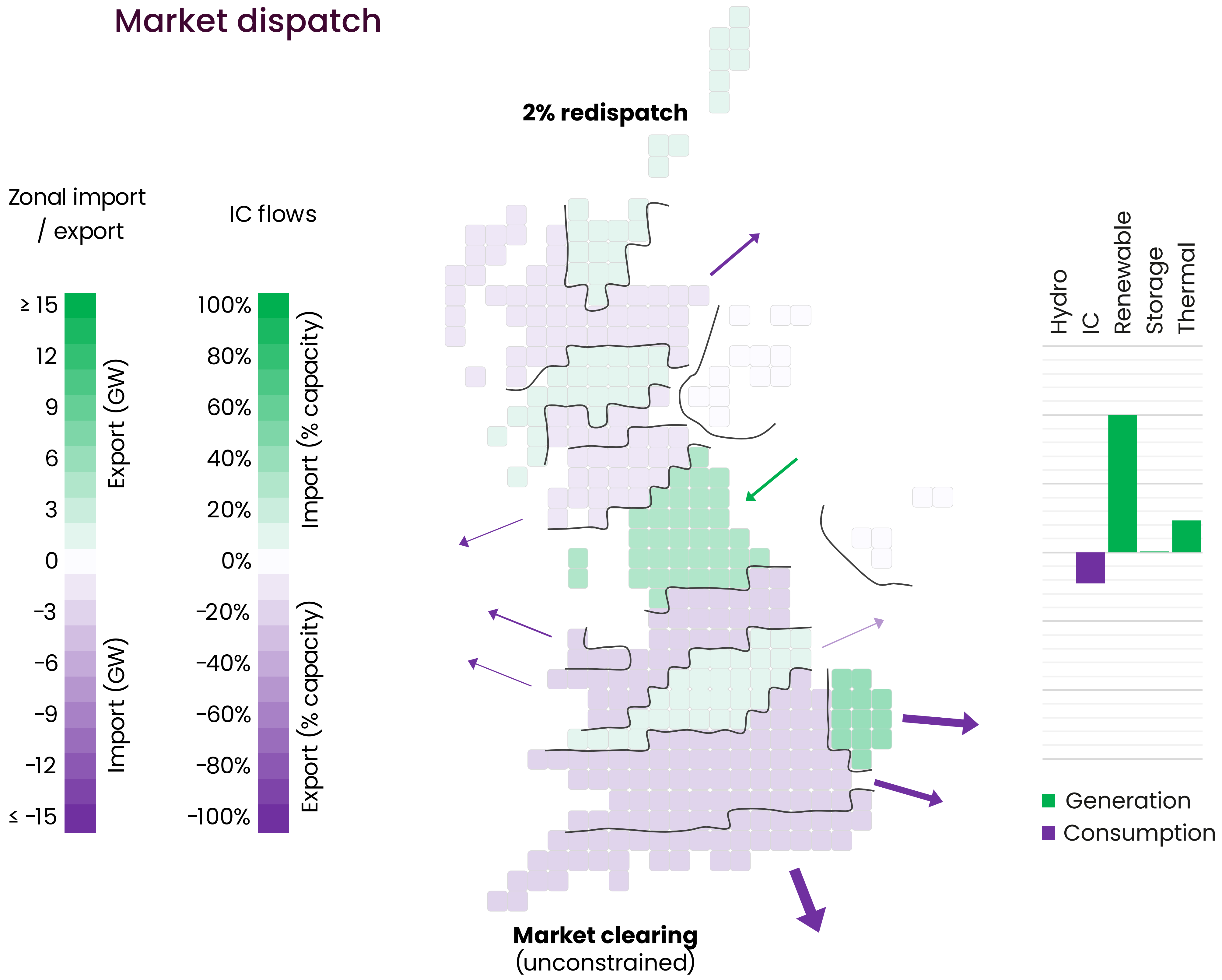
Managing periods of negative pricing

Periods of excess supply can lead to negative wholesale electricity prices. Where this occurs, subsidised plants may switch off simultaneously due to the Contract for Difference (CfD) negative pricing rule. Under this rule assets do not receive CfD payments during negative price periods, which can cause multi-gigawatt swings in power output as supply decreases, and demand increases to take advantage of negative prices. This can lead to NESO taking additional actions to manage network frequency, stability and voltage (see the Supply and Demand Ramps section for further information). Our suite of frequency management services will be key in maintaining system security during these conditions. NESO are improving forecasting capabilities to help with forward planning and procuring sufficient reserve volumes to manage negative pricing periods.

Ensuring sufficient margin

During the early morning of our 2030 example day, market dispatch primarily meets demand using firm generation (nuclear and combined heat and power (CHP)), solar and wind. This results in a generation mix that provides limited operational margin in addition to our Balancing Reserve (BR) service. In this scenario, we would expect to meet our upward margin from CHP and biomass generation, pump storage and hydro generation. Where operational margins are insufficient, wind, biomass or CHP could be curtailed to increase the volume of available generation on those assets. Implementing improvements to our forecasts and visibility of weather dependent generation, and the power available from these assets, is important for ensuring access to sufficient operational margins.

Figure 6: Summer minimum single period redispatch



Market dispatch

Market dispatch

NESO redispatch for constraints

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Managing voltage across network boundaries

Periods of high distributed generation output, coupled with low demand can result in localised high voltage challenges. During the example day, high solar PV coupled with low wind, reduces the number of transmission connected reactive power assets. High levels of distribution connected generation can result in active and reactive power flowing from the distribution network to the transmission network. Regions such as the South West of England are particularly susceptible to reactive power flowing from distribution to transmission. This is due to the high rates of solar PV that require additional reactive power capabilities to ensure voltage remains within safe operating limits.

We are working with distribution network owners (DNO) to improve our understanding of why the transfer of reactive power between networks is increasing and will collaboratively develop solutions to mitigate further increases. This will complement our innovation project to improve forecasts of reactive power transfers.

Insufficient Downward Margin

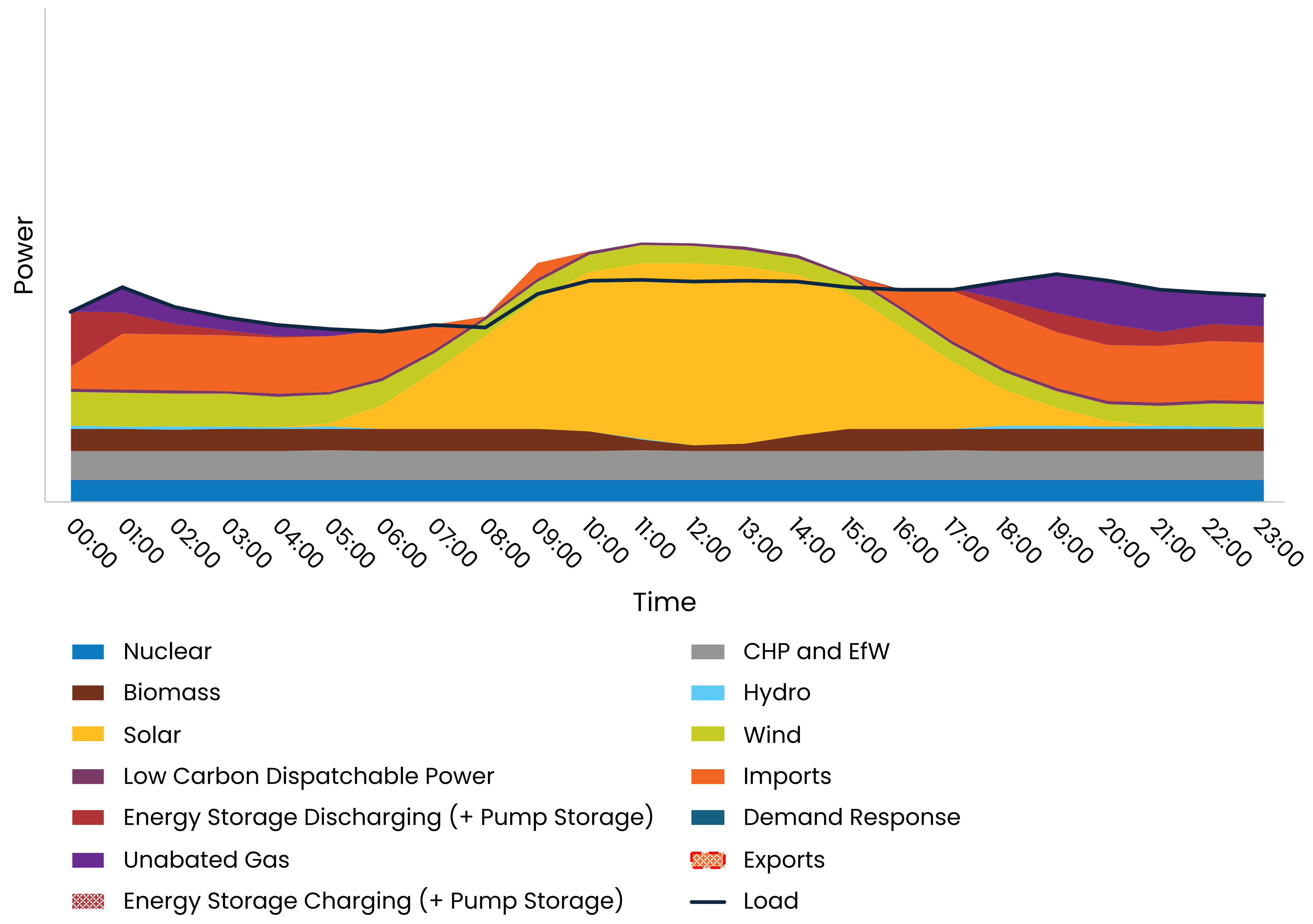
Periods where demand is principally met by firm generation, such as nuclear and distribution connected renewables, reduces the downward margin available to NESO to maintain frequency. In our example (Figure 7), market dispatch meets morning to evening demand using mostly solar PV, nuclear, combined heat and power (CHP) and energy from waste (EfW). Throughout this period, there are low volumes of generation that offer access to downward margin on the system. During the midday peak, we see a reduction in biomass output and an increase in energy storage charging, further reducing available downward margin. Redispatch is required to manage a thermal constraint in the South of England, that is likely resultant from high volumes of solar PV generation (see Figure 8).

Preparing for periods of low downward margin

Downward margin is the amount of active supply that NESO can easily instruct to reduce output, such as unabated gas, dispatchable low carbon (e.g. gas CCS and hydrogen to power), wind and interconnectors. Demand turn-up can also be used to increase system off-take and provide downward margin. Holding sufficient downward margin is essential to maintaining frequency in the event of a sudden demand loss.

Our principal method for managing periods of low downward margin is to procure negative reserve in Quick Reserve, Slow Reserve and Balancing Reserve auctions. Accurately forecasting supply and demand will be essential to procuring sufficient reserve, please refer to the Summer Minimum section for further details.

Figure 7: Low demand, insufficient downward margin market dispatch



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Alternatively, we can create additional downward margin by increasing generation output from sources that provide margin, whilst simultaneously increasing demand, or removing firm generation units within the Balancing Mechanism.

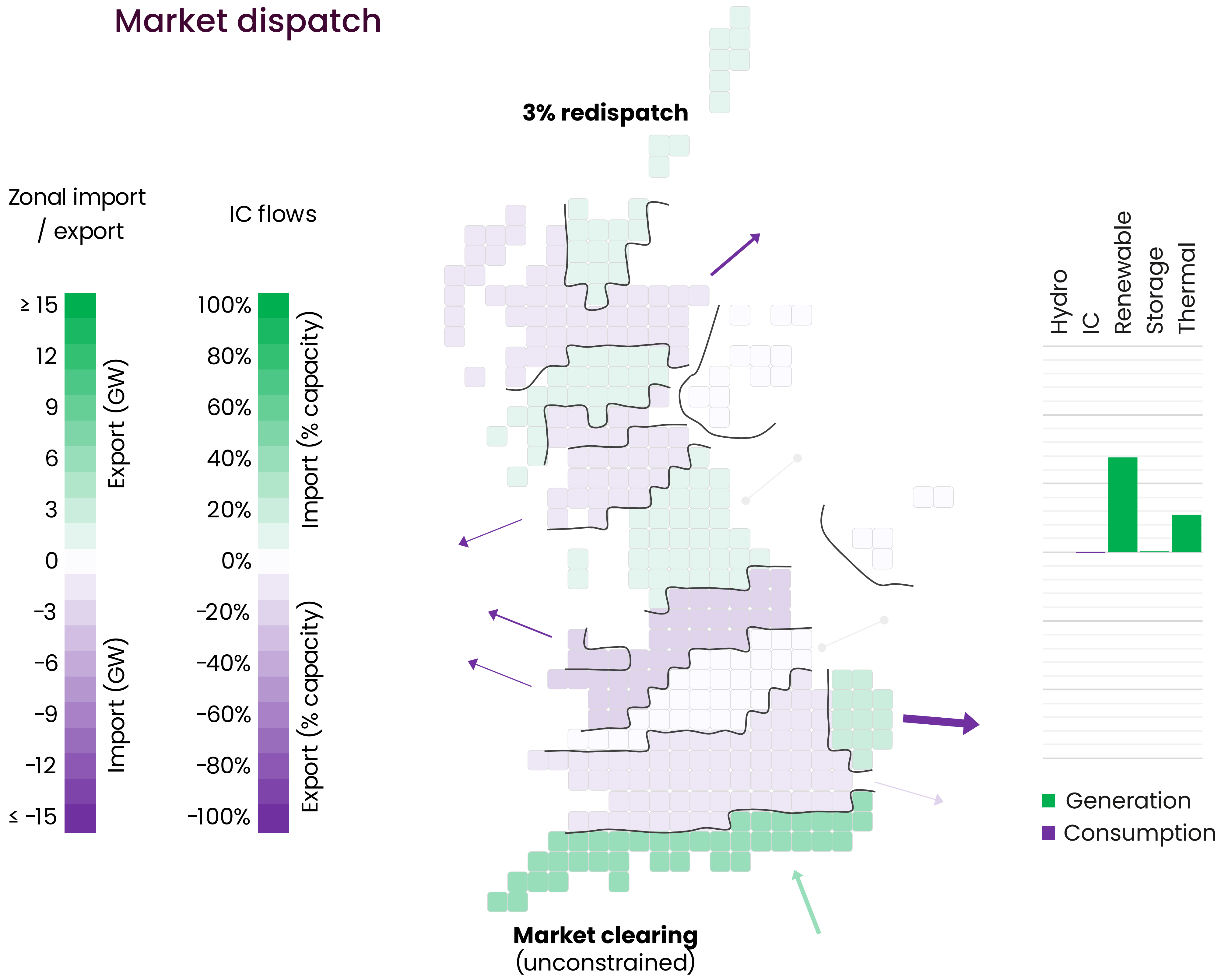
This is reliant on reliable access to flexible demand and is likely to be a method utilised more frequently beyond 2030, as downward margin challenges may increase following the connection of new firm generation. Further improvements to our forecasting capabilities are required and we will publish our strategy to achieve this later in 2025.

Interconnector utilisation

Prolonged periods of consistent weather across Europe can lead to interconnectors neither exporting or importing. This is most likely during sunny summer weeks, where interconnected countries are unable to facilitate export from GB, as they are all experiencing an excess of solar PV supply. This scenario can increase the likelihood of insufficient downward margin within the GB electricity system. Interconnectors are utilised throughout our study day to help manage frequency, yet they are not included within our margin calculations due to the time it can take to action new trades. However, the Emergency Assistance (EA) service enables NESO and its international counterparts to increase, or decrease interconnector flows in near real-time (within 15 minutes), which can be used as a tool to help resolve low downward margin challenges.

Figure 8: Insufficient downward margin single period redispatch

Market dispatch



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High Demand

Clean Supply Shortfall

In GB, the highest demands on the electricity system usually happen during cold, dark, winter evenings and can lead to periods where our forecast of demand exceeds our forecast supply of clean electricity. In our example, the market dispatches a range of technologies to meet demand across the day. Demand side flexibility reduces peak demand, as consumers and assets respond to high price signals. Storage discharges during the evening demand peak and interconnectors remain on import throughout the day. New low carbon dispatchable power options, such as gas carbon capture and storage (CCS) and hydrogen to power also contribute to reduce supply shortfall. As clean power options are unable to make up the shortfall, unabated gas is dispatched to maintain security of supply. In our example, there is sufficient network to transport the power between zones so no redispatch is required for thermal constraints.

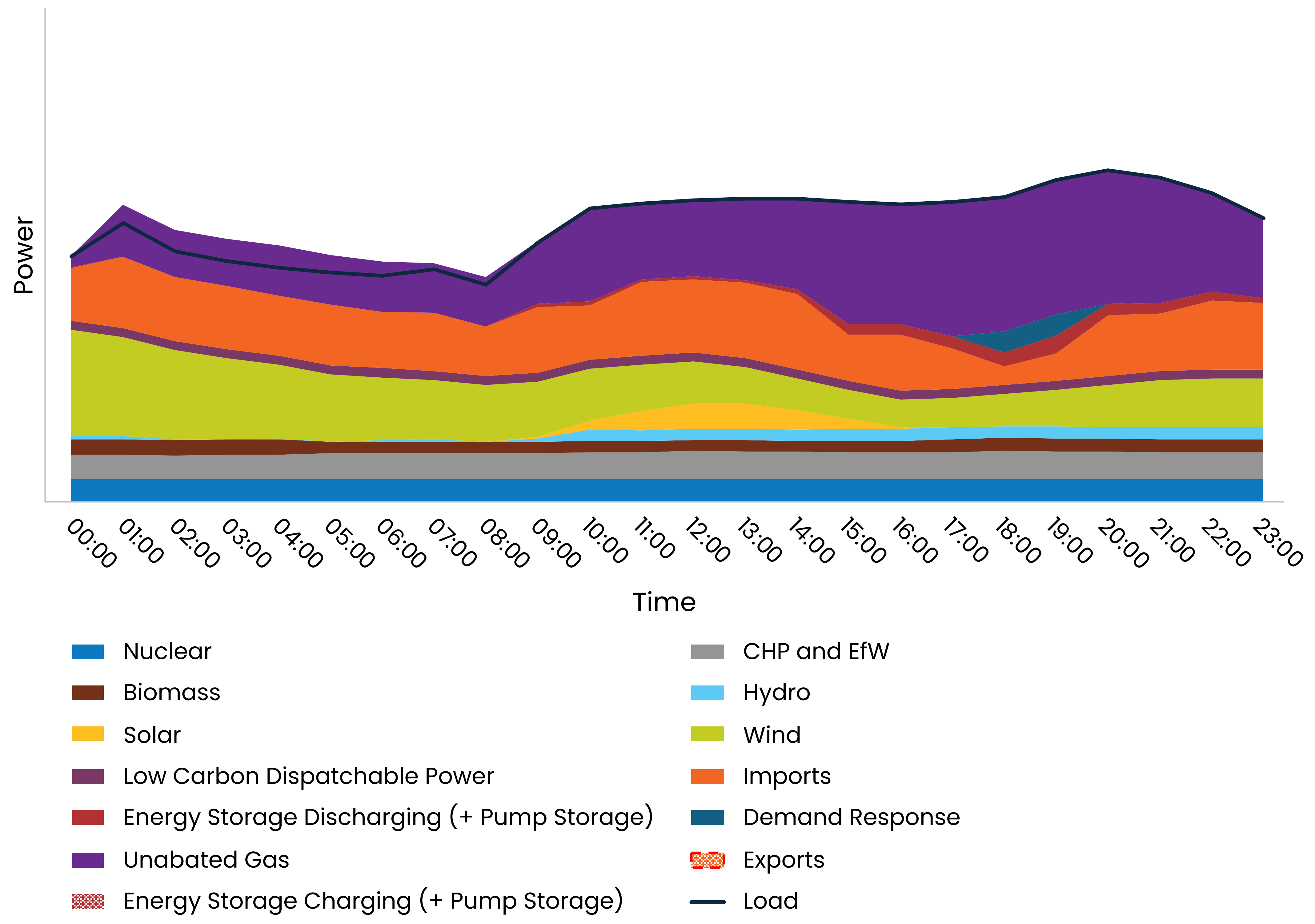
Maintaining security of supply

Supply shortfalls typically occur during periods of high demand or when there are multiple plant outages. As we transition to an electricity system with higher volumes of renewable supply, we may also experience supply shortfalls when the weather is unfavourable to produce sufficient power to meet demand.

As stated in our recent Clean Power 2030 report, we expect most existing gas generators to remain on the system to cover the highest demands periods. Yet, delivering a clean power system between now and 2030 means we need to increase the number of periods where demand can be fully met by clean power sources, minimising the periods in which unabated gas is used. To achieve this, there needs to be sufficient clean power available on the system and demand needs to be flexible to help smooth out peaks.

Gas plant used as a backup power source will be reliant on the gas network managing the changes in flows on the network. Forecasting of gas flows for power will be driven by the output of renewable energy. Our Clean Power 2030 report explored the implications for the upstream gas network.

Figure 9: High demand, clean supply shortfall market dispatch



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We modelled over various time intervals, both nationally and regionally, and considered stress events, such as the loss of a compressor. In this analysis, which assumes a similar level of gas network asset availability as we have today, the gas network remains within safe operational limits.

Low carbon dispatchable power

Ensuring sources of clean power continue to grow at pace is also key to preventing supply shortfalls and reducing the windows in which unabated gas is used in 2030 and beyond. Clean power generation sources will need to provide sufficient flexibility to account for the variability in demand and renewable generation. This can be partially mitigated by bringing forward investment into low carbon dispatchable power options, such as hydrogen to power, or gas CCS.

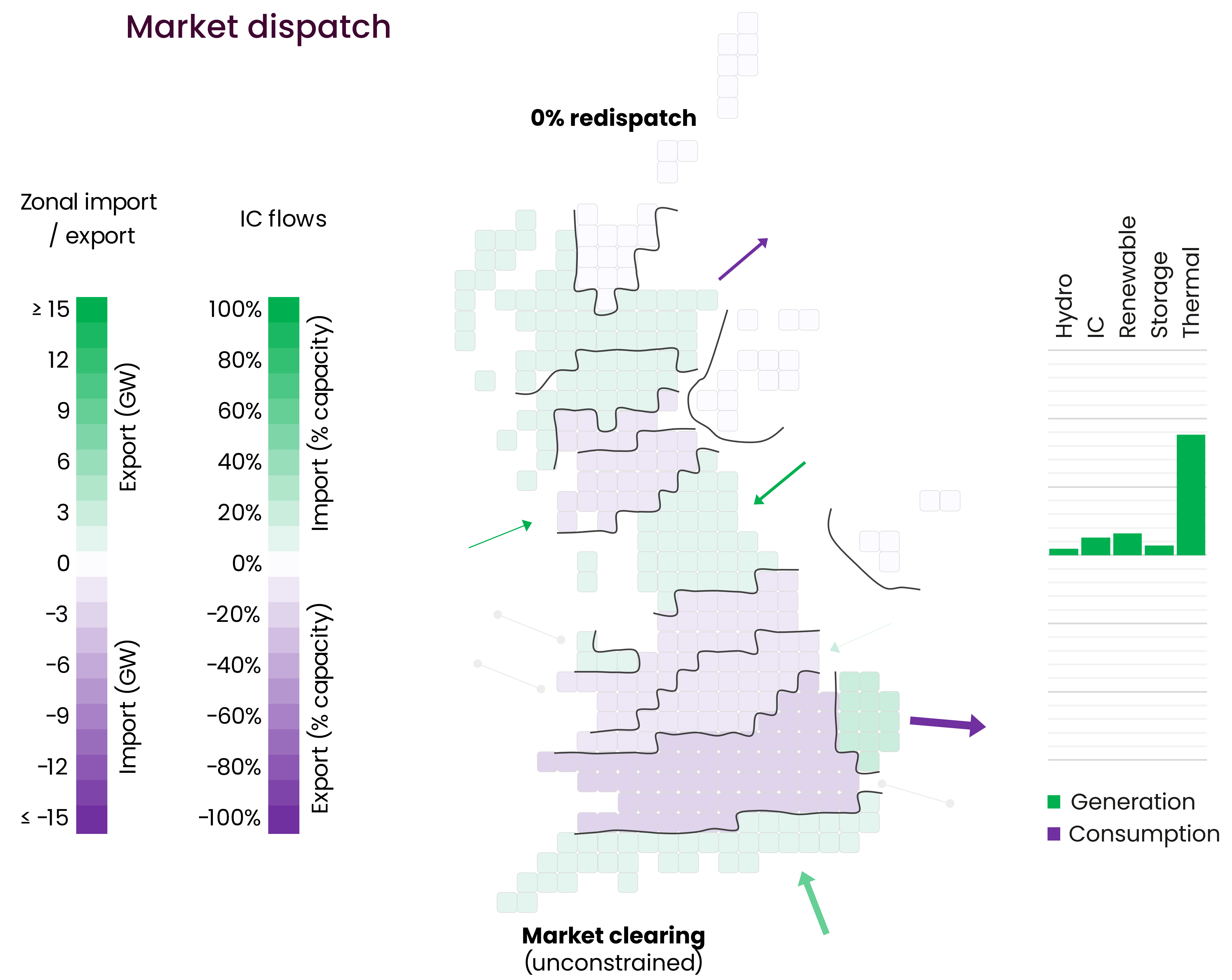
New low carbon dispatchable power technologies will have dependencies on the capability of the wider infrastructure for gas, hydrogen and CCS. Hydrogen and CCS networks will initially be of a smaller scale than the national gas network and may not have the same level of flexibility. Greater access to low carbon long duration storage from new technologies, such as compressed air, and increased interconnection can also help to manage high demand periods.

Low carbon generation investment signals

The running of power sources on the system is largely driven by the energy market. As the volume of renewable generation assets connected to the electricity system increases, weather is becoming a more prevalent driver for supply availability and market prices. We are reliant on market signals through the variability of power prices, the Capacity Market (CM), and Contracts for Difference (CfDs) to ensure that there are enough power sources available. These signals are being reviewed through the Review of Electricity Market Arrangements (REMA) with adequacy and operability at the heart of its security of supply objective.

In the medium-term, the Connections Reform programme is expected to improve the process for connecting new sources of power to the electricity system.

Figure 10: High demand supply shortfall single period redispatch



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Beyond 2030, our Strategic Spatial Energy Plan (SSEP) will provide an assessment of the best locations for electricity generation, and the storage and transportation of electricity and new fuels, such as hydrogen, in the longer term. This will feed into our Centralised Strategic Network Plan (CSNP) which will identify the network investments required to ensure sufficient generation can be connected to achieve net zero.

Utilising demand and flexibility

A range of factors will impact the scale of the demand peak. Our Clean Power 2030 analysis indicates that we expect to see an 11% demand growth from 263 TWh in 2023 to 287 TWh in 2030. Beyond 2030, we anticipate that electrification will accelerate, growing at a pace of around 19 TWh per year throughout the decade. Energy efficiency measures and flexible demand that shifts consumption away from peaks will become increasingly important to manage periods of supply shortfall.

We are likely to see changes in the shape of the demand curve as the types of demand on the system change. The timing of the peak demand may become less predictable due to changing demand patterns, as smart appliances are automated to respond to low power prices. NESO will publish a consultation later this year on its forecasting strategy to overcome these changing demand patterns.

Transmission and distribution connected flexibility can help manage periods of high demand and low renewable supply by smoothing the demand curve and reducing the size of demand peaks. Having greater access to flexible demand would also provide NESO with useful operational tools. The Transformation to Integrated Distributed Energy (TIDE) programme will increase visibility of distributed energy resources (DER) data so that NESO can enhance its modelling, forecasting and situational awareness of DER behaviour. The Smart, Secure Electricity Systems programme, led by DESNZ, will help ensure domestic appliances contribute to reducing the demand peak through the standardisation of smart appliances and time of use (ToU) tariffs.

In December 2024, we published our Enabling Demand-Side Flexibility in NESO Market Report, which outlined our vision of "enabling all flexibility resources to move seamlessly between markets, driven by effective market signals, delivering whole electricity system value to consumers". It also sets out the outcomes and strategic objectives that need to be met before 2030. Our demand side flexibility route to market review will help to identify and remove barriers for demand side flexibility. Further information will be included in the electricity Markets Roadmap.

Constrained Clean Power

Increased volumes of renewable generation at the periphery of the network can contribute to network constraints, where there is insufficient network capacity to transport supply to demand centres. In our example high demand, winter day in 2030, renewable supply, primarily wind generation, leads to a supply excess. Whilst interconnectors remain on export throughout the day, redispatch is required to resolve network constraints and keep the system in balance.

Managing network constraints

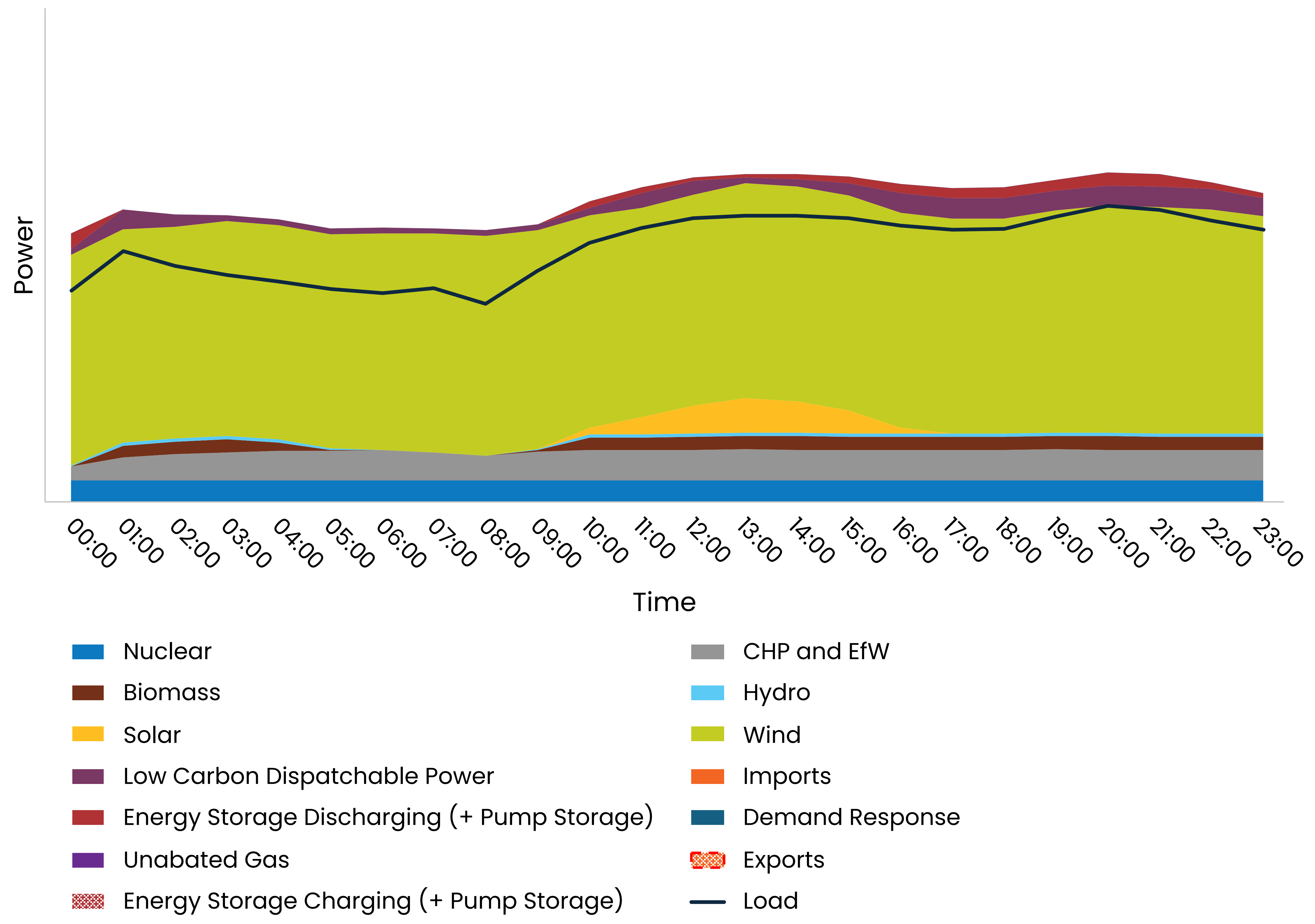
Currently, NESO actively manage network constraints on the electricity network by redispatching supply and demand in the Balancing Mechanism. In more recent years, we have introduced commercial intertrip schemes through our pathfinder programme. These intertrips allow for more power to flow, resulting in reduced redispatch actions.

Network constraints on the system typically occur when there are high power flows from the North to the South of GB. As the pace of renewable deployment remains high relative to the commissioning of new transmission network capacity, we expect this to remain a challenge in 2030.

Figure 12 illustrates an example of the redispatch required by NESO to manage network constraints on a high demand day with high renewable supply, dispatched based on national pricing in 2030. The main constraint on the network is on flows from North to South leading to a reduction in supply in the North behind the constraint. This results in replacement power being dispatched the other side of the constraint from a combination of thermal generation, storage and interconnectors in the Midlands and the South.

Short term solutions to constraints include the role out of intertrip schemes and the Constraints Collaboration Project (CCP). CCP is assessing both market and technical options to reduce the cost and volume of constraints management, independent of network reinforcement and wholesale market reform. More information can be found in the electricity Markets Roadmap.

Figure 11: High demand, constrained clean power market dispatch



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Options under consideration include extending intertrip schemes and deployment of new technologies, such as grid boosters, to support capacity pre and post fault.

In the longer term, we are taking a strategic approach to network reinforcement to help ensure that we identify the necessary network reinforcements or service requirements to reduce future constraints. Beyond 2030 we expect strategic network planning products (e.g. CSNP and SSEP) to further reduce impacts of network constraints through more coordinated placement of low carbon generation. The location of new technologies like power generation combined with CCUS and hydrogen assets will be dependent not only on the constraints of the electricity transmission system but also wider factors like production, transport and storage for other vectors. Adopting a whole system approach to energy system planning will help us to better understand and optimise these trade-offs.

Optimisation of offshore networks can also help to reduce the constraints on the network, by increasing offshore network capacity in addition to onshore network build and allow NESO to manage network flows in operational timescales. Improved understanding of the location of demand flexibility will facilitate greater access to flexibility around constraints.

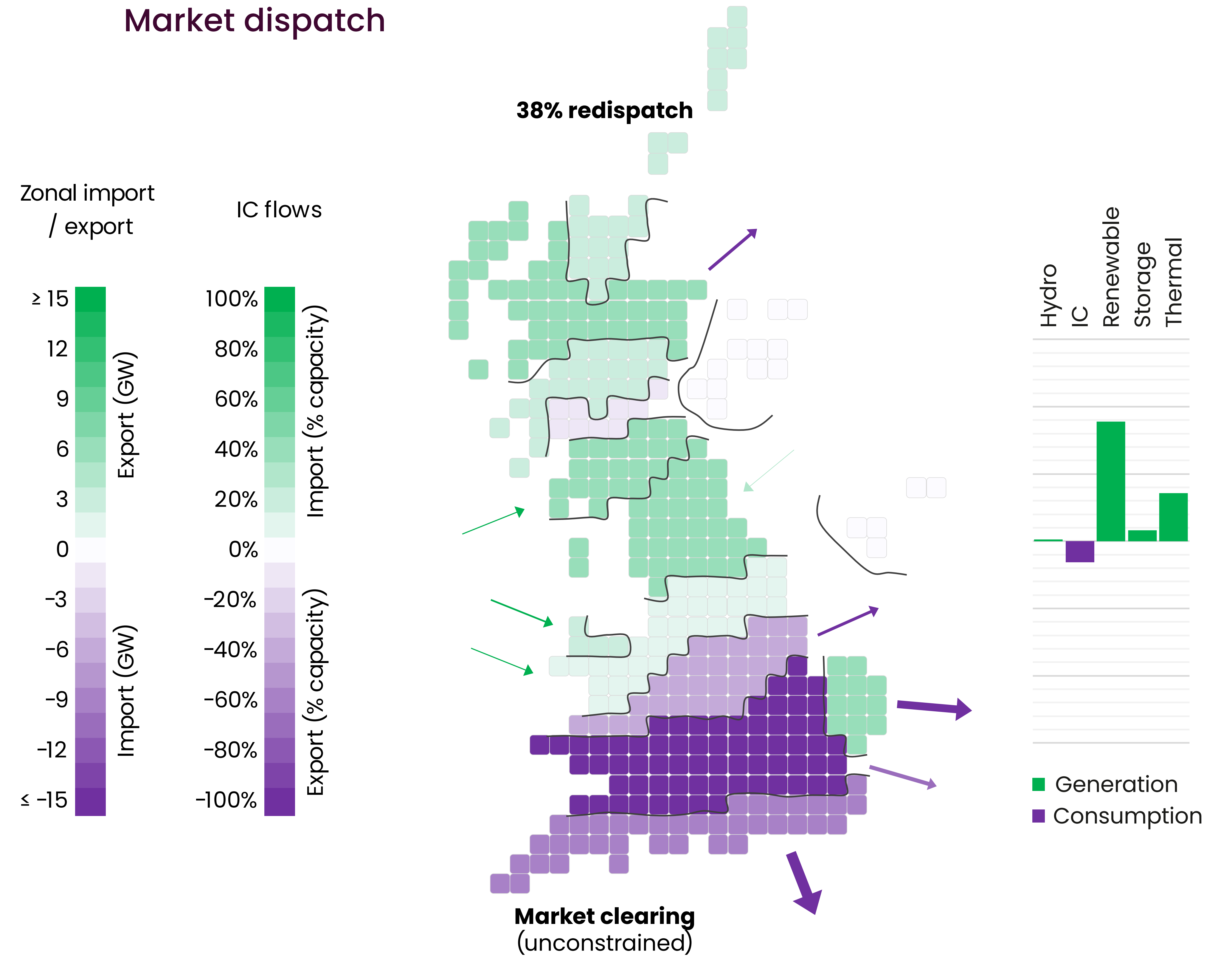
Elsewhere, existing market arrangements mean there is no market incentive to dispatch generation to mitigate constraints. Locational signals for dispatch and asset development could help reduce constraints. Locational pricing options are being reviewed as part of REMA (see the Market Design section for more information).

Maintaining system stability

The reduced provision of stability from synchronous generation has been a challenge during periods of low demand but over time will likely spread to more periods of the year. In the shorter term, the implementation of stability services will manage these requirements and in the longer term, the CSNP will assess stability needs across a range of different scenarios over the year. We will continue to source stability capabilities from assets like synchronous compensation and through a potential code mandate for grid forming technologies.

Figure 12: High demand constrained clean power single period redispatch

Market dispatch



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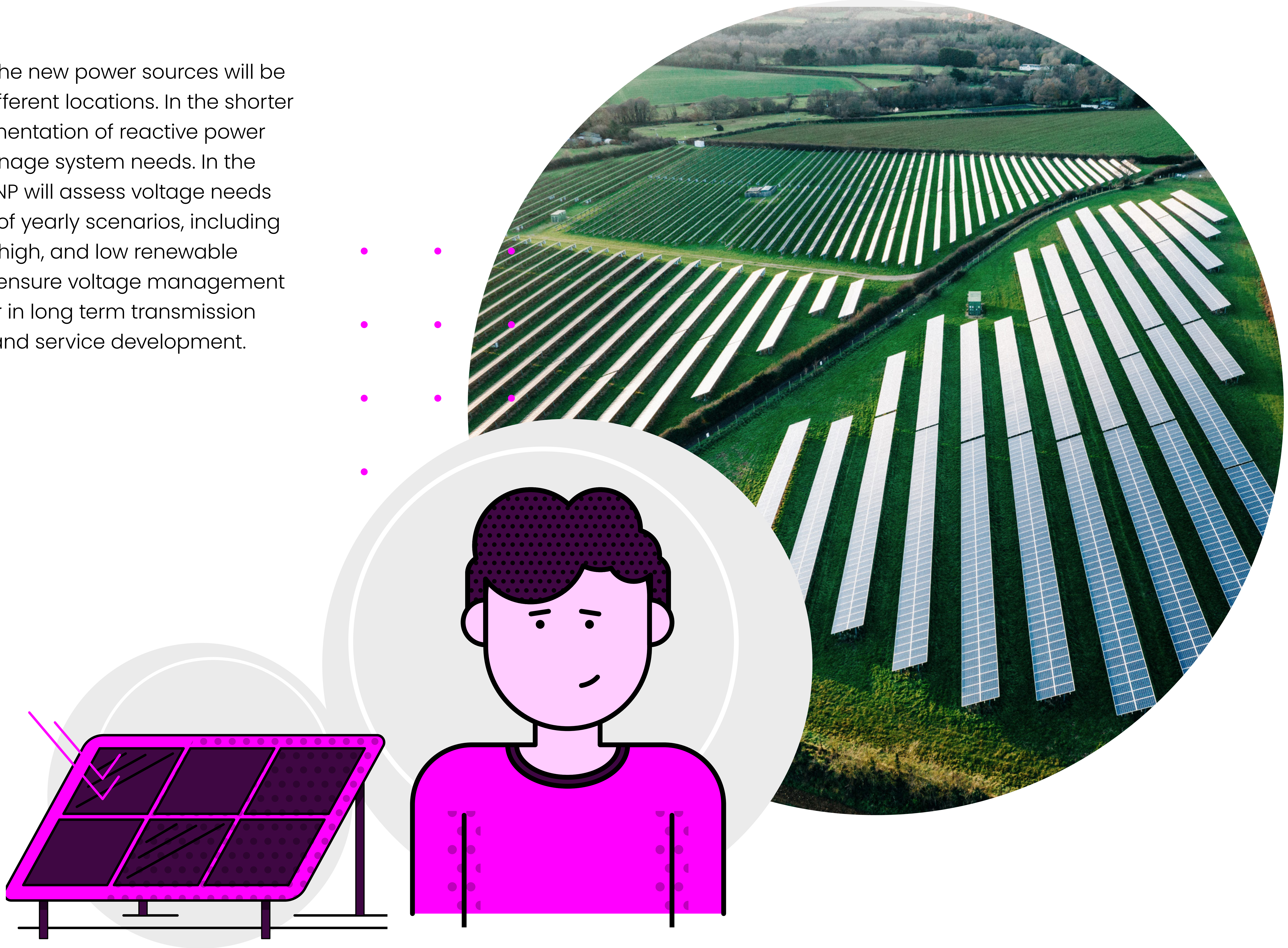
Even when the system is experiencing high demand, additional energy is required as reserve to manage unforeseen issues, such as demand forecast error, or loss of power sources. In the future we will increasingly need to hold this reserve on clean power sources rather than relying on gas plant. In Figure 11, energy storage, pumped hydro and low carbon dispatchable power sources are contributing to this flexibility. The provision of frequency response and reserve services can be restricted in areas with higher volumes of power transfer. This emphasises the importance of incorporating spatial considerations into the planning and utilisation of our response and reserve services.

Low voltage management

Higher flows on the transmission network can lead to lower voltages. Increasingly power is being transported from the periphery of the network and at times of high demand we are relying on a higher proportion of the network capacity. Clean power sources are capable of providing reactive power, but this may not fully replace the historic provision from synchronous generation as requirements are locational and the new power sources will be connected in different locations. In the shorter term the implementation of reactive power services will manage system needs. In the longer term, CSNP will assess voltage needs across a range of yearly scenarios, including both periods of high, and low renewable output. This will ensure voltage management is accounted for in long term transmission system design and service development.



Supply and Demand Ramps

Securely operating the electricity system requires generation and demand to be closely matched to ensure system frequency is maintained. In our spring day example (see Figure 13), we observe a swing in energy flows in the early morning, as demand and supply move in opposite directions. The market responds to rising demand by discharging energy storage and pumped hydro. Demand then falls, likely due to electric vehicles (EV) and heat pumps ceasing nightly operation, and solar PV output increases as the sun begins to rise. When solar generation increases sufficiently, storage assets begin to charge to take advantage of low prices and absorb excess generation. After the midday supply peak, where solar PV output is at its highest, interconnectors begin to export, replacing energy storage which has potentially reached storage capacity. Access to higher levels of demand flexibility has helped the system to remain balanced during these times of greater volatility by providing access to new volumes of shiftable energy.

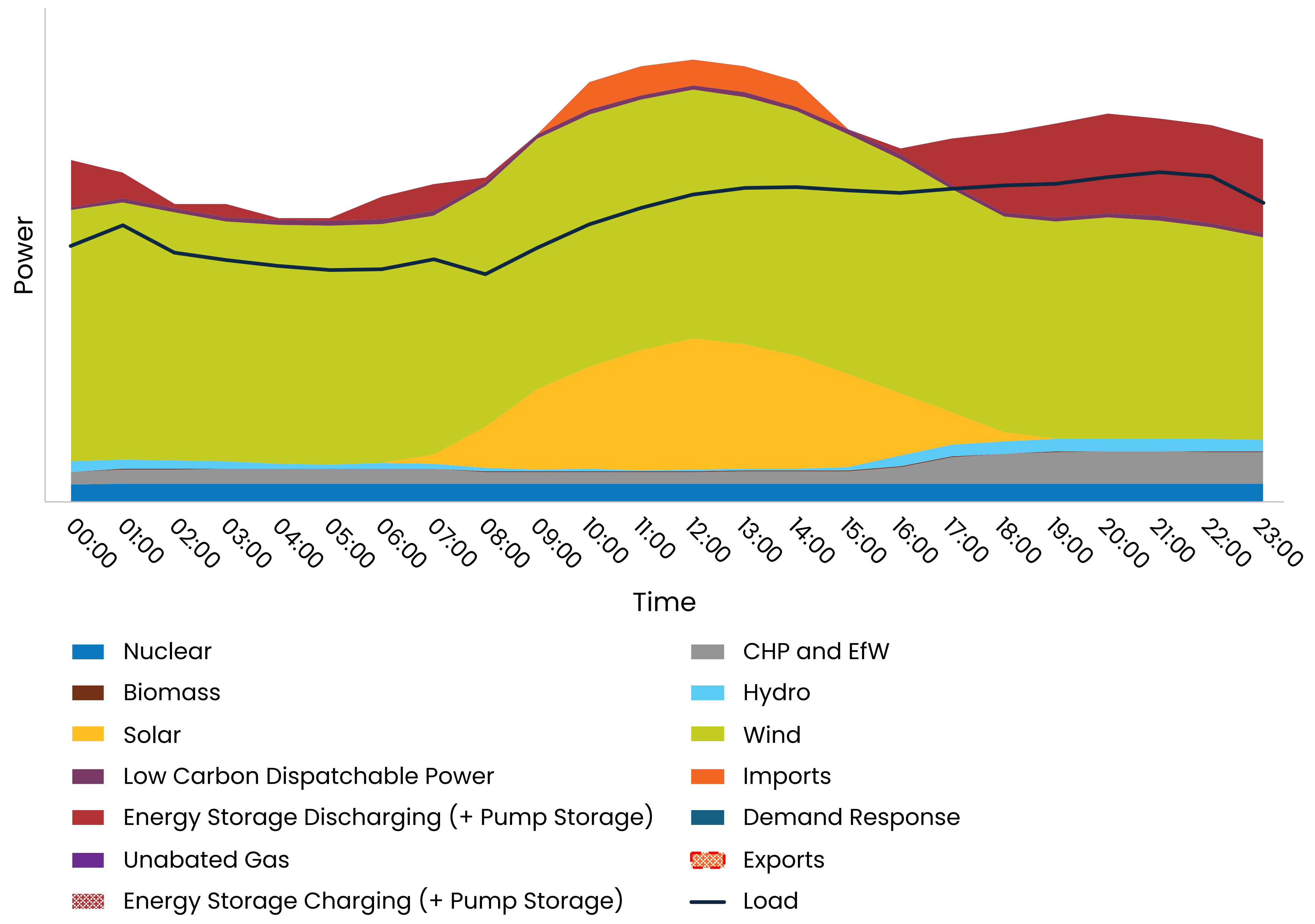
Increasing situational awareness

Supply and demand ramps can occur for a variety of reasons, most commonly they are due to:

1. A significant change in the output of weather dependent generation, made more pronounced when coinciding with a movement of demand in the opposite direction.
2. A significant change in the energy output of bi-directional assets (including interconnectors, demand-side flexibility and battery assets) as they respond simultaneously to price signals.

Increasing volumes of variable, weather dependent generation (e.g. wind and solar) increases the likelihood of rapid generation output changes and the magnitude of the subsequent energy imbalance. Wholesale market price signals should encourage demand resources and bi-directional assets (e.g. storage, interconnectors and demand assets) to alter their operational behaviour in response to variable supply output.

Figure 13: **Supply and demand ramps market dispatch**



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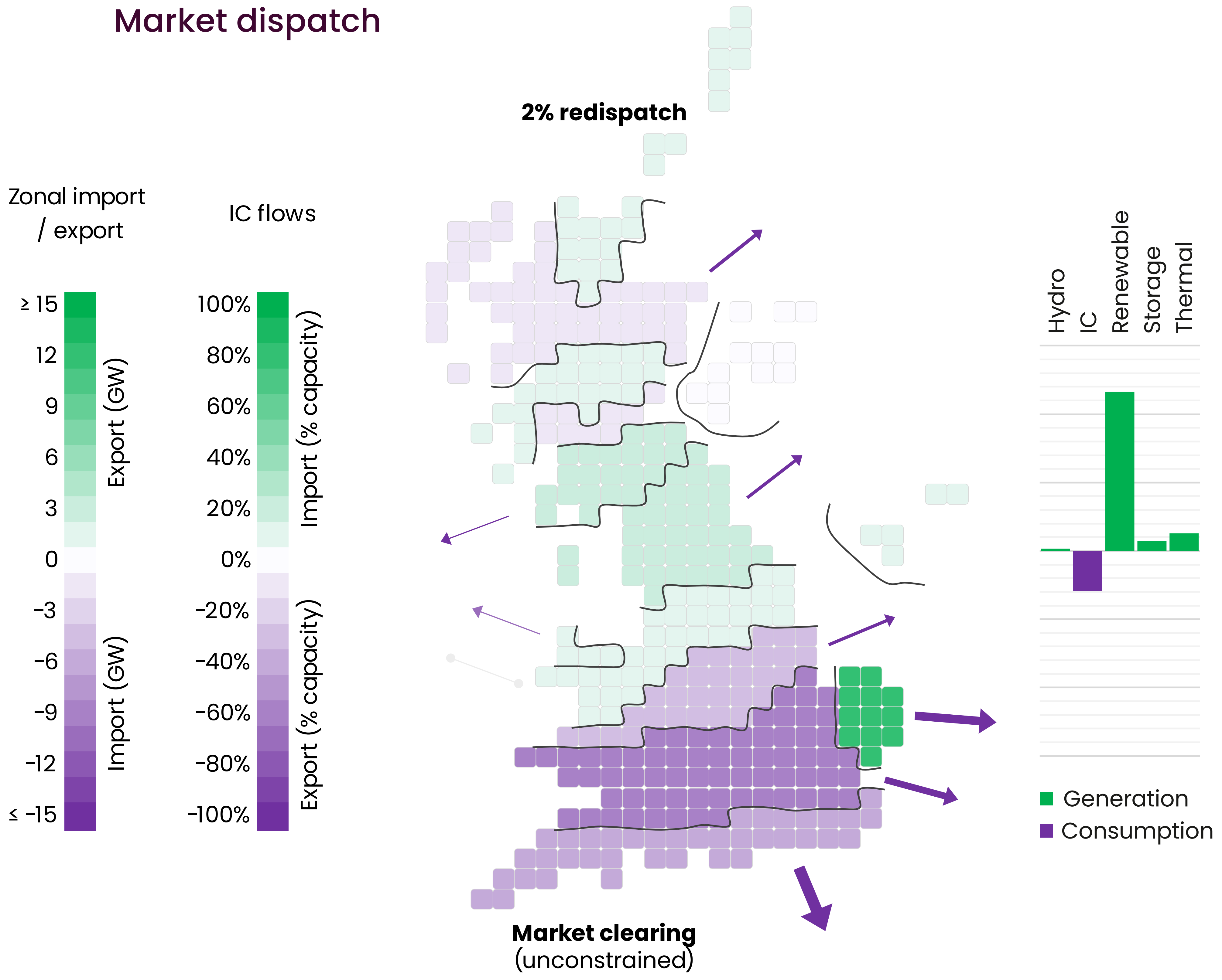
However, if assets respond to a signal that does not complement system needs, a change in energy output could result in frequency management challenges.

Managing large, fast changes in supply and demand requires NESO to have early warning of events and the appropriate situational awareness capabilities to respond. Ensuring weather, generation, and demand forecasts remain accurate is essential in resolving energy imbalances before they occur. Visibility of expected and real-time system flows is key to understanding the size of the energy imbalance and taking appropriate actions to re-balance energy levels. Our forecasting strategy (due in Q4 2025) will outline how we deliver the capabilities necessary to effectively manage demand and generation ramping events.

Currently, NESO have limited visibility of resources that operate outside of the Balancing Mechanism (BM). This can reduce forecasting accuracy as generation and demand profiles for some non-BM assets, such as smaller, distribution connected assets, are not fully accounted for in national forecasts. As deployment of distribution connected assets continues to increase, there is a higher likelihood that consumer demand and distributed flexibility assets lead to greater national forecast errors. We are working alongside the Electricity Network Association (ENA) and distribution operators to increase visibility of distribution connected assets. This includes assessing new and improved data transfer methods as part of our Transformation to Integrate Distributed Energy (TIDE) and the Data Sharing Infrastructure (DSI) programmes. We are also facilitating access to NESO markets and the BM for smaller distributed assets through our work on demand-side flexibility and operational metering BM trials. These are key components of operating the electricity system more efficiently in the future.

Figure 14: Supply and demand ramps single period redispatch



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Optimising frequency services

Our primary capabilities for managing near real-time system imbalances are our frequency response and reserve services. These ensure we have access to fast-acting volumes to rectify energy imbalances and maintain system frequency.

Improved forecasting allows imbalances to be rectified before real-time, with response and reserve services continuing to act closer to real-time to manage residual imbalance and maintain system integrity following a network fault. We periodically review our response and reserve modelling approach and requirements to ensure they satisfy the balancing needs of the system.

Managing changing power flows

Changes in generation or demand can lead to power flows shifting on the network, impacting voltage regulation, constraint management, system stability and frequency management. Flow changes can result in an increase or decrease to localised voltage, such that additional steady state voltage regulation is required.

Sudden changes to generation or demand may reduce system inertia, making the system more susceptible to larger, faster frequency swings. Additional response and reserve holdings may be required to minimise the impact of lower inertia on the system which will be assessed during our routine reviews and Frequency Risk and Control Report (FRCR) analysis.

In our example (see Figure 14), minimal redispatch is required to manage network constraints. Redispatch actions are taken during the early morning period to manage a network constraint by discharging storage in Scotland and reducing renewable generation in the South of England. However, occurrence of larger power flow changes may lead to more significant impacts to constrained network volumes, potentially increasing the need for localised constraint management services.

The electricity Markets Roadmap outlines how we are addressing these future challenges through new reactive power and stability markets, the constraints collaboration project and constraint management intertrip schemes.

Weather-dependent ramps

Renewable generation assets that have Contracts for Difference (CfD) arrangements can drive supply and demand ramps by ‘herding’ in response to the negative pricing rule. Periods of excessive renewable supply can result in negative wholesale prices and lead to CfD payments ceasing and subsequently assets switching off en masse. Reforms to CfD design to mitigate operational distortions, such as uniformed behaviour, are being considered as part of the Review of Electricity Market Arrangements (REMA).

Higher volumes of solar PV connecting to the distribution network may lead to daytime demand suppression and a subsequent ramp up into the evening peak demand. Our work with ENA on TIDE will help provide the situational awareness to manage distribution network changes.

Price-dependent ramps

To minimise the impact of price-dependent ramps, market signals must reflect the operational needs of the system. NESO are currently working alongside the ENA and the distribution operators to define and implement market primacy rules, to ensure interoperable management of national and local flexibility markets. We will continue to develop this work with the Market Facilitator in the future.

The introduction of Market-wide Half Hourly Settlement (MHHS) and potential market reforms via REMA is expected to introduce stronger incentives for market participants to adjust supply and demand. This is predominantly expected to come forward through the day-ahead and intraday wholesale markets which are currently settled on a 30-minute settlement period basis.

Increased flexibility may lead GB demand profiles to shift away from the typical 'morning and evening peak' periods, becoming more dynamic. Consequently, the volume of generation and demand on the system may become more variable from one settlement period to the next. This could lead to flow changes at settlement period boundaries becoming more significant. We observe similar behaviour on today's system, where interconnectors respond dynamically to prices in GB and overseas on a half-hourly basis.

New interconnectors are expected to connect over the next decade. As behaviour of interconnectors is heavily price driven, a higher interconnected volume may expose us to larger price driven fluctuations in energy output. NESO will utilise tools such as Quick Reserve, and fast-ramping units within the Balancing Mechanism, to manage rapid changes in energy output.

Over the next 10 years the number of distributed assets with smart control is expected to increase. This increases the likelihood of demand 'herding' where intelligent assets change operational behaviour simultaneously due to market signals. Our demand forecasting team will proactively assess the impact of smart assets deployment on demand swings to ensure any system operation risks are identified and mitigated appropriately. The DESNZ Smart Secure Electricity Systems (SSES) programme will introduce the regulatory framework and standards for smart assets, further mitigating the risk of smart asset behaviour not complementing system operation.

03

Wider Operability Considerations

Introduction

In Chapter 2 we discussed the electricity system operability challenges associated with specific system conditions using illustrative examples of modelled dispatch behaviour in 2030 to bring challenges to life. Whilst resolving these challenges will be key in effectively operating a clean power electricity system in 2030 and a net zero system beyond 2030, there are additional operational considerations that must be resolved to ensure a clean power electricity system can be operated in 2030.

In this chapter, we will explore several topic areas that present current and future operability considerations and our approach to resolving associated challenges and capitalising on opportunities. These include:

Distribution Network. Increasing volumes of distributed energy resources (DER) and consumer energy resources (CER) resources is driving a need for greater collaboration and coordination between national and regional systems. We are working with DNOs to increase data sharing through Transformation of Integrated Distributed Energy (TIDE), Regional Energy System Plans (RESP), Regional Development Plans (RDP), Data Sharing Infrastructure (DSI), and Open Networks. Distributed connected flexibility will be key in meeting CP30 and maintaining system operability. Market-wide Half Hourly Settlement (MHHS) can help smooth demand, but where price signals deviate from operability needs it can impact system frequency. We will continue to work with DESNZ and Ofgem to progress the Low Carbon Flexibility Roadmap in 2025 to provide an actionable vision to accessing the flexibility required for clean power in 2030 and net zero in 2050.

Market Design. Locational pricing can help reduce thermal constraints, as the wholesale price would reflect the local balance of supply and demand, and network congestion. Reforming and developing markets that incentivise flexibility will be key in transitioning to a system where demand follows supply.

Stability Phenomena. A supply mix with high volumes of asynchronous generation is leading to a reduction in the overall strength of the system to respond to, and resolve faults on the network. Harmonics, voltage imbalance and fluctuations are all symptoms of increasing asynchronous generation, which would degrade network power quality without intervention. Grid forming inverters were identified as a key CP30 enabler to replace lost inertia and SCL from synchronous assets. NESO are working with industry, as part of the grid forming best practice working group, to develop and deploy this new technology, and ensure the system remains operable, strong and secure.

Situational Awareness. A changing supply mix and increasing volumes of DER is changing modelling and forecasting requirements, as the system becomes more complex and dynamic. We need to be able to model more data points, variables, and higher volumes of data. We are addressing this through increased collaboration and data sharing with DNOs and development of our forecasting strategy.

Electricity System Restoration. New restoration standards will apply from December 2026, ensuring more demand can be reconnected sooner as the system decarbonises. We have been developing our restoration plans to meet these new standards to a backdrop of a changing technology mix.

Distribution Network

Operating a Clean Power electricity system in 2030 and a net zero system beyond 2030 will require greater transmission and distribution collaboration and coordination. This is primarily driven by:

- **Increasing volumes of distributed and consumer energy resources (DER/CER)** such as renewable generation (e.g. solar PV and wind), batteries, smart appliances and heat technologies connected to the distribution network.
- **Greater volumes of distributed flexibility** resultant from higher volumes of DER and CER technologies which will be essential in maintaining local and national system balance.
- **Changing demand patterns** as consumers shift usage using time of use (ToU) tariffs and connect smart appliances, which automatically alter consumption patterns in response to market signals.
- **New and evolving markets** as distribution system operators (DSO) increase network management capabilities and peer to peer trading becomes more commonplace.

Increasing volumes of DER

Visibility of distribution connected assets, including their location, technology type, capacity and current/planned operational behaviour will be central in optimising energy balancing and maintaining network resilience. Improving asset visibility will increase our modelling and forecasting accuracy and subsequently, planning effectiveness, ancillary service procurement and network operations. Benefits are expected to go beyond MW control and reduce the unpredictability of reactive and active power flows at the distribution/transmission boundary, reducing the number of actions taken by NESO, therefore lowering costs.

Our joint Transformation to Integrated Distributed Energy (TIDE) project with distribution operators aims to provide a greater transfer of DER asset data allowing for better planning and operation of the electricity system. Data exchange from TIDE will be two ways, such that distribution operators will also benefit from the increased exchange of transmission network data to meet equivalent use-cases.

High volumes of DERs connecting to the distribution network can lead to localised operability challenges, such as constraints, or volatile reactive power flows. We are working with distribution operators and stakeholders across GB to progress our Regional Development Plans (RDP)s which aim to enhance transmission and distribution system coordination and control, through the introduction of new tools and resources. For example, Our Megawatt Dispatch RDP is investigating innovative market solutions to resolve constraints along the South coast of England during periods of low regional demand and high DER output.

It makes use of the Distributed Energy Resources Management System (DERMS) infrastructure to provide an alternative route for DER to assist NESO in managing an increasing number of regional transmission constraints, without requiring high levels of flexibility in the Balancing Mechanism (BM). We are also progressing an RDP in the Southwest of Scotland to develop new arrangements for network connections and the provision of constraint management to unlock the high renewable generation potential in the area.

Accessing distribution connected flexibility, in particular demand flexibility, will be critical in effective national energy balancing and in achieving the Clean Power 2030 ambition. Demand flexibility has been identified as a key clean power enabler, as it is not subject to the same planning, development, consenting, connections, or supply chain challenges typically associated with building energy infrastructure. However, as domestic consumers and smart assets become more responsive to market signals, there is a risk that demand may become more unpredictable and uncertain, resulting in sudden demand losses, and balancing and network reliability challenges. The completion of Market-wide Half Hourly Settlement (MHHS) in 2027 is expected to enable greater access to time of use tariffs (ToU) and consequentially incentivise consumers to act flexibly. The effectiveness of consumers flexibility provision will depend on the timing and accuracy of market signals. We continue to work closely with DESNZ and Ofgem to progress the Low Carbon Flexibility Roadmap in 2025, which will provide a collective, actionable vision to enable access to low carbon flexibility.

Enhanced system control, coordination and planning

DSO flexibility and network services, such as reactive power markets, continue to grow and evolve. Coordination between local and national markets will be essential in maintaining operability across transmission and distribution networks. We are working closely with distribution system operators (DSO)s and the Energy Networks Association (ENA) as part of the Open Networks programme to develop primacy and stacking rules. We look forward to continuing this work with the Market Facilitator.

Enhancing transmission and distribution system coordination and control will require additional data transfer capabilities between NESO and network operators. We are currently building the Data Sharing Infrastructure (DSI) pilot and minimum viable product (MVP), with the MVP expected to launch in early 2026. This will enable fast, secure, transfers of information between network and system operators for the purpose of outage planning. This is a cornerstone capability which will improve data transfer between the system operator and network owners. Future iterations of the DSI is anticipated to have additional network and wider industry use-cases incorporated.

Effective planning of regional energy systems will be key in optimising operation of local systems and contributing to effective operational management of the national system. In our role as the Regional Energy System Planner (RESP), we will work alongside local Governments, and local electricity and gas distribution operators to produce regional plans across 11 regions in GB. Regional energy plans will ensure local energy systems are designed to meet local consumer needs, whilst integrating with national energy planning to create an optimal whole energy system.

Market Design

Changing market needs

The existing market design implemented as part of the New Electricity Trading Arrangements (NETA) in 2001, has evolved from a set of arrangements designed for a small number of large centralised dispatchable generators close to demand centres, to a varied set of markets, mechanisms and services. Large centralised dispatchable generators provided many technical characteristics which enabled efficient system operation and could be easily redispatched to resolve network constraints.

As the electricity system decarbonises, it is becoming increasingly decentralised, with supply moving away from demand centres to areas with high renewable yield. This, combined with a slower relative build-out of transmission network infrastructure, leads to increasing curtailment and greater constraint costs, as there isn't enough network capacity to transport power adequately.

For the GB energy system to reach its decarbonisation goals, reforms are needed to reflect the shift towards a system characterised by weather dependent generation, increased energy storage solutions, greater whole energy interactions, and growth in active participation of energy users, with smarter and more responsive demand.

Much of GBs weather dependent generation is located on the periphery of the network, such as Scotland, the North of England and offshore, which often results in power flowing from the North to the highest demand centres in the South of GB. The electricity network cannot always accommodate the total volume of power generation, which must be turned down (constrained) to ensure the network remains safe and reliable. The cost of managing network constraints through redispatch can be high and is forecasted to continue to increase, as we progress to 2030. Reducing network constraints primarily requires new electricity network build and reinforcement to existing infrastructure, or new generation to be connected in regions with sufficient network capacity. For more information on constraint action costs within the Balancing Mechanism, please refer to our Balancing Cost Report, or the electricity Markets Roadmap.

The current market arrangements use a national pricing model which does not incentivise generation or demand to schedule according to operational requirements, namely, to respect network constraints. NESO is working closely with DESNZ and has undertaken significant research (see our Net Zero Market Reform webpage) to progress the Review of Electricity Market Arrangements (REMA). It aims to establish enduring wholesale electricity market arrangements that enable the transition to and optimised running of a decarbonised energy system. REMA is considering a broad suite of policy and market reforms, one of which is whether locational pricing should replace the current national pricing arrangements.

Locational pricing would embed the locational value of energy into the wholesale price at different points on the network. The wholesale prices would reflect the local balance of supply and demand and network congestion. The operational signals from locational pricing would incentivise assets to align with system needs to reduce (but not remove) the volume of redispatch required.

In addition, locational pricing would enable more efficient use of flexible technologies, such as storage and interconnectors, to maximise whole-system value. In the absence of locational signals, flexible technologies will likely add to network constraints.

Increasing flexibility access

Our recent Clean Power 2030 advice to Government highlights the growing need for consumer and demand flexibility, with our clean power pathways including a four-to-fivefold increase in demand flexibility to nearly 12 GW. They will play an important role in NESO operating a secure, economic and efficient system, as discussed within NESO's inaugural Enabling Demand Side Flexibility in NESO Markets report. Historically, the market and system operator would dispatch generation to meet a demand profile. However, for an electricity system dominated by variable weather-dependent generation, dispatching or moving demand to follow generation will become more important to maximise benefits of a renewable-based system.

Reforming and developing appropriate markets will be key in encouraging the right behaviours across the industry; from transmission connected storage and interconnection, to domestic consumers using electric vehicles, heat pumps and smart appliances. New flexibility service providers are beginning to offer digital solutions to consumers, which will help to unlock flexibility. However, left unmanaged, it could result in unpredictable demand profiles, creating problems for operating a secure system and balancing supply and demand, as explored in Chapter 2 Supply and Demand Ramps.

It is important that industry-wide programmes like the Market-wide Half Hourly Settlement (MHHS) deliver alongside wholesale market reform to better enable suppliers to offer tariffs that can incentivise consumers to act flexibly. Changing consumer behaviour is unlikely to happen overnight and will require cross-industry collaboration to ensure consumers change behaviours in a way that support system operability.

More information on how we are developing ancillary service markets and supporting reforms of wholesale markets through REMA can be found in our electricity Markets Roadmap.

Stability Phenomena

Increasing volumes of asynchronous generation

The GB power system has traditionally relied on synchronous generation from sources such as coal, gas, and nuclear power plants to provide inertia, reactive power (voltage) and short circuit level (SCL), which are critical components for maintaining system stability and voltage levels. Inertia is the energy stored in the rotating mass of synchronous machines, which acts as a buffer against sudden changes in system frequency. When a disturbance occurs, such as the sudden loss of a generator or an unexpected surge in demand, inertia slows the rate of change of frequency. This buffering effect allows time for control systems to respond and restore balance, maintaining the stability of the grid.

SCL is a measure of the system's fault response capability. Synchronous machines naturally contribute to SCL, which is essential for detecting and clearing faults quickly. Lower SCL can delay fault clearance times and impact protection systems, increasing system stability risks. The reduction in synchronous generation reduces network stability by reducing both inertia and SCL. This can result in high impact system events, such as severe frequency deviations and failure of transmission protection schemes to detect and isolate faults, increasing the risk of equipment damage and outages.

The growing penetration of asynchronous assets, such as solar PV, wind farms, and battery energy storage systems, introduces a range of challenges to system strength. Unlike traditional synchronous generation, asynchronous assets do not inherently provide SCL or inertia. NESO is proactively tackling the decline in system strength through the development of new markets, outlined in the electricity Markets Roadmap, innovation projects and potential code changes.

Power quality and harmonics

Harmonics are unwanted electrical frequencies, generated by non-linear loads such as power electronic devices in renewable energy systems and other appliances, and can distort waveforms and degrade overall power quality. To address the challenges associated with the increasing integration of asynchronous generation and declining system strength, we have investigated the impact on power quality, including the presence of harmonics. These frequencies are multiples of the fundamental frequency (50 Hz in GB) and cause distortion of voltage and current waveforms, potentially leading to grid instability and other operational issues. Further details can be found in the Power Quality in the GB Transmission Network Report and we continue to work closely with transmission owners to understand and resolve power quality challenges.

In addition to harmonics, other stability phenomena, such as voltage imbalance and voltage flicker, may exceed standard planning limits. Voltage imbalance refers to the unequal voltage levels across the phases of a three-phase system. This imbalance can cause several issues, including reduced lifespan and damage to rotating equipment, as well as decreased performance in three-phase motors. Voltage flicker, also called voltage fluctuations, refers to rapid changes in voltage on electricity networks that can cause visible variations in lighting. We have initiated studies to address these emerging phenomena, as detailed in the System Operability Framework (SOF).

Grid-forming inverters

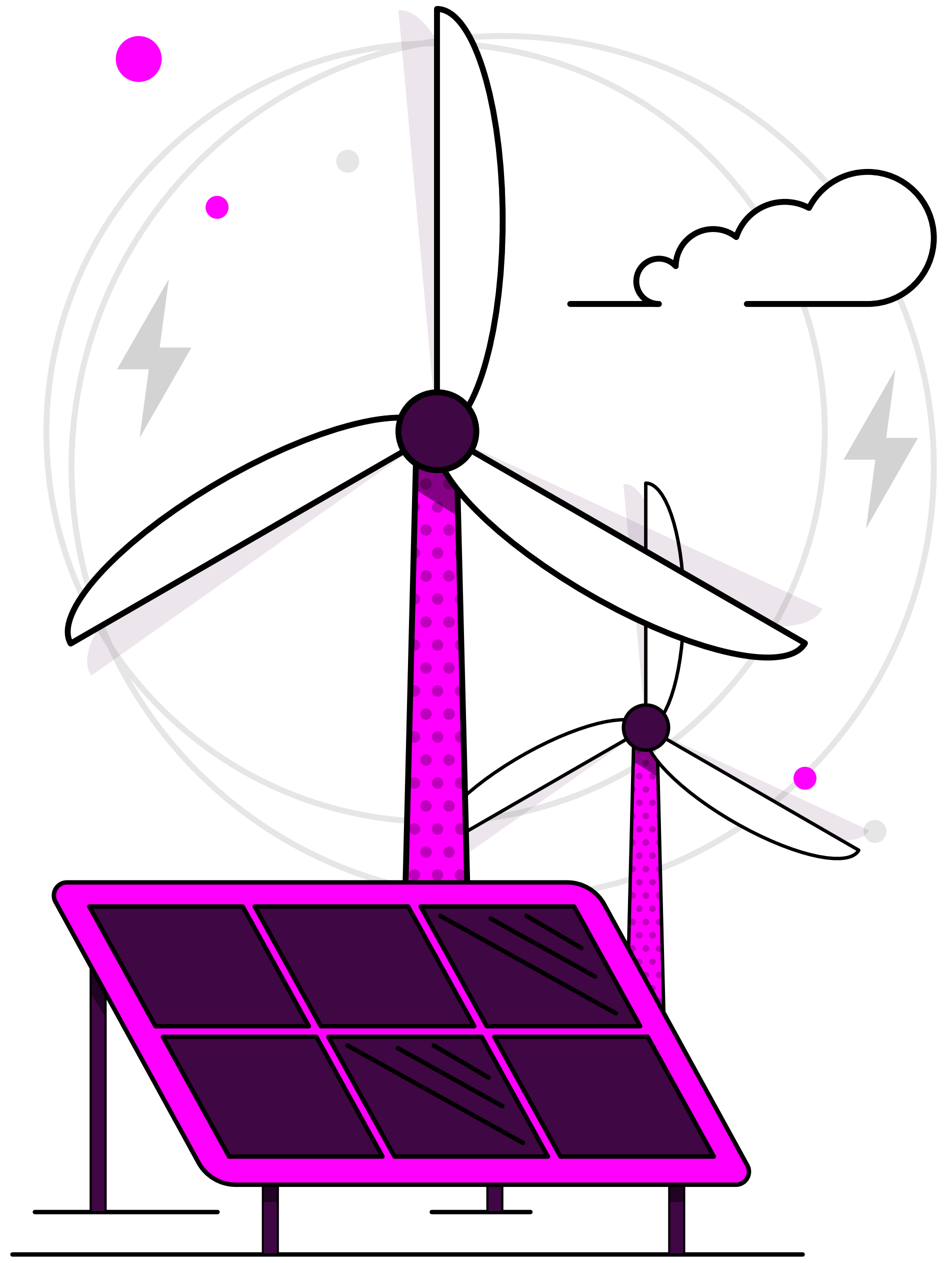
As we connect new technologies to the GB power system at scale, there are inherent risks that unknown challenges may emerge.

For example, grid-forming inverters (GFM) enable asynchronous assets to contribute towards inertia and SCL and have been identified as a key clean power enabler to replace lost inertia and SCL from synchronous assets. To ensure that we have early sight of potential risks when deploying GFM's at scale, we are working with industry as part of the grid forming best practice group to ensure this new technology is deployed safely and contributes to improving electricity system stability.

Sub-synchronous oscillations

One of the recent stability challenges we are tackling is sub-synchronous oscillations (SSO). SSO are power system oscillations at frequencies that are less than the power frequency of 50 Hz in Great Britain. If left undamped, SSO can cause equipment damage, disconnection of generation and in the worst-case scenario loss of supply. We have witnessed in recent years several SSO events. None of these events resulted in loss of demand. Nevertheless, we are determined to reduce the risk of these oscillations and their occurrence in collaboration with the industry. We have implemented measures to reduce the risk of SSO and improve our visibility of it. We have published a new SSO assessment guidance for Inverter Based Resources (IBRs) to help users assess the performance of their plants. We have also invested in our electromagnetic transient (EMT) modelling capabilities to enable us to assess wider system performance, including resilience against SSO. We have deployed tools in our control room to enable real time assessment of system damping while working on deployment of Wide Area Monitoring System (WAMS) that's capable of detecting the source of SSO. We have invested in various innovation projects to improve our understanding of the SSO phenomenon and develop tools that are tailored to the challenges we are facing. Further details on our plan to tackle SSO can be found in our recent report.

As the decarbonisation of the GB electricity system progresses and the generation mix shifts towards renewables, some uncertainties remain. We will continue to monitor the system closely, while engaging in wider industrial collaboration and adapting our approach to effectively address any challenges that may arise.



Situational Awareness

Increasing forecasting complexity

Due to higher numbers of distributed assets and weather-dependent generation connecting to the network, enhancing forecasting and modelling capabilities is becoming increasingly important. Models, energy forecasts and network forecasts are growing in size and complexity as they must include larger, more variable data sets.

Increasingly granular data is required to produce accurate energy and network flow forecasts, improve situational awareness, and ensure secure and cost-effective system operation. Access to more accurate, detailed data will allow NESO to more readily identify, understand and resolve operational issues in a timely manner. It will also allow us to produce precise active and reactive power, inertia and electro-magnetic transient forecasts, increasing the effectiveness of operational planning and real-time operations. Our forecasting strategy (due in Q4 2025) will outline how we plan to deliver the capabilities necessary to effectively manage these complexities, including understanding the interactions between demand forecasting, generation forecasting, battery and flexibility optimisation.

The distribution network boundaries are becoming increasingly complex to manage as consumer demand behaviours change in response to market signals, and higher volumes of distributed energy resources (DER) and consumer energy resources (CER) are connecting to the distribution network. Greater collaboration between NESO and distribution system operators (DSOs) will help ensure the timely transfer of the DER and operational data necessary to ensure accurate forecasting of power flows across the distribution and transmission boundaries. Major industry programmes and policy changes are helping address some of these challenges. These include the Market-wide Half Hourly Settlement (MHHS) programme and the smart-meter roll out, which will help provide more granular data on consumer output, making it easier to accurately forecast and model demand.

In addition to our joint Transformation to Integrated Distributed Energy (TIDE) programme with distribution operators (see Distribution Network section), changes to the Electricity Distribution RIIO-3 Framework (ED3) are expected to drive greater transmission and distribution system collaboration and coordination. The ED3 Framework specifies that transitional Regional Energy System Plans (RESPs) are to be in place in 2026, with full output expected to be delivered by 2028. Forecasting information, including high and low voltage, curtailment, demand, and DER data will be key in producing the transitional RESPs and will have further applications in improving national control situational awareness.

Forecasting new technology behaviour

The transmission network is continually evolving to meet transitional energy needs, introducing new operational challenges. For example, Britain is observing an increasing volume of direct current (DC) networks, such as offshore windfarm connections and interconnectors, connecting to the existing alternating current (AC) system. To ensure secure system operation, it's essential to co-optimise both the AC and DC networks by accurately modelling their outputs and interactions. Other challenges may involve new technologies connecting to the network, such as Multi-Purpose Interconnectors (MPIs).

MPI's are interconnectors that have offshore windfarms directly connected, meaning the output of these windfarms can be traded between neighbouring countries.

This increases the complexity of accurately modelling connected windfarm output, as generators can shift supply across international electricity markets.

Real-time operation of new technologies can be challenging due to their complex modelling requirements. For example, static synchronous series compensators (SSSC) allow for a change in the active power transfer of a line to help with constraint management, yet require increased modelling capability to be effective in real-time. Whilst our studies allow us to anticipate many challenges associated with new technologies, there remains a risk that unknowns may emerge once new technologies are connected to the network. This emphasises the importance of effective monitoring of system behaviour to ensure emerging challenges are resolved quickly and do not result in delays to our clean power and net zero ambitions. We will continue to collaborate with relevant customers and stakeholders to monitor the performance of new technologies as they connect, as we did with synchronous compensators in Stability Phase 1.

Decarbonisation has led to an increasingly dynamic electricity system, yet most studies used to produce forecasts are based on steady state analysis, or dynamic studies focused on a single point in time. Whilst steady state or dynamic analysis are effective in managing the system during daily peaks or troughs, they don't provide the same level of detail for the in-between periods or for the transition from one study point to the other. However, with increasingly variable supply, more intelligent demand, and new technologies and services coming to the network, real-time operation requires managing fluctuations throughout the day. We are increasing the number of data points and study scenarios within our models, whilst developing new simulation tools and capabilities, which will help enhance our dynamics analysis and ensure secure system operation whilst maintaining analysis performance from users.

Electricity System Restoration

A successful path to zero carbon necessitates changes to our existing electricity system restoration preparation arrangements. Investments in services, new technologies, frameworks, operational tools and methods will be required to accommodate the transition efficiently. In 2021, the Department of Business, Energy and Industrial Strategy (BEIS), now the Department for Energy Security and Net Zero (DESNZ), released a policy statement setting out the need to strengthen the current regulatory framework by introducing a legally binding target for the restoration of electricity supplies in the event of a nationwide or partial power outage on the national electricity system – a new Electricity System Restoration Standard (ESRS).

System requirement

This new ESRS obligates NESO to have sufficient capability and arrangements in place to restore 100% of Great Britain's electricity demand within five days. This should also be implemented regionally, with an interim target of 60% of regional demand to be restored within 24 hours. NESO must ensure that everything is in place to comply with this standard by no later than 31 December 2026. To support the implementation of the ESRS, we proposed modifications to the Grid Code. These changes led to consequential modifications to other industry codes, including: System Operator Transmission Code/System Operator Transmission Code Procedures (STC/STCP), Security and Quality of Supply Standard (SQSS), Balancing and Settlement Code (BSC) and Connection and Use of System Code (CUSC).

In addition, several important industry codes and standards were modified to align with these changes, such as: System Defence Plan, System Restoration Plan, System Test Plan, Electrical Standards, including Control Telephony, Communication Standard and Distribution Restoration Zone Control System Standard. All these modifications were approved by Ofgem in 2024.

Capabilities to meet our requirement

While substantial progress has been made in meeting the changing ESRS obligations, continued collaboration and engagement across all parties will be essential to maintain momentum. To stay on track, we must intensify efforts to encourage adoption and address critical gaps. The following steps, are crucial to achieving full ESRS compliance and meeting our objectives:

1. Securing additional Restoration Contractors (RCs) from onshore, offshore, and Distributed Energy Resources (DERs).
2. Continuing implementation of approved modifications for ESRS compliance, including Grid Code GC0156, System Operator Transmission Owner Code (STC) CM089 and CM091, Security and Quality of Supply Standard (SQSS) GSR032.
3. Continuing collaboration with vendors to deliver the Restoration Decision Support Tool (RDST) on schedule to assist control engineers during restoration.
4. Conducting industry-wide compliance monitoring of ESRS Assurance Activities, including Week 24 submissions for existing generators and Operational Notification Compliance Checklists (ONCC) for new connections.
5. Providing targeted industry training and ongoing support to transmission operators (TO) and distribution network operators (DNO)s to identify specific network requirements supporting ESRS.

6. Monitoring and mitigating ESRS implementation risks to ensure timely progress.
7. Assumptions around future generation mix and their availability and reliability hold true.

Procurement route & operational readiness

To achieve compliance with the ESRS, we are focusing on key measures to enhance restoration capability and encourage industry-wide collaboration:

Increase in tendering volumes for new Restoration Contractors: Tenders are ongoing to contract more Restoration Contractors, including distributed restart services, using diverse technologies across the seven Restoration Regions. This approach aims to ensure uniform restoration across Great Britain. We are also able to procure essential services through alternative procurement mechanisms or on a bi-lateral basis if a competitive method is not feasible or there is a critical need for a service.

Inter-Control Centre Communications Protocol (ICCP) links to DNO: Our strategy includes the creation of Distribution Restoration Zones (DRZs) that utilise embedded generation as Restoration Contractors. Currently, we lack the required visibility of the DNO networks to monitor the parameters necessary for operating the DRZs. To address this, the Distributed ReStart project recommended that we set up resilient communication links with all 6 DNOs, covering all 14 DNO licence areas.

Deliver the Restoration Decision Support Tool (RDST): The RDST will provide decision support capabilities and enhanced visualisation for Control Room Engineers during restoration events, reducing restoration time and easing their cognitive load. The tool will recommend quick, secure and efficient restoration routes to Control Engineers, supporting our ability to meet the ESRS. The RDST will also provide real-time updates on restoration progress for both the transmission and distribution networks and log critical decisions made during the restoration process.

Inclusion of offshore generation in the restoration process: New requirements in the STC for developing an offshore transmission network have enabled offshore resources to participate in restoration.

Compliance progress monitoring: We continue to coordinate industry-wide compliance with ESRS Assurance Activities by receiving, assessing and reporting on both compliance and noncompliance to Ofgem. We also report on our own activities to meet the ESRS.

The requirement for additional industry-wide training has also been identified, and individual training/benchmarking sessions are to be considered for all relevant parties across the energy system including but not limited to NESO, TOs, DNO's, CUSC parties, National Gas, ELEXON, and neighbouring System Operators (SO's). It will be critical to ensure that training sessions are bespoke and highlight strengths and weaknesses, allowing the continuous development of ESR awareness and capability across the industry.

Post implementation

Following 31 December 2026, the ESRS will be fully integrated into our normal business operations. Our post-compliance activities in the years beyond 2026 will include:

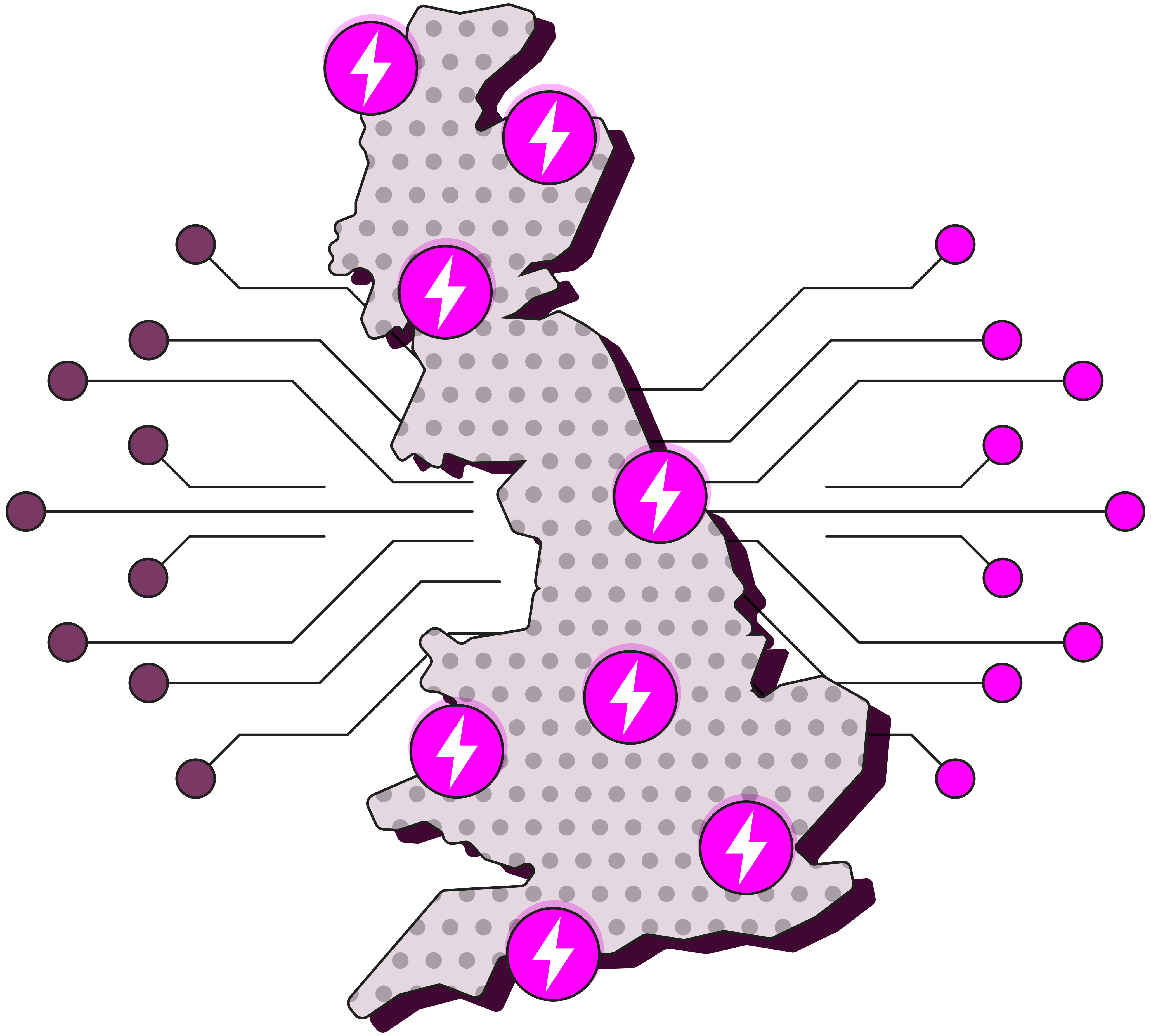
Securing additional Restoration Contractors: We will continue to secure additional Restoration Contractors through competitive tendering processes to expand restoration capabilities as needed.

Ongoing ESRS Assurance Activities: Week 24 submissions will confirm compliance with the Data Registration Code (DRC), Schedule 16, Parts i, ii and iii. These parts outline the data provision requirements, detailing the types of data each party must submit for system restoration planning and operation, along with processes for validating and maintaining data integrity.

eNAMS outage reporting: We will utilise eNAMS outage reporting to gain early insight into outages affecting Local Joint Restoration Plans (LJRPs) and DRZ plans, ensuring proactive management of system restoration activities.

Maintaining the RDST Tool: We will maintain the RDST and ensure its compatibility with control room restoration training exercises. Focus will be placed on improving the tool's usability and enhancing its role in training efforts.

Annual restoration training: NESO will conduct annual restoration training sessions for control room staff, emphasising the achievement of ESRS restoration goals set by DESNZ. Training will prioritise the use of the RDST tool to assist control room staff throughout the restoration process.



04

Making Progress

Introduction

In this OSR, we have set out key operability challenges in operating a clean power electricity system, illustrated through example system conditions. The following chapter provides an overview of system needs across different system challenges and the work NESO are progressing to meet and overcome these challenges. We also provide a summary of some of the ongoing innovation projects which are supporting the 2030 commitment and beyond.

Overview of system needs: A summary of the system requirements across each of our key operability areas – thermal, voltage, stability, electricity system restoration, frequency, within-day flexibility and adequacy. We set out a description of each of the key operability focus areas and describe how we identify and calculate the requirements needed to effectively manage the system. We also summarise how these requirements may change in future years as Britain progresses towards 2030.

NESO Operability Programmes: These tables provide a summary of in progress and planned activities taking place across NESO to help us proactively understand and manage future operability challenges to progress towards the 2030 ambition.

Innovation: We have provided a non-exhaustive overview of innovation projects that are supporting NESO to overcome some of the complex operability challenges we face today. These projects are led by NESO but involve support and input from a range of industry parties, showcasing the collaboration required to enable change.

We are committed to achieving a clean power system by 2030 and are proactively working to overcome some of the major operability challenges the system may face in the future. When read in conjunction with the electricity Markets Roadmap, this report provides insight into our direction for how we identify challenges, what we are doing to work through these and how we are able to utilise market arrangements to meet the future system needs.

Overview of System Needs

Please click on each operability workstream to find out how we calculate our system requirements.

+ Thermal + Voltage + Stability + Electricity System Restoration + Frequency + Within-day Flexibility + Adequacy

Thermal

Description

The electricity transmission network has limited capacity to transport power. The thermal workstream covers how we manage this capacity.

What are the system requirements?

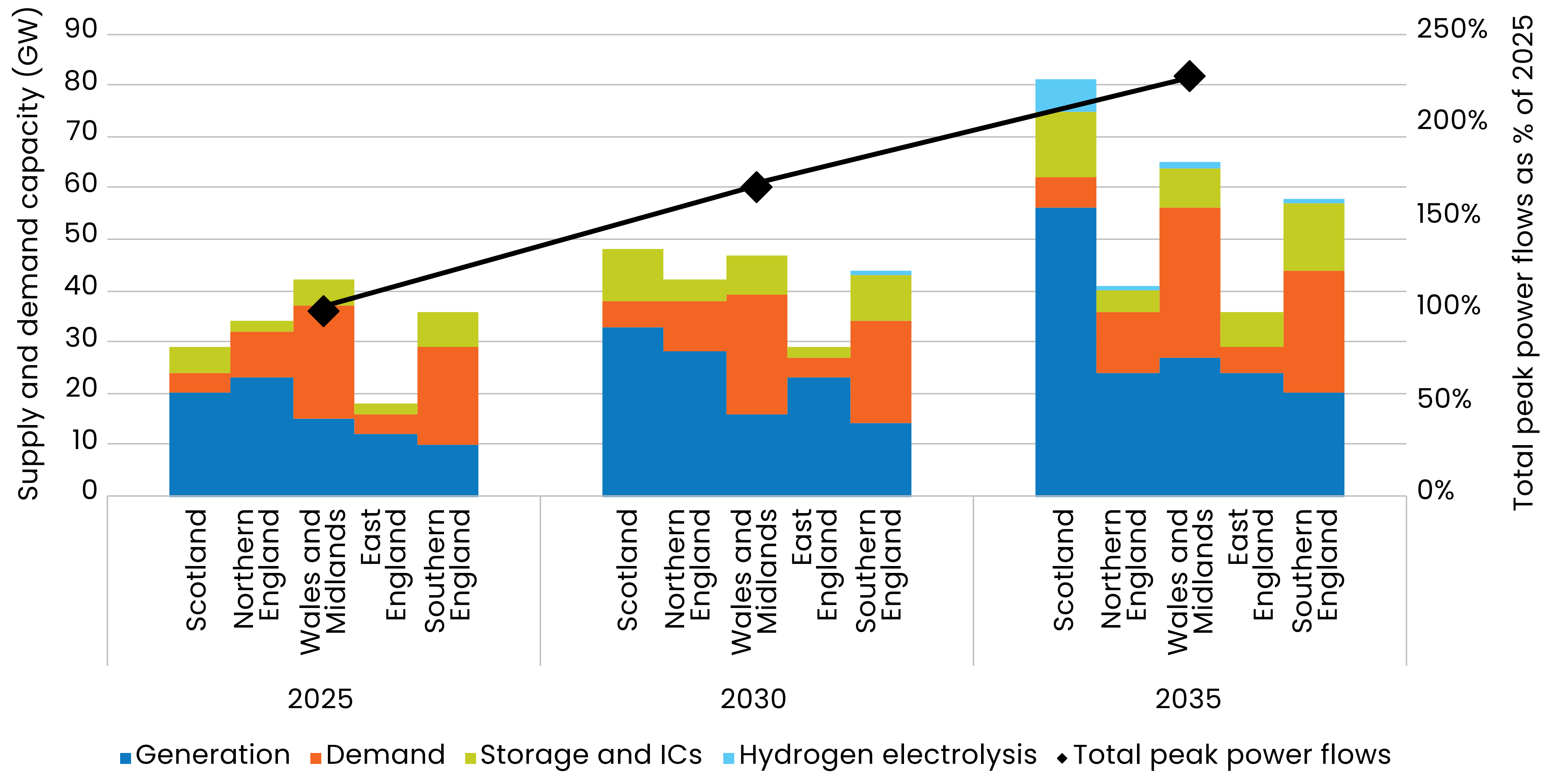


Figure 15: **Supply and demand capacities with GB aggregated power flows**

How do we calculate our requirements?

The Network Options Assessment (NOA) balances network investment with the forecast cost to constrain generation behind a constraint boundary. Where new capability is recommended by the NOA, in line with the Electricity Ten Year Statement (ETYS), it is delivered by transmission owners. Moving forward, new network capabilities will be published within the Centralised Strategic Network Plan (CSNP).

How do we currently meet these requirements?

Market options: Balancing Mechanism, Trades, MW Dispatch and Local Constraint Market.
Technical options: Re-arranging the network, enhancing network (Constraint Management Intertrip Scheme).

How are our requirements likely to change?

As we move towards Clean Power in 2030 and net zero by 2050, higher volumes of generation will connect to the network. Careful management of where new assets connect to the network will be essential, to reduce costs being incurred through constraining low and zero carbon generation due to insufficient network capacity. Our Strategic Spatial Energy Plan (SSEP) and CSNP will be central in ensuring we plan an optimal future electricity system.

How will we meet these requirements in the future?

Largely through similar means, though new market and non-market solutions may be deployed as a result of the Constraint Collaboration Project.

NESO Operability Programmes

Maintaining operability of a clean power in 2030, and a net zero system beyond 2030, will require NESO to increase its readiness and capabilities. The following tables summarise the in-progress and planned activities discussed throughout sections 2 and 3.

＋ Chapter 2

＋ Chapter 3

Key:

CP30 Identified as an enabler from NESOs CP30 advice.

＋ Operational Readiness ＋ Increasing Capabilities ＋ System Needs

Chapter 2: Operational Readiness

In Progress	Planned
Innovation project with Reactive Technologies to gather insights into two parameters using XMU monitoring devices 1) system oscillations and 2) regional RoCoF trends	
Define the outcomes and associated activities in our Enabling Demand Side Flexibility programme so that we can access the demand flexibility necessary for clean power and net zero operation	
Deliver joint Transformation to Integrated Distributed Energy (TIDE) with distribution operators and the Market Facilitator to increase visibility of DER asset data so that NESO can enhance its modelling, forecasting and situational awareness	
Identify operability interactions between energy vectors so that we can identify challenges and opportunities to optimise electricity system operation	
Advise DESNZ on how to achieve the Clean Power in 2030 ambition through our Clean Power 2030 advice and Clean Power 2030 Implementation Plan	

Innovation

System Needs

+ System Needs
+ Operational Readiness
+ Increasing Capability

Improving our capabilities to conduct EMT studies

GridConnectX: Develop a tool that allows vendor plant owners to connect their proprietary models at designated points for EMT studies without accessing sensitive network data, thereby enhancing network stability, accelerating model validation, and facilitating the integration of renewables.

Grid Connection Simulator tool (GridConnectX) | ENA Innovation Portal

Optimising system strength metrics

Strength to Connect: Developing a new method to measure grid strength as an alternative to short circuit level.

Strength to Connect | ENA Innovation Portal

Improving overall system studies

Neural BB: Developing a machine learning-based surrogate model from a black box model of an AC/DC converter in power system computer aided design (PSCAD) for use in stability studies, ensuring it is accurate, source code-available, and adaptable to different time steps.

Neural BB | ENA Innovation Portal

Trial on Implementation of Wide Area Monitoring and Control System (WAMCS): Exploring the use of the phasor measurement unit (PMU) based wide area monitoring and control systems (WAMCS) on the GB electricity network, fitting its hardware into the NESO's control room, defining communication requirements, establishing and trialling a prototype, and specifying communication latencies during various system events.

Trial on Implementation of Wide Area Monitoring and Control System (WAMCS) | ENA Innovation Portal

NB: This is a non-exhaustive list of our innovation pipeline. For more details on NESO innovation or to get involved, contact us at innovation@nationalenergyso.com

NESO

National Energy
System Operator